ANL-7934

12/15/72
ANL-7934

REGISTER

**PROCEEDINGS OF THE
INFORMAL COLLOQUIUM ON
POLLY AND POLLY-LIKE DEVICES**

**HELD AT
ARGONNE NATIONAL LABORATORY
JANUARY 11 & 12, 1972**

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Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.95

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60439

Proceedings of the Informal Colloquium on
POLLY and POLLY-like Devices

January 11 and 12, 1972

Edited by
Carol Kosner

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PREFACE

These proceedings have been prepared directly from the transcripts submitted by the authors. The discussions following the papers were transcribed from tape recordings with a minimal amount of editing. I apologize for any inaccuracies or misrepresentations which may have been introduced in the editing process.

I would like to express my appreciation to the authors for their cooperation in text preparation. Also, may I extend an acknowledgement to all on the Argonne staff who have helped in the preparation of these proceedings. In particular, the staff in Graphic Arts; Mrs. Joyce Kopta of the Technical Publications Department; Mrs. Patt Fiala, Martin Stern and Mrs. Jean Troyer of the High Energy Physics Division for their help in covering the discussion periods at the conference; Miss Sandra Klepec of the High Energy Physics Division for her help in transcribing the tape recordings; and lastly I would like to express my great indebtedness to our group secretary Mrs. Mary Keigher for her invaluable help from preconference arrangements to the final copy of the proceedings.

I would like to dedicate these proceedings to the memory of Professor R. O. Haxby of Iowa State University whose untimely death occurred during the conference.

Carol Kosner
Editor

TABLE OF CONTENTS

WELCOME	1
T. Fields, ARGONNE NATIONAL LABORATORY	
INTRODUCTORY REMARKS	2
F. Beck, ARGONNE NATIONAL LABORATORY	

SESSION I

Chairman: J. Phillips (University of Toronto)

ARGONNE NATIONAL LABORATORY

Status Report on the ANL POLLY System	4
The POLLY III Track Discriminator	22

COLLEGE DE FRANCE

Coccinelle - 4 View Film Transport	27
--	----

CARNEGIE MELLON UNIVERSITY

The Carnegie Mellon University - Case Western Reserve University POLLY	37
---	----

UNIVERSITY OF ILLINOIS

University of Illinois DOLLY Hardware	41
Some Software Techniques in the DOLLY System	48

PURDUE UNIVERSITY

The Purdue POLLY - Status Report	61
A Micro-Programmed POLLY Controller	67

SESSION II

Chairman: R. McIlwain (Purdue University)

IOWA STATE UNIVERSITY

General Description of the Ames Laboratory POLLY	78
The Ames Laboratory Interactive Hardware Programmed POLLY	82

The Ames Laboratory HOLLY Programming System	87
UNIVERSITY OF CALIFORNIA at LOS ANGELES	
MOLLY - A Progress Report	97
NATIONAL ACCELERATOR LABORATORY	
Status of NAL SAMM	108
The NAL Simulator	115
AFTER DINNER SPEECH	
R. Royston, ARGONNE NATIONAL LABORATORY	125
SESSION III	
<u>Chairman:</u> D. Bogert (National Accelerator Laboratory)	
BROOKHAVEN NATIONAL LABORATORY	
A Progress Report on the BNL Vertex Guidance System	129
BRUSSELS UNIVERSITIES (ULB-VUB)	
The Brussels On-Line System - BROL Progress Report	141
ARGONNE NATIONAL LABORATORY	
ALICE, A General-Purpose Image Processing System	149
UNIVERSITY OF TORONTO	
University of Toronto Progress Report	160
Applications of POLLY to Biology and Hydrodynamics	172
CALIFORNIA INSTITUTE OF TECHNOLOGY	
The Caltech POLLY: Status Report	178
Transient Analysis of Deflection and Photomultiplier Circuits	186

THE UNIVERSITY OF MICHIGAN

Progress Report on The University of Michigan CRT Measuring Equipment	195
--	-----

SEACO (OPTEK, INC.)

Lens Resolution versus Field as Applied to the POLLY Program	200
---	-----

LIST OF ATTENDEES	208
-----------------------------	-----

WELCOME

T. Fields

It is a pleasure to welcome all of you to this conference on POLLY-like devices. There are enough people in the audience to indicate that POLLY is on the verge of becoming an industry with a well-established product, ready to join the ranks of such particle physics subcultures as the Regge pole industry or even the accelerator building industry. For all such industries, we should hope that their application continues to grow beyond the boundaries of particle physics, in order to focus and test their powers on a very broad range of scientific problems.

These days every industry must have its sociology explored, so I began my study of the sociology of POLLY-like devices by musing over some of the names of devices listed on the program -- POLLY, DOLLY, HOLLY, and MOLLY. Although that sequence leaves only three more interesting first letters, there is a decided bureaucratic advantage to using new names whenever possible. Even within a single laboratory, I do not recommend the ANL naming scheme of POLLY I, POLLY II, and now POLLY III. The bureaucratic questions are all too obvious -- where does it all end? - what was the matter with POLLY N-1? - are you stuck in a rut? - etc., etc. ! Of course one can quickly come up with suitable bureaucratic counter arguments.

Another observation on the program is that the talks will be given in alphabetical order of institution name. Whether this implies that the field of POLLY-like devices is still developing too rapidly to be categorized and compartmentalized, or just that the conference chairman is from Argonne, is something we should not decide until after hearing the talks. And so I will now conclude by saying on behalf of all of us at Argonne that I am very pleased to have this opportunity to hear about POLLY-like progress at so many laboratories.

Introductory Remarks

Frank Beck

Argonne National Laboratory
Argonne, Illinois

There are now more than a dozen POLLY-like devices planned, under construction, or installed. What is a POLLY-like device? One would be tempted to define it as a computer-controlled flying-spot digitizer using the spot on a precision cathode-ray-tube, having facilities for operator viewing of the actual picture being measured, and allowing operator interaction. However, not even these simple criteria are met by all the devices described in these proceedings. One has facilities for a line-segment on the CRT, and at least one lacks the facility for direct projection of the picture currently being measured.

However hard it is to define a POLLY-like device, one thing which became clear to me some months ago was that a large number of people existed with similar interests. This area of interest was sufficiently different from that dealt with at the PEPR conferences for a new kind of meeting to be required. The first purpose of the meeting, then, was to allow POLLY people to get together. The second was to record, in the form of proceedings, the state of this particular art in January, 1972. I hope both functions have been fulfilled.

The design of a POLLY-like device involves many major decisions, and the original Argonne POLLY and the commercially available copy represent only one of a large number of sets of solutions to the design problem. Questions which face the designer are: Four CRT's or one CRT and a suitable optical system? Will the advantage of a curved slice-scan still be evident with film produced with fish-eye lenses? Are line-segments, multiple hits and elaborate slice-scan patterns worth the extra trouble? Many of these questions are asked in the proceedings, and the answer to some of them will only be known in the next months.

A shadow was cast over the meeting by the tragic occurrence at the conference banquet on Tuesday evening. An appreciation of the

late Bob Haxby has been written by his colleague, Bill Higby of Iowa State University, and precedes Professor Haxby's paper in these proceedings.

In all other ways, the conference was a success, and many people contributed to this. My colleagues on the organizing committee took responsibility in many areas. Dorothy Carlson and her Argonne conference office looked after so many details that I wonder how people without such a facility can organize conferences. Carol Kosner worked on many pre-conference arrangements, as well as editing the proceedings, and Mary Keigher has done the bulk of the secretarial work.

I hope it is not out of order to add a small personal note here. By the time this is published I shall be working on the construction of the new accelerator at CERN after some 10 years in bubble-chamber data processing. I would like to take this opportunity to say goodbye to all my colleagues, and to express my wish for the health, development and continued funding of bubble-chamber film-measuring techniques. These techniques are not only indispensable to a whole area of experimental physics, but constitute a fascinating and worthwhile field of study in their own right.

Status Report on the ANL POLLY System

F. Beck, G. Charlton, R. Engelmann,
R. Marema, B. Musgrave, P. Peeters,
B. Phillips, G. Thelen, B. Zieman
(Presented by R. Engelmann)

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ABSTRACT

Two cathode ray tube systems, POLLY II and POLLY III, are in operation at ANL. POLLY II is measuring bubble chamber photographs from the 30" MURA bubble chamber. POLLY III was built to process film from the ANL 12 foot bubble chamber. Production measurements on the 12 GeV/c pp film have begun. Considerable effort is being made in improving the POLLY III software in order to increase measuring speed and quality.

A XDS $\Sigma 7$ computer controls one of the two installations at a time.

I. POLLY II

POLLY II has been in operation for three years. In the 2.3 GeV/c $\bar{p}p$ film from the 30" MURA bubble chamber about 350,000 events were automatically scanned and measured. Additionally about 240,000 events were measured in various other films from the 30" chamber. The measurement rate is about 100 events/hour. Currently 5.5 GeV/c K^+p two prongs are being measured on POLLY II.

II. POLLY III

POLLY III was constructed to process film from the ANL 12 foot bubble chamber. It is very similar to POLLY II. The main innovation in POLLY III is the four film transports. Any of these 70 mm

transports can be selected as a measuring station by flipping an indexing mirror. POLLY III has started to measure 12 GeV/c pp pictures from the 12 foot bubble chamber.

In the following pages a brief outline of hardware features, the software status and some results are given.

A. Hardware

This is not a complete description of the hardware which can be found in Ref. 1. The arrangement of components in the four view system is briefly described as they are different from POLLY II.

Fig. 1 shows the active components when the computer examines the film (measuring path). A 9" CRT with vertical axis creates a light spot which is computer controlled. The thick dark line shows the optical path. A precision lens creates a half size image of the CRT face on the film, which is switched into the optical path by an indexing mirror. A beam splitter directs the light onto a photomultiplier which is input into a signal discriminating circuit. The beam splitter in front of the precision lens, a pellicle, transmits about 70% of the blue-violet region where the photomultipliers are most sensitive. Contrary to POLLY II, there is no reference multiplier to monitor the CRT light. The pellicle allows its installation if found necessary. The beam splitter close to the film and the pellicle provide an optical path for projecting the bubble chamber picture onto a screen in front of the operator.

The projection path is shown in Fig. 2. In this mode the photomultipliers are protected by shutters. A projection lamp and condenser illuminate the film. The precision lens and the pellicle throw a green image into a plane corresponding to the CRT face. A field lens in this plane collects the light onto the projection lens. The optical path from there on is folded in order to keep it short. The beam splitter in front of the projection lens allows the projection of a pointer onto the bubble chamber picture. The two crossed mirrors which move the pointer image are driven from the same D-A converters which are used for the pincushion correction in the precision circuits for moving the CRT spot. This enables the operator to point out a track on the projection with high accuracy which is essential for the processing of film from the 12 foot chamber.

Fig. 3 shows the back side of POLLY III with the arrangement of the four view system. The center box contains the indexing mirror which flips any of the four film transports mounted at 45° to the optical path. This change of view is done in less than 1 second.

Fig. 1 Measuring Path

Fig. 2 Projection Path

Fig. 3 Four film transports around the indexing mirror

The indexing mirror positions a point reproducibly within two-three microns which is adequate.

Fig. 4 shows POLLY III as seen by the operator. A 12 foot picture is projected onto the screen. The display below it shows the results of the measurement of a six prong on the left hand side of the bubble chamber picture. (Currently the IDI display CRT on POLLY II is used and its image sent over to POLLY III with a TV camera. POLLY III will be shortly equipped with its own display.) Also visible is a set of push buttons for operator intervention. High quality projection of the bubble chamber picture and a clear display of the digitizations are essential since the measurements on 12 foot film require a considerable amount of operator help.

Another important new piece of hardware is the signal discriminating circuit. It determines the discriminator level for the current sweep in a slice scan from the previous sweep. It discriminates in this way dynamically across the whole 12 foot picture which shows quite a bit of backward variation. B. Phillips discusses signal discrimination in a separate contribution to this meeting.²

B. Software

The software is essentially the POLLY II system for 30" film, modified for POLLY III hardware and 12 foot bubble chamber film.

POLLY III Interface

POLLY II and POLLY III are both connected simultaneously to the XDS $\Sigma 7$ computer. The symbol routine package to handle all input-output operations was expanded to include the POLLY III software interface. A software switch set by the user controls which POLLY is accessed.

Software Relevant to Specifics of 12 Foot Bubble Chamber Film

Fig. 5 shows a 12 foot bubble chamber picture with incident 12 GeV/c protons. It illustrates three main characteristics which have to be considered when changing the software for POLLY III on 12 foot film:

- 1) The events are projected into about half of the picture and tracks get crowded together. For three view reconstruction in the geometry program there is usually one view far away from the event which is seen strongly demagnified with tracks crowded considerably as the event downstream illustrates in the figure. Track following and keeping track quality high without attaching wrong pieces from other tracks becomes more difficult.

Fig. 4 Operator console of POLLY III

Fig. 5 12 foot bubble chamber picture with
12 GeV/c protons incident

2) Tracks, mainly due to the large stereo angle, are only poorly approximated by circles in the projection. To guess ahead to the next measuring position during track following becomes more difficult. The same holds for vertex association of tracks and for kink detection.

3) The bright field illuminated film is noisier in general. Track detection in particular becomes more difficult.

The major changes to the existing POLLY II software are outlined below:

i) Track Following

The track following routine was changed to realize better a change of curvature while following the track. Due to the crowded track configuration and the noise too many bad measurements were made. Use of more detailed information from a slice scan than just the center of mass coordinates of all accepted hits was needed. A least squares fit to a straight line through all hits with acceptable widths was made resulting in a track element orientation and a chisquared, a measure of track element quality. Fig. 6 shows these results from a slice scan. It also illustrates how bad measurements are obtained and track pieces or whole tracks are "invented" by the track follower if only the slice scan's center of mass coordinates are used. The χ^2 cutoff tolerates one noise hit about half the slice width away from the least squares line. POLLY III has 64 slice scan orientations. Currently the track following routine eliminates measurements off by $1\frac{1}{2}$ slice scan orientations which corresponds to about eight degrees. The track element orientation is not yet used in the prediction for the next measurement. This feature will be incorporated. It takes about $\frac{2}{3}$ of one sweep's time in a slice scan to calculate all the sums needed for the least squares fit. Hence most of the calculations can be done while the hardware is busy with the slice scan.

ii) Track Search and Track Identification

Once the vertex position is known, the event is automatically measured. A hit within a search slice scan along octagon sides around the vertex position signals a possible track. The track following routine follows the track outwards and then back inwards to the vertex. The tracks already found which were parametrized by circles and interrogated at each new octagon search are now identified by their intersections with the octagons in order to eliminate multiple measurements. There are seven octagons with appropriately chosen radii for the 12 GeV/c pp film. The intersections are calculated only for further octagons to come in the track search. Possibly intersecting octagon sides are quickly determined by a fast symbol routine.

Fig. 6 A straight line fitted to all acceptable hits within a slice scan. Angle and χ^2 cut eliminate bad measurements.

iii) Fiducials

The lower two rows of chamber based fiducials as shown in Fig. 5 are automatically measured. The fiducial routine uses a map of their positions, armlengths, and arm orientations. Comparison between measurements done on conventional manual measuring machines (Hermes) and POLLY III showed that the fiducial arms can be sufficiently well approximated by straight lines. Fig. 7 shows the result of search and measurement of a chamber based fiducial. The center of mass values of the measurements on each arm define two intersecting straight lines which give the fiducial position.

Apart from these changes, the software for processing 12 foot film was tuned by appropriately varying parameters and tolerances in various routines.

C. Calibration

The calibration of POLLY III is done in the same way as for POLLY II. A grid with 5 mm grid spacing is measured. All optical distortions and the residual pincushion distortion (pincushion distortion is corrected for in a first approximation by a hardware analog method) are parametrized by a 5th order polynomial. The output data are corrected with its coefficients. The calibration at the time is good to two-three microns. Fig. 8 shows a comparison between measurements of 2.3 GeV/c $\bar{p}p$ events from 30" film on POLLY II and POLLY III. The RMS deviations from a helix fit in TVGP are slightly higher on POLLY III, about one-two microns. The accuracy on POLLY III is sufficient for the measurement of 12 foot film. (In this comparison the Coulomb contribution to the RMS is not subtracted.)

D. Measurement of 12 Foot Film

With the existing software about 350 four and six prongs were measured in the 12 GeV/c $\bar{p}p$ film from the 12 foot chamber. These event types are quite difficult, having a lot of tracks close to each other. Fig. 9 shows the display of unfiltered real time digitizations in the vertex area of a six prong. It gives an impression of the noise level and the complexity of the event. In many cases the outgoing tracks stay close to each other for quite a long distance away from the vertex. The same events were also measured on the manual Hermes machines. Fig. 10 shows a comparison of the RMS distributions in TVGP for both measurements. The POLLY III results are slightly less accurate but adequate for the 12 foot film. (Here the Coulomb contribution to the RMS was subtracted.)

The POLLY III measuring rate for these difficult events was

Fig. 7 Measurement of a camera based fiducial

Fig. 8 RMS deviation in a helix fit, 2.3 GeV/c $\bar{p}p$ TVGP results on POLLY II and POLLY III (Coulomb contribution included)

Fig. 9 Real time digitizations of a six prong vertex area on the CRT display

Fig. 10 RMS distributions on Hermes and POLLY III, 12 GeV/c p p TVGP results (Coulomb contribution subtracted)

seven events/hour. The success rate in TVGP was 65%. (A single track which fails or has a RMS bigger than 50 microns fails the whole event.) The corresponding numbers for the manual measurements on Hermes were three events/hour and 85% success in TVGP. The POLLY operator had to assist the automatic measurement in practically every case. The program requested from the operator an inspection of each track end point and the complex vertex area after all tracks were found. This inspection of the whole event, the addition or deletion of tracks and the cutoff of bad track ends by the operator is very costly in time and has to be brought to a tolerable level in the future software development.

The physics program with the existing software is to measure secondary neutron interactions, V^0 's and gammas with primary pp vertices on 70,000 12 GeV pp frames. The vertices are predigitized on scan tables. It is expected that the measurement speed will at least increase by the ratio of average tracks per event which gives fifteen to twenty events/hour. Also the throughput of events through TVGP will increase considerably.

E. Software Development and Plans

The following is an outline of the software improvements being worked on or planned in the future. They may be of interest to those who plan to automatically process film from the new large bubble chambers. The aim here is to cut down operator assistance to a tolerable level and achieve economic measuring speed and throughput of events through the geometry program.

1. Track Following and Kink Detection

Currently the track element orientation is only used to eliminate bad measurements from crossing tracks (see Fig. 6). If a track close by or an outgoing track from a secondary interaction have roughly the same orientation as the track being followed, the track follower very likely accepts measurements on these false tracks. Another problem is the crossover of two tracks with roughly the same curvature and orientation. These cases are shown in Fig. 11 and illustrate the main problem in the measurement on 12 foot film. The most important point is to make sure that the track follower holds on tightly to a track once it is on it, and that the kink detection eliminates cases as shown in Fig. 11. For the time being, raw measurements are combined into masterpoints and the kink detection is done using these. The quality of raw measurements after χ^2 and track element orientation cutoff is high enough in order to kink detect using raw measurements and orientations. Even then for crossings of tracks at very small angles have to be realized by an increase in multiple hits in the crossing zone. The digitization of areas before and after the crossing may establish two crossing tracks, and

Fig. 11 Cases where the track follower continues on wrong track.

the right one after the crossover may be kept.

Work on this is in progress.

2. Track Pick Up in the Track Search Around the Vertex

Quite often tracks are lost in the search slice perpendicular to the track. Currently at least two consecutive hits in the slice are taken to be a track signal. (Only one hit would give too many candidates from noise and take too much time.) By repeating the search slice and requiring coincidences as well as a minimum width of the hit, it is hoped to increase the signal to noise ratio.

3. Track Linking to Vertex

Tracks which have been successfully followed get lost, i.e. are not linked properly to the vertex. Currently a circular approximation to the track piece using a few masterpoints is made. Use of the track element orientations and a few raw measurements close to the vertex should improve the linking.

4. Elimination of Single Hits Far Off the Least Squares Line Element

Quite often slice scans with one or two hits far off the average positions of all the other hits cause a large χ^2 and the rejection of the whole slice. It happens that a series of otherwise acceptable measurements gets eliminated in noisier areas. The necessary sums for the least squares line and the χ^2 are accumulated in one pass through the slice scan input buffer. By reexamining the input buffer and rejecting one or two such bad hits, measurements can be saved. This is essential since the power to predict the next measurements position ahead is small in the 12 foot film. An illustration of this situation is given in Fig. 12.

These software improvements will be worked on while the production measurements proceed, hopefully with increased speed and higher quality.

Fig. 12 Reexamination of slice scan input buffer in order to find noise

Discussion

T. Palfrey (Purdue) What is the accuracy needed in the optical projection of the reticle?

R. Engelmann Very often it has to be accurate within a track width on the projection; especially with events where there are many tracks very close together.

P. Connolly (BNL) How do you parameterize the track for prediction purposes?

R. Engelmann As a circle. The number of points along the arc is a function of how many points we already have and change of curvature. The greater the change in curvature, the closer the points have to be. Typically, 3 to 10 points.

P. Connolly (BNL) In the individual slice-scan, what is the error on the individual digitizer?

R. Engelmann Three to five microns depending on the signal-to-noise ratio.

P. Connolly (BNL) If you are doing chi-squares on digitizings of individual slice-scans, then what kind of cut-offs do you use, etc.?

R. Engelmann There we are pretty tolerant. The cut-off is one noise hit more than half of the slice width away from the average hit position. (The slice width is 100 microns typically).

The POLLY III Track Discriminator

H. B. Phillips

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ABSTRACT

A new track discriminator circuit has been tested on the bench using POLLY-like signals. The new circuit, as does the previous one, uses information obtained during each sweep to set the discriminator level for the following sweep.

INTRODUCTION

When the title for this paper was announced, it was hoped to be for a report on the operation of the "new" track discriminator in POLLY III. However, due to the usual problems encountered during the shake-down of a new machine, the new discriminator has not been installed in POLLY III as yet, although the circuits have been tested on the bench using simulated POLLY-like signals. I will, therefore, describe the philosophy underlying the present track discriminator, and then outline the operation of the new one.

The Present POLLY III Track Discriminator

When POLLY III was first turned on, and we were able to examine the signals actually obtained, we found that CRT phosphor noise was much smaller than had been anticipated. I believe this is caused by a larger CRT spot than had been hoped for. I had expected a CRT spot of somewhat Gaussian shape with a $2\text{-}\sigma$ width of about $16\text{-}18\text{ }\mu\text{m}$. Visual examination of the spot would indicate this estimate to be about right, but the signals appearing from scanning the spot across a sharp edge in the film plane give a value of about $18\text{ }\mu\text{m}$ at the film. Since we use a 2:1 reduction between the CRT and the film, this would imply a $36\text{ }\mu\text{m}$ spot at the CRT, which is larger than it appears to the eye. I believe this discrepancy to be caused by a non-Gaussian spot having a fairly intense central amplitude and wide skirts. Because of the non-linearity

of the eye, the spot looks smaller than it actually is. With a larger spot the individual phosphor grains are less well resolved and the phosphor noise is correspondingly reduced, but the track finding capability is also reduced.

Since POLLY III uses a short sweep (500 μ m maximum in the film plane,) film background is practically constant over a sweep. This fact, together with the small phosphor noise, eliminates the need for a reference photomultiplier, and therefore a track discriminator was built without using the reference channel.

In the present track discriminator the photomultiplier signal is pre-amplified by a conventional transresistance amplifier, and is then fed to a pseudo-sine-squared filter for enhancing the signal-to-noise ratio. This is an active filter having $\times 10$ voltage gain and a graceful transient response which tends to preserve the symmetry of track pulses. The time-constant of this filter can be changed by merely plugging in different resistance values.

Following the filter stage is an analogue integrator whose time-constant is set by the computer to be proportional to the slice-scan sweep width. This integrator is switched on during each sweep and is reset between sweeps. Since the time-constant is proportional to sweep width, the effective gain is inversely proportional to width. Therefore, at the end of a sweep the integrator output is proportional to the average value of the signal during the sweep. For a track-free sweep, the integrator output is a direct measure of background pedestal level. At the end of each sweep the integrator is sampled before the integrator is reset, and this sampled value is held for use in the following sweep. This held value, made to equal the average signal height, is next amplified by a factor β which is under computer control; for clear tracks on dark background β is usually set at about 1.2, while for dark tracks on a light background β is usually set to about 0.8. This modified voltage level is then used as the reference level in a comparator whose other input is taken directly from the preamplifier-filter channel, resulting in a discrimination level which is updated at the end of each sweep.

This circuit has the desirable property of automatically changing the discrimination level when tracks are encountered, and causes the track-to-background ratio to be greatly enhanced. This track detection scheme is being used for both 12 ft. bubble chamber film and 30 inch bubble chamber film with very good results, with one exception. As the sweep width is made small, so that track signal width is a large portion of the sweep width, the contribution of the track signal becomes large, and tends to boost the discrimination level too much. This sometimes results in the loss of track signals when narrow sweep widths are used, or if two tracks are encountered within one sweep, and therefore a some-

what different (and simpler) track detection method is to be tried.

The New POLLY III Track Discriminator

As mentioned earlier, the observed POLLY III signals are well-behaved: film background is essentially constant over such a small sweep, and phosphor noise is small. Therefore, during a sweep the minimum signal level is a good measure of the pedestal height (using 12 ft. chamber film) while the maximum signal level is a measure of track amplitude. Accordingly, the new discriminator uses these values instead of the average of the entire sweep.

In the new circuit the original preamplifier and filter are used. The resulting signal is then fed to a maximum detector and to a minimum detector. During a sweep one circuit seeks the maximum amplitude of the signal, while the other circuit seeks the minimum value. At the end of a sweep these two levels are averaged and held in a sample-and-hold circuit for use as the discrimination level during the subsequent sweep. Thus, the discrimination level during a sweep is $1/2 (\max + \min)$ as obtained during the preceeding sweep. Again consider a track-free pedestal which has a certain amount of random noise (mostly from photomultiplier shot noise). The value $1/2 (\max + \min)$ is therefore a good measure of the pedestal level. If, however, a track signal is present, then $1/2 (\max + \min)$ represents the 50% level of the track signal, which is an excellent discrimination criterion. As in the present circuit this sampled value is compared with the input signal during the next sweep. It will be noticed that for reverse film $1/2 (\max + \min)$ is still the 50% amplitude level if the two comparator inputs are merely interchanged.

These circuits have been assembled using very simple (and inexpensive) gated transconductance amplifiers, RCA type CA-3080's and have been tested using simulated pulses. These test signals were produced by combining square waves, representing pedestal and signal, with a small asynchronous pulse train representing noise. After filtering, the resulting signal appears very POLLY-like, and signal-to-pedestal and signal-to-noise are easily varied. Also two track signals can be generated, which simulates the situation in which two adjacent tracks are encountered during a sweep.

The results of these bench tests are very encouraging, since the system behaves just as expected. The final circuit boards are now being constructed and should be installed in POLLY III within the next few weeks.

Discussion

R. Glasser (Argonne) One of the problems with the 12-ft. film is that its background often isn't as flat as you have drawn it, but over a given sweep is roughly linearly rising. How does the discriminator cope with that?

B. Phillips In photographs of typical sweeps of 100 microns, or so, the slope you mention is very small. Tiny artifacts in the film are usually more pronounced than this slope. In any event, the new circuit could give the same pedestal measurement as does the present integrator method.

J. Power (Caltech) Can you tell me why you have a sine-squared filter in there, and also why is it called a sine-squared filter? I'm not familiar with that term.

B. Phillips The reason for having a filter at all is to improve the signal-to-noise ratio. If one looks at the raw signals from the phototube, they are very trashy, mostly due to statistical noise from the PM. Since we want to degrade signal slope as little as possible, we need to use some kind of filter which has a graceful and symmetrical transient response, and one such filter is the sine-squared, which gives a nice sine-squared response slope from a unit impulse. Also, this type response more or less matches the slope of our input track pulses. The exact pulse response is not critical as long as we remove the high-frequency noise components, which can kill you, and still retain the symmetry of the track pulse.

P. Oddone (Caltech) I am interested in some of the parameters, in particular, what spot size are you obtaining on the film, and what is the bubble size that you are seeing now with the 12-ft. film?

B. Phillips I am not sure what the bubble size is at present (Rod Engelmann said 30 microns on film), but the spot size on the film seems to be about 18 microns, which is larger than we had anticipated. We measured this by putting a sharp edge in the film plane, and sweeping the spot across it and observing the signal. Since we use a 2 to 1 transfer lens this means we have a spot something over 30 microns at the CRT, which is hard to believe, since we can look at slice scans on the CRT and resolve individual traces. That leads me to believe that the spot is not Gaussian, but has long sloping sides.

J. Deery (Toronto) Have you done ionization measurements with POLLY III, and also, are you using dynamic astigmatism? If so, what is the magnitude of the correction?

B. Phillips We haven't used ionization information yet, but we plan to. We do use dynamic astigmatism correction. Without correction our spot growth is about two to one, and with correction the growth is about 30% - 1.3 to one.

COCCINELLE: 4 View Film Transport

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ABSTRACT

This paper describes the progress on COCCINELLE, a CRT device for large bubble chambers. The four view film transport, which is of an unusual design, is described together with the reasons for choosing this design.

INTRODUCTION

COCCINELLE is a CRT device designed to scan and measure big bubble chamber pictures, especially those from MIRABELLE, BEBC, and GARGAMELLE.

The apparatus is being developed with two SDS computers: an SDS-92 is used to control the CRT, displays and film transport. It also performs most of the track recognition. An SDS 9300 computer is used on a stand-alone basis for all calculations requiring floating point operations. Most of its work consists of doing geometrical correlations between different views.

At the present time the hardware is completely built except for the film transport, which is still at the assembly stage and will be completed in a few weeks.

All electronics is operating quite satisfactorily but a few points have still to be improved in order to get the required accuracy. It has recently been decided to expand the device into a 4-unit system in order to satisfy the needs of all Paris Laboratories. A new medium size computer will be ordered very soon with a view to delivery on January, 1973. A study has been undertaken to decide which one of the following XDS

Sigma 7, DEC, PDP-10 or CDC CYBER72, meet our specifications best. The control computers (one per unit) which have been considered are the PDP-11 and the CII MITRA-15. The system will be built at the LPNHE (Paris University).

Of course, the task of adapting the software to the new computers is not an easy one. Nevertheless, it is expected to get a second unit working on the new computers about a year after the first one. As soon as unit 2 is operating, unit 1 will be connected to the new computer.

I. Main Characteristics

These have been described in previous papers (Ref. 1) and we shall just recall here how it differs from POLLY (a general layout of the unit is shown on Fig. 1).

- (1) The sweep is digitally generated using two up-down counters for x and y coordinates, DAC's and amplifiers. All sweep parameters can be set from the control computer.
- (2) A wired-in track element detector, working in simultaneity with the sweep, sends to the control computer the origin (x, y) and the angle of all line elements found in the scanned area. (Single track digitizings can also be used by by-passing the T. E. D.) The detector is built on the same principles that were described in previous reports but it has been re-designed and uses M. O. S. shift registers instead of analog delay-lines.
- (3) Three displays are provided to the operator:
 - 1) A computer display used in a way very similar to the POLLY display
 - 2) A "TV-display" which is actually a slave display using the CRT and photomultiplier as a camera. (Its deflection circuits are directly connected to those of the precision CRT through a simple circuit that removes the continuous component representing the middle of the current scan pattern.) This TV display allows variable magnifications and manual measurements of points on the tracks by means of a light-pen.
 - 3) An optical projection is normally used to show a view different from the one being measured ("stereo view"). It can stay on while measuring but no provision has been made to allow operator interaction, (although this could be added if required).

II. Film Transport

MIRABELLE, BEBC and GARGAMELLE films are all 70mm sprocketed, but each chamber has a different film arrangement. BEBC

Fig. 1 Block diagram of the Coccinelle system

has 4 views on 4 films, GARGAMELLE has 8 views on 2 films and MIRABELLE has 8 views on 3 films.

For example, in MIRABELLE the same 70mm film is fed to the three (or two) cameras of a given line. This arrangement leads to a 2-meter distance on film between two adjacent views of the chamber. Different exposures are interleaved allowing a constant distance of 313.6mm between two exposures of the same view.

Overlap between adjacent camera fields is not very large. Hence it does not seem possible to use a strongly reduced set of cameras, even at the scanning level.

Basic Specifications

A fast access ($\simeq 150\text{ms}$) to four views and a fast film transport (3m/s) were required at the design level. A fast access to eight views did not seem really needed as both operator and program must follow some systematic order in going from view to view. Therefore, it is almost always possible to move one of the films when scanning another one.

A repositioning accuracy of about $30\text{ }\mu$ was thought good enough to allow view commutation without fiducial search (scanning level).

Optical display of one of the fast access views was also required as the best means of having a good view of the complete picture, whereas the TV display offers a better viewing of small image portions.

Several possible solutions were considered, among them:

- a) Semitransparent mirrors. At least half of the light-output of the CRT is lost, which does not seem acceptable in view of signal-to-noise difficulties that are expected with some chambers (especially BEBC).
- b) Two views side by side with the same CRT. This requires one more bit of accuracy.
(Each of solutions a) and b) allows access to only two views, or they must be used together.
- c) Mirror shuttle. We were not able to avoid parity symmetries between different views. They cannot be compensated by adequate parities at the film loading as two views are on the same film. (This argument does not apply to BEBC film). Symmetries complicate the program's task and make optical display useless.
- d) Two or more CRT's. Apart from price considerations, this

system multiplies calibration and maintenance tasks. The scanning and measuring program has to handle different distortion formulas.

- e) Moving stage systems are simple and inexpensive if capstans reels and motors lie on a fixed frame. Stage displacements can be encoded and allow manual measurements (see ERASME, Ref. 2). But they cannot meet our 150 ms specifications for view commutation.
- f) Flipping-mirror or rotating-mirror systems have also been envisaged, but we could not succeed in satisfying both speed and precision requirements.

Our view commutation system was retained mainly on the basis of low cost and possibility of quick implementation, although it may seem fairly complicated. The principle is the following: In order to bring a view into the (unique) measuring position, the film gate is rotated 90° along an axis parallel to and near of the edge of the film (Fig. 2).

In fact we have four film gates mechanically linked two by two and so we have only two rotation axes.

Each film can therefore be in one of two positions:

- "Neutral". The film gate is parallel to the optical axis. The film transport can be energized.
- "Active". One of the films is in the measuring position, the other can be projected on the operator table.

Advantages

- No parity problem.
- Only one measuring position, hence one set of distortion parameters. (Accurate positioning of all film gates is guaranteed by the same three precision stops).
- The four film transports are identical. Each one consists of a plate carrying the two reels with their motors and vacuum boxes, the capstans and pinch-rollers. The same capstan motor can even be used for two film transports (each one having its own brakes and clutches) (Fig. 3).

Drawback

- Before the film gate can be rotated, one must create two free-hanging loops. This requires one more capstan.

Fig. 2 Film Commutation System

Fig. 3 Film Transport

- The film is twisted by the film gate rotation. One might be afraid of permanent film deformations. From our test on a model, this does not seem to happen. (Films are submitted to much more severe stresses in film-developing machines).
- Film gates are much heavier than a mirror shuttle, for instance. In order to ensure a 150ms flipping time, very powerful drives have to be used.

Special features

- With all films in neutral position, a calibration grid can be brought into measuring position for routine calibration of the CRT assembly.
- A mirror system makes it possible to read the binary numbers in neutral position.
- To allow access to four views of Mirabelle, one of the films must travel through two film gates. Film loops are then absorbed by special vacuum boxes, called "film storage vacuum boxes". (For Gargamelle film, this special loading is used for the two films; for BEBC no problem arises, each film being independent.

III. Conclusion

The software system has been described in a recent paper (Ref. 3). As we have not yet experienced the difficulties that can be encountered with big bubble chamber pictures, we have tried to make the software as flexible as possible. All track recognition routines which have been written are very straight forward and we intend to improve them as we gain experience with the first MIRABELLE pictures.

Fig. 4

Fig. 5

Film transport and commutation system. (The CRT has been removed from its bench. The aluminum column is for adjustment purposes. It sits right to the optical axis. Film is in measuring position).

ACKNOWLEDGEMENTS

We would like to acknowledge A. Dionigi, C. Fritsch, J. J. Jaeger, A. Karar, P. Lutz, R. Merzoug, J. Morinaud and P. Rancon for their contribution to the development of the system.

REFERENCES

- Ref. 1 - The use of COCCINELLE, a CRT digitizer to scan and measure big bubble chamber pictures.
B. Equer, et al., College de France - International Conference on data handling systems in high energy physics Cambridge March 23-25, 1970.
- La logique de generation du balayage, la logique de transfert des donnees au calculateur et la tampon dans l'appareil COCCINELLE.
College de France internal report 1970
- Ref. 2 - The ERASME project summary
D. Lord - CERN DD/DH/70/20
- Ref. 3 - The film transport and programming system of COCCINELLE
International Symposium on Data Handling of Bubble and Spark Chambers - Dubna (USSR) October, 1971

The Carnegie-Mellon University-Case Western
Reserve University POLLY

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ABSTRACT

In conjunction with Case Western Reserve University, we have undertaken to construct a POLLY III. To date, we have fabricated and assembled approximately ninety percent of the machine. We hope to have a simple measuring system by late Spring, 1972.

The CMU-CWRU POLLY system consists of a POLLY III as designed by Argonne National Laboratory and a Digital Equipment Corporation PDP-15/20 computer. The POLLY is being constructed from the drawings supplied by ANL. The PDP-15/20 is an 18 bit word computer with 8K memory, index register, extended arithmetic element, Dectapes, and a high speed paper tape reader and punch. In addition, we have a disk of a quarter of a million word capacity and floating point hardware. A line printer (on loan) and an Ampex tape transport complete the system.

Construction is almost complete. Only the reticle stage and the mirror indexer mount remain to be finished. The POLLY main logic and interfacing is done (with the exception of a few cards in the discriminator circuit) and is being debugged. Within a month or so, we should have all the wiring completed so that we should be able to move film and turn the CRT spot on. The precision D-A converter, focus supply and associated power supplies were constructed for us by the Electronics Division of ANL and will be installed shortly.

Thus far, the programming effort has been mainly directed towards developing our own system and short routines such as slice scan controller and track following. The software also includes a simple system for overlaying routines from the disk and time sharing different programs.

We have used approximately three man years of machine shop time and three man years of electronics shop time. In addition, we have spent about \$140,000, \$60,000 of which was for the computer.

There is only a slight variation in the external appearance of our POLLY. We have a square display scope instead of the IDI system, and we have only eighteen buttons instead of thirty two. At present, our only plans for the future are simply to replace the film reel holders, rollers and platens to accommodate 35 mm film.

Internally, the appearance is much the same. Since we are not using the IDI system, we have placed in that position, two short racks to mount the capstan motor drives and the mirror indexer drive. Instead of using XDS modules, we have redesigned the main POLLY controller logic around DEC Flip Chips, using the M series modules. This decision was influenced by our familiarity with DEC's products as well as by our previous decision to use a DEC computer. The rest of the electronics is the same. All the precision CRT driver electronics are the same as ANL's, having been built by ANL from ANL prints. We are copying the discriminator logic and the film transport logic as furnished by ANL.

The display system is a simple point by point display driven by the computer. However, the single scan time becomes very long if we make the computer calculate the intermediate points, and for complicated displays, the flicker becomes very great. This means that we will probably have to invest in a vector generator or allow more buffer space, more than likely, a combination of both. To alleviate some of this problem, we have been contemplating installing a video terminal for messages.

The basic difference in our system lies in our decision to purchase a small computer. Although the basic philosophy of how to drive a POLLY remains the same, the actual implementation must be different. Added to this is the difference in the philosophy between the use of a small, dedicated computer as opposed to a large, general purpose computer. One of the prime differences is the fact that it is quite simple to build our own monitor system with stripped down handlers, with no regard for outside users. Another advantage is that the computer is completely free for on-line debugging. With this in mind, we have designed a system which includes a time shared DDT and a simple system for overlaying routines from the disk.

DDT (dynamic debugging technique), a name borrowed from one of DEC's programs, is a routine for examining core and changing instructions at will. By time shared, we mean that other programs may be executing while we do this. Our time shared DDT will give us not only the capability of on-line debugging, but the possibility of real time program development. This means that minor improvements should take only minutes to hours instead of days to weeks. In most instances, this could be done while the POLLY is being used for measuring.

In the disk overlaying routine, we have allowed for two types of overlays, open ended routines, ones which may never be completed, and closed routines, those which will always return. Open ended routines are ones that require a response from the programmer or operator. The

closed routines have been divided into two categories, one which executes slow output (to a typewriter, for instance) and those which strictly calculate. Of the 8K memory, we have devoted about 2K to the various handlers, 2K for the overlay working area, and the remaining 4K for buffers and storage.

With this system, we are presently engaged in arranging the various routines into a simple measuring procedure, one that can be expanded at will, as experience dictates.

One variation we intend to implement is the manner in which the POLLY console buttons are used. In addition to the fixed courses of action defined by the buttons at one level of operation, the buttons will be used on another level for entering indicative information and answering still other questions not provided for by the buttons. We are thinking of displaying questions for the operator in such a manner that they can be answered by a YES or NO response.

We are in the process of obtaining an additional 8K of memory. We could then probably go over to FORTRAN and the DEC system if it seems desirable. It would also provide more buffer space for the display. Most importantly, it will provide space for routines that must at present be called from the disk, this increasing the speed of the machine. It will also enable us to use the DEC system for preparing and assembling programs more efficiently. Along this line, another disk would be desirable since the present DEC system occupies half the disk, and we anticipate the POLLY system occupying the other half, leaving no scratch disk area for the DEC system. Our plans also call for another tape transport to provide easier access to scanning information as well as to enhance the PDP-15 as a general purpose computer.

With lots of luck, we hope to have all construction completed within a couple of months, everything debugged, aligned, and calibrated within a few months after that so that we shall attempt measuring by late spring.

* Work supported by the U. S. Atomic Energy Commission and the National Science Foundation.

Discussion

J. Goldberg (Technion) What fraction of the total work done on the Sigma 7 would you hope to do on the PDP-15? In 8K, can you also provide for automatic scanning?

T. Kikuchi I expect to do everything that they can do, just a lot slower. Right now, I am sacrificing my speed.

J. Deery (Toronto) How many levels of overlay will you need in order to go through the whole thing from fiducial locating through track following per event?

T. Kikuchi Per track, I only anticipate about one or two.

J. Deery (Toronto) Oh, you are going to have to overlay per track. I see.

University of Illinois DOLLY Hardware*

by

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Abstract

DOLLY is a precision multiple film CRT film measuring machine similar to POLLY, however, by the use of digital hardware a more flexible slice scan may be generated. The arithmetic unit, D/A converter, and optical system will be discussed in this paper.

INTRODUCTION

At the October, 1968 Conference on "Advanced Data Processing for Bubble and Spark Chambers" we described a multiple CRT machine under construction at the University of Illinois, called DOLLY. This machine was placed on-line to the CSX-1 computer February, 1970 with a single CRT station. The first large production run on 500,000 spark chamber pictures was made from July to October, 1971.

When considering designs for a machine at Illinois in early 1968 it seemed to us that the 'slice-scan' technique held the most promise. We also wanted an optical image for an on-line operator as in POLLY II. We decided, however, to make two basic hardware changes. The first was to implement the machine as completely as possible with digital integrated circuits. Second, we needed to change the mechanical configuration to handle our wide range of film sizes and formats.

The multiple reel, multiple CRT hardware was chosen for looking at different views during measuring without remeasurement of fiducials. For the distorted optics chambers this look-around feature was felt to be necessary to resolve ambiguities. We also find good flexibility results from this configuration for mixing film formats.

*Work supported in part by U. S. Atomic Energy Commission

D/ACONVERTERS

In order to implement the digital philosophy in DOLLY it was necessary to design a stable, high current, 16 bit D/A converter. The initial design was published in R.S.I. (Vol. 42, No. 6, 797-800, June 1971) by Zander. The present DAC has the properties listed in Table I.

MAX OUTPUT	1.4 AMPS
MEAN STEP	$23\mu a + 4\mu a$
LINEARITY	1/4 LSB.
STABILITY	1/4 LSB/hour
TEMP. COEF.	1/2 LSB/ $^{\circ}C$
TOTAL POWER	112 WATTS
SETTLING TIME	
UNSATURATED TO 0.001%	11.5 μ sec (11 low order bits)
SATURATED TO 0.001%	81.5 μ sec. max. (5 high order bits)

Table I

16 Bit D/A Summary

This D/A converter is a set of binary weighted current sources which drive the deflection coils push-pull. Each axis uses a sixteen bit DAC as a base point for the sweep. The sweep is generated from twelve bit DAC's of similar design that are current summed in the coil. Each CRT in DOLLY has its own set of DAC's.

INTERNAL ARITHMETIC UNIT

The DAC's are controlled by a hard-wired arithmetic unit. This unit consists of a sweep generator, segment generator, and track hit buffer. The sweep generator is given the sine, cosine, and length of the sweep by the main computer. A sweep of up to 4 mm. in length is driven by two high speed adders. The basic stepping parameters for these adders are corrected for pincushion distortion before being used. This insures constant sweep velocity over the face of the CRT. The sweep occurs symmetrically about each base point to minimize measuring errors.

The sweep speed may be changed by adjusting the clock frequency or by changing the magnitude of the sine and cosine parameters from the main computer. The sweep speed may be varied from essentially 0 to 64 μ/μ sec. We currently use 4 μ/μ sec. for precision scanning.

The sweep unit in DOLLY was used without a segment generator for the initial software development. The position of each scan line in a segment was sent to DOLLY. This allowed the algorithms for the segment to be tested before wiring them into the machine.

The algorithm has been hard wired since February, 1971. Two modes of operation can be used. The first mode consists of taking the first and second differentials of a second order curve and performing an iteration with these.

The equations are

$$\begin{aligned}u_{i+1} &= u_i + \Delta_i u \\ \Delta_{i+1} u &= \Delta_i u + \Delta^2 u \\ \Delta^2 u &= \text{CONSTANT}\end{aligned}$$

The equations for v are similar. The u, v's are the center of the scan and are sent to the 16 bit DAC's. The main computer supplies u_o , v_o , Δu_o , Δv_o , $\Delta^2 u$, $\Delta^2 v$, and the number of scan lines to the segment generator.

The second mode is a circle generator where the equations are:

$$\begin{aligned}u_{i+1} &= u_i + \Delta_i u \\ \Delta_{i+1} u &= \Delta_i u + \alpha v_i \\ \alpha &= 2^{-N}\end{aligned}$$

and

$$\begin{aligned}v_{i+1} &= v_i + \Delta_i v \\ \Delta_{i+1} v &= \Delta_i v - \alpha u_i\end{aligned}$$

At this time we only use the first mode for measuring.

The internal arithmetic unit handles one CRT at a time. To switch to another CRT station the main computer must send a new set of scan parameters.

The digital signal from the detector is received by the track unit, digitally filtered for maximum and minimum width and put in a buffer for transmission to the main computer.

CRT & OPTICS

The cathode ray tube magnetics are similar to that described by Wilder (Doctoral Thesis, University of Oxford, 1970) except there are no diquadrupoles. By using dynamic astigmatism correction the spot can be kept to under 25 μ diameter over a 5" x 5" square on the tube face.

In most CRT scanners the detectability of a track is dependent upon the signal to noise or S/N of the PMX signal. For a given spot diameter and track width the S/N at the photomultiplier output is given by:

$$SN \propto \sqrt{\text{incident light.}}$$

The first CRT optical system in DOLLY schematically looked as in Fig. 1. The percentage values are the measured percent transmission or reflection for the Ferranti Q phosphor spectrum. These values produce a total efficiency of:

Fig. 1 DOLLY 1/1 System Optical Element Transmission

$$\begin{aligned} \text{Eff} &= (.93)(.51)(.60)(.93)(.90)(.87)(.91)(.87) \\ \text{Eff} &= 16\% \end{aligned}$$

This 1:1 optical system was used during the initial testing and for the first production run. The machine is now implemented with improved 2:1 optics on three of four stations.

Since the pellicle transmitted only 60% it was removed and the unused light from the CRT collected for the reference. This increases the transmission to 27%, or a 1.7x increase. The use of a 2:1 lens with a numerical aperture of 1/18 compared to 1/24 for the 1:1 lens gains a factor of 1.8. The new signal to noise is:

$$\begin{aligned} S/N(2:1) &= S/N(1:1) [(1.7)(1.8)]^{1/2} \\ S/N(2:1) &\cong 1.7 S/N(1:1) \end{aligned}$$

CURRENT STATUS

Initial calibration measurements have been made and stability tests show 2-4 micron RMS errors over 24 hours. Resolution tests give 50 line pairs per mm. over the 5" x 5" usable tube face. Testing is being done on the last two stations with 2:1 optics in preparation for production measuring on 100,000 streamer chamber photographs.

Discussion

P. J. Oddone (Caltech) This is a question concerning your curved slice scan. It seems to me that what you show is quite impressive. It also seems, in this particular case that you knew which curvature to use for that particular slice scan. How do you choose the curvature to make your picture look pretty?

R. Downing (asks R. Brown to answer the question)

R. Brown (Univ. of Illinois) We have some estimate of the curvature of the track from the scanning process. Obviously if you have no information except a linear approximation you must use other techniques of track initiation. However, once you have found the curvature and you continuously monitor it, you can insert this information into your track following procedure to obtain much longer segments and better signal-to-noise ratio.

A curved slice scan allows you to go clear through, in an exaggerated fashion with the idea being that you want to look at the minimum amount of area possible. Cluttered film and a rectangular slice scan makes this very difficult. A curved slice scan allows you to draw your scan with past history and as a result background noise is minimized. If you did this in rectangular coordinates, the problem becomes one of collecting data from everything that is adjacent to the track and letting the computer do the curvature.

W. E. Slater (UCLA) What is the maximum useful curvature in your curved slice scan?

R. Downing I think that was found empirically. Dick, do you know what the current value is?

R. Brown (Univ. of Illinois) I believe the maximum that the computer arithmetic and fixed point representation will handle is 8 millimeters; I mean, the minimum radius is 8 millimeters. I think the limits are not so much set by the curvature or by the length, but uncertainties of projections on this and the accuracy of it. I would hesitate to give you any limit of a table, for example, of curvature versus scan segment width. We don't go actually to eight millimeters minimum radius very often. We have done some games with electron spirals, but they're only games.

Voice from Audience Is that 8 millimeters in space?

R. Brown No, it is not 8 millimeters in space. We are working in the computer world and 8 millimeters on 70 millimeter film would be 80 millimeters in space.

B. Chrisman (NAL) You mentioned you had a buffer for feeding back on each minor scan. How big is that buffer?

R. Downing The buffer is four words. The minute we get the first word, we try and transmit it to the computer. If it can't keep up, the buffer will fill and the next scan line will be held up until that buffer is empty.

R. Sunde (ANL) How fast will your computer accept data?

R. Downing At the moment, we have only a programmed I/O channel. I don't think we can run much faster than about 20 microseconds a word.

Some Software Techniques for the DOLLY System*

by

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Abstract

The use of histogram techniques for pattern recognition and filtering is discussed. Also described is an interpretive sequencer used to control both complex measuring sequences and detailed scanning procedures.

This paper discusses several procedures which have been useful in the development and operation of the DOLLY system. The first concerns the generation and analysis of histograms used in the pattern recognition and filtering of measured data. The second, an interpretive sequencer, involves flexible control of the varied processes composing the measuring sequence.

To understand the use of histograms for data filtering and pattern recognition, it is helpful to view the histogram bins as miniature scanning slits whose width is given by the bin size. Analysis of the histogram pattern corresponds to looking for hit correlations between adjacent scans. The advantage of histogramming lies in the fact that it yields the noise or interference rejection properties of thin scanning slits while permitting a single search scan over a much larger area. This is most useful in two applications:

1. Track following with moderate to heavy background interference where a single slit scan would produce too weak "a signal to noise ratio".

* Work supported in part by the U. S. Atomic Energy Committee

2. Frame mark or fiducial measurements where there is considerable uncertainty in the position of the pattern being searched for.

The data from DOLLY is directly suited for histogramming since hit coordinates (I,J) are given in integer count values for steps along and perpendicular to the scan segment axis. In addition, second degree position correction arising from track curvature or CRT distortions are removed by the iterations of the digital scan generator. When it is appropriate for the measuring process underway (e.g. fiducial measurement or track following), the DOLLY software constructs a histogram of the segment cross section as the data streams into the computer. Figures 1-5 illustrate the resulting histograms generated under varying conditions.

Figures 1 and 2 show the resolving properties of the histogram for parallel tracks. Figure 1 indicates the smearing effect when the histogram axis is not aligned with the track axis. Figure 2 illustrates the sharpening effect of proper alignment.

Figures 3-5 illustrate the filtering properties of the histogram on a track which passes through an electron spiral. Although the existence of the track is evident in histogram 3, there is considerable muddying and uncertainty of position. In Figure 4, the width of the scan has been reduced and the length increased so as to sharpen the histogram and isolate the track data. Figure 5 repeats the process to show the degree of sharpening possible. The second plot in Figure 5 indicates the additional sharpening effects when track curvature is applied to the scanning process.

The detection of a pulse in a data histogram is, in itself, a non-trivial pattern recognition problem. The current DOLLY software treats this as a "pulse detection" problem; i.e. it examines the histogram serially and looks for leading and trailing edges of the pulse. Subsidiary checks are also made for a sufficient number of hits and maximum allowed width. To detect the leading or trailing edges, the program forms two sums, each consisting of the total hits contained in three successive bins. The two sums are phased so as to lie two bins apart; therefore they overlap by one bin. The two sums are then compared; when one is more than twice the other an edge is declared. The center of the pulse is determined relative to the leading and trailing edges so located. This use of sums of three successive bins is equivalent to the generation of an ideogram which is often used to smooth rough data. Figure 6 shows two histograms with the accompanying ideogram or sums which would be generated by the sums of three adjacent bins at the various bin locations. The arrows in the figure indicate the leading and trailing edges. The upper "pulse" of the two shown would normally satisfy acceptance criteria; the lower "pulse" would fail because there were too few hits contained in it.

It should be mentioned that in normal track following, the DOLLY software first attempts to filter the data using the POLLY conditions involving the number of single and multiple hits. Only if these quite fast tests fail, does the program examine the histogram generated during data ingestion. The adaptive approach to data filtering provides the speed of the simpler POLLY strategy when feasible and backs off to the slower but more powerful histogramming technique when necessary.

Turning now to the DOLLY sequence interpreter, a common problem in the measuring of film from a variety of sources and experiments is the amount of reprogramming necessary for each experiment and under changing film formats. Fiducial geometries and arrangements vary, requiring different location and measurement programs. Track geometries and bubble densities differ, necessitating different filtering procedures. Furthermore, in any significant program development it is helpful to have simple procedures to speed up program debugging and tuning.

The most convenient way to handle such problems would be to have a special higher order language in which the various complex operations appropriate to data filtering, pattern recognition, and other elements of film data processing were implemented as commands in the language. Unfortunately, the generation of a translator or compiler for such a higher order language is a major task in itself; furthermore such an implementation might not be completely successful in view of our imprecise understanding of the necessary elements of such a language. However there is an alternate method which is normally ignored because of potential slow down in execution. This is the use of interpretive procedures in which the desired higher order commands are executed at run time itself. Such interpretive execution has been used in some versions of LISP and in the now obsolete IPL-V. One can be assured that the overhead involved in such interpretive execution is negligible, provided only that the functions of each instruction interpreted be sufficiently complex.

We have implemented such an interpretive procedure on the DOLLY system. The primitive elements of this system consist of:

1. Simple lists of subroutines to be executed sequentially and,
2. An interpretive routine, called a sequencer, which controls the actual sequential execution of the subroutines in the list.

The sequencer routine itself is a re-entrant procedure so that interpretation can occur concurrently at several levels. Thus the sequencer can be controlling the global steps in a film measuring process and at a different level also controlling the microsteps involved in setting up individual POLLY-type scans and filtering the data therefrom. The sequencer subroutines resemble ordinary function subroutines, with the exception that they must preserve the effective "program counter" which points to the current position in the sequencer execution list. Since each subroutine saves this pointer, it is also capable of modifying the same to provide for conditional execution or jumps. A common procedure, for example, is for a subroutine to treat the entry following it in the sequence list as a failure exit which is skipped under normal conditions. Such a skipping procedure would, for example, follow a filtering procedure requiring a success or failure exit.

A variety of special subroutines have been developed for use with this interpretive sequencer. There is, of course, a controlled jump procedure which includes the transfer address as a parameter. There is an analog of a subroutine call and subroutine exit so that a given sequence entry may itself call on another sequence list as a subroutine. Figure 7 illustrates

the sequence list for overall control of a bubble chamber measuring program. The various elements consist of complex subroutines whose execution may take many milliseconds. Figure 8 illustrates a "micro-sequence" used for the control of a measurement of a single segment of track. Both sequences may be under execution at a given time.

It is evident that the same effect could be achieved by a series of subroutine calls. However the sequencing lists are more compact, easier to modify, and tend to be self documenting by their format and labeling. It is also a trivial matter to overwrite these lists for special tests or for debugging procedures. We have found that this has been a most convenient technique for use in the development and modification of the various DOLLY measurement programs.

Fig. 1 Histogram and plot of three tracks measured at an oblique angle.

Fig. 2 Same three tracks as in Figure 1 with the scan aligned correctly.

Fig. 3 Plot and histogram of a track going through an electron spiral. The histogram aids in finding the track in the background clutter.

Fig. 4 The data of Figure 3 is improved by making the scan narrower (top) and then longer (bottom).

U	1	-
U	2	-
U	3	-
U	4	-
U	5	-
U	6	-
U	7	-
U	8	-
U	9	-
U	10	-
U	11	-
U	12	-
U	13	-
17	14	-XXXXXXXXXXXXXXXXXXXX
110	15	-XX
7	16	-XXXXXXX
U	17	-
U	18	-
U	19	-
U	20	-
U	21	-
U	22	-
U	23	-
U	24	-
U	25	-
U	26	-
U	27	-
U	28	-
U	29	-
U	30	-
TOTAL=	134	

Again the same area except above
the width has been reduced even further
and below the curvature of the segment
has been adjusted to the specific track.

Plot V

U	1	-
U	2	-
U	3	-
U	4	-
U	5	-
U	6	-
U	7	-
U	8	-
U	9	-
U	10	-
U	11	-
U	12	-
U	13	-
6	14	-XXXXXX
120	15	-XX
3	16	-XXX
U	17	-
U	18	-
U	19	-
U	20	-
U	21	-
U	22	-
U	23	-
U	24	-
U	25	-
U	26	-
U	27	-
U	28	-
U	29	-
U	30	-
TOTAL=	129	

Fig. 5 The data of Figure 3 may be improved even more by making the scan even narrower (top) and finally curving it to match the track's curvature. (bottom)

Fig. 6 Histogram with the ideogram which is used to detect the leading and trailing edge of the pulse superimposed.

FOLLOWING IS MAIN X BUBBLE CHAMBER MEASURING SEQUENCE			
XRESTART	DEC	XNEWFRAM	SET UP NEW EVENT FRAME
	DEC	XSETVW1	INITIALIZE FOR VIEW 1
	DEC	FRTCARRC,XBASEPT1	ESTABLISH OPERATOR POINTER
	DEC	CALLSEQ,XVWSEQ,XVWERR	*CALL* VIEW MEAS SEQUENCE
	DEC	XSETVW2	SET UP FOR VIEW 2
	DEC	FRTCARRC,XBASEPT2	ESTABLISH PCINTER IN FRAME 2
	DEC	CALLSEQ,XVWSEQ,XVWERR	MEASURE 2ND VIEW
	DEC	XSETVW3	SET UP FOR VIEW 3
	DEC	FRTCARRC,XBASEPT3	ESTABLISH POINTER FOR VW 3
	DEC	CALLSEQ,XVWSEQ,XVWERR	MEASURE 3RD VIEW
	DEC	XENDER	DO END CHECKS AND WRITE DATA TAPE
	DEC	NEWSEQ,XRESTART	JUMP BACK FOR NEXT EVENT

Fig. 7 Sequencer list for measuring an entire bubble chamber event.

FOLLOWING IS MAIN LOOP FOR NORMAL TRACK FOLLOWING			
TRKSEQ	DEC	RSETPRMK	RESET MEAS/FILTER PARMS IF NECESSARY
	DEC	SETSEG	SETUP SEGMENT DATA FORM
	DEC	CRCPRDCT,TRKERRN	PREDICT INTO SEG VIA CIRCLE
NO SCAN SEGMENT, USING NORMAL SCANNING AND PREPROCESS DATA FOR BOTH POLLY AND HISTOGRAM FILTERING			
	DEC	SCANSEQ,SCANNERN,DPROCHP	
	DEC	POLYFIT,POLYERR	FILTER A LA POLLY FIRST, THEN HISTFIT
	DEC	CIRCFITP	FIT MEASURED DATA TO CIRCLE
	DEC	SETTELM	WRITE STANDARD SEG DATA FORM
	DEC	STEPSEG	INCREMENT SEGMENT COUNTS AND FLAGS
	DEC	ADVTBAS	ADVANCE PREDICTION BASE
	DEC	NEWSEQ,TRKSEQ	RECYCLE FOR NEXT SEG MEASUREMENT

Fig. 8 Sequencer list for measuring a single track in a bubble chamber or streamer chamber event.

Discussion

A. Dzierba (Caltech) Have you essentially used the Argonne code in your subroutine list?

R. Brown First of all, I may have misled you. This is not a higher order language. These are not FORTRAN subroutines. We do not have a FORTRAN compiler on our machine. It is a home-built machine. Our code implements to a great extent the same strategy that the POLLY program does but they are not identical routines.

A. Dzierba (Caltech) In the DOLLY strategy, typically, how many bins do you use in track following? Also, what's the bin size?

R. Brown Bin sizes range over quite a number depending upon whether we're searching for frame fiducials - there we will have a very wide bin size. On 35 or 70 mm film, it may be as high as a 125 to 200 microns on the film. Under normal track following for bubbles of the order of 20 to 40 microns on the film with a scatter which may be upwards to 70 microns, we would try to bin so that a perfectly aligned track will fall in three bins. We'll straddle essentially three bins with that scatter. This implies about a 40 to 80 micron bin size. The number of bins we use incidentally is going to be equal to the scan segment width divided by the bin size. We rarely get beyond 32 bins.

J. Deery (Toronto) Have you considered the problems involved in using your histogramming technique in the measurement of events in the large chambers, for example, the 12-foot chamber at Argonne, where track curvature is not constant but can and does change rapidly?

R. Brown No, I think the answer we should give is we are capable of doing a local circle segment. If that assumption is violated, we have to back down until it is a good approximation just as without that curvature you back down on a linear approximation whenever you're in trouble.

P. Connolly (BNL) In one of your early examples of histogramming, you still had a straight slice scan which was not quite aligned with the track. In that case, you choose to realign and rescan rather than do rotating histograms in memory arithmetically?

R. Brown We were being a little honest at that point in showing that if you do not align, obviously, it won't find anything. In our particular strategy, we do have comb histogramming ala our illustrious predecessor at BNL; but they are exceedingly expensive in computer time and we have used them only when we're attempting to get started and do a search. Comb histogramming, for those who are not familiar with it,

is a term meaning you histogram at a sequence of angles trying to identify the angle at which you get the sharpest histogram information. It's very expensive in computer time. What we normally do is a binary choice; either there is adequate histogram information and the pulse that comes out is acceptable according to width, background, edges, and everything, or it is not. If it is not, we simply invoke an error procedure. We do not attempt to do any alignment, except in startup.

W. Slater (UCLA) In practice, how much length of the total slice scan do you gain by having the curved ability over what you would have if you only had a straight scan?

R. Brown Our current logic says that the length of a scan under normal, healthy, track quality will vary up to 6 millimeters on the film. We use a table lookup. At the time we're doing normal track following and scanning, we ask what is the curvature that we have learned to date. If the curvature is slight, we will go out as far as 6 millimeters. If the curvature is great, because of the problem of making accurate predictions with a high curvature we will come down to a minimum of 2 millimeters. We do use smaller lengths under certain conditions on fiducials but under normal track following 1-1/2 or 2 millimeters is the minimal length.

The Purdue POLLY -- Status Report

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ABSTRACT

The present status and distinctive design features of the Purdue POLLY are described. Software and hardware layout and status are presented separately.

INTRODUCTION

At Purdue we decided late in the spring of 1970 to build a POLLY-type measuring device. The SMP and digitized microscope system then and still in use is too expensive to operate, too inconvenient and expensive with respect to film-format changes, inappropriate for film from other visual devices than bubble chambers, and less accurate than some other devices. We chose a CRT device over HPD's on the basis of assumed greater flexibility.

Boundary conditions special to Purdue are the following: POLLY construction and testing may not adversely affect our present measuring rate of about 175,000 events per year. The ultimate configuration must leave the existing 360/44 computer available for reconstruction and physics analysis after the POLLY operates. Construction and development must be on a two-year shoestring budget.

Our first problem was choice of a control computer. Criteria for its selection were effective CPU speed, data channel speed, ease of interfacing into our 360 system, and cost. The computer selected was a Data General Corporation Supernova. It is a 16-bit, 4-register, 800 nsec cycle time device. We acquired it in August, 1970, with a high-speed data channel (1.25 MHz) and an initial 8K of core. Data General will replace this with 20K of 300 nsec semiconductor memory when we are ready for it; or, if this is not yet possible, will add 16K of 800 nsec core and 2K of 300 nsec ROM. The cost (including the upgrading) was \$33,000.

The configuring of the computer support for our POLLY can best be understood by starting from our present system, shown in Figure 1. Note that the 360/40 controls the SMP system; it is thus busy during the 70 scheduled hours of weekly measuring, and is available the remaining 98 hours of each week. The 360/44, on the other hand, is heavily loaded most of the time by batch processing, reconstruction, and filtering. Furthermore, when the SMP's go off the air, the 360/40 will be able to concentrate on supporting the POLLY. Note that connecting the Supernova to the 360/40 puts it (indirectly) on line to the 360/44. Figure 2, showing the whole configuration, makes this clear.

POLLY SYSTEM -- SOFTWARE VIEW

Initial programming concentrated on taking advantage of the close tie-in of the Supernova with the 360's, with the following support now provided:

1. Assembler (360 level G, but creating Supernova, rather than 360 code). Macro assembler, and Macro library. Output is in the form of 360-type "modules", on cards or on a module library (disk or tape).

2. Linkage editor (again modified 360 type) to link modules into absolute code, stored on disk.

3. Absolute loader and initial program loader, to bring desired program or phase into Supernova from disk, through the 360/40.

The above three items have been made everywhere as consistent as practicable with System 360 conventions, so that they look nearly like 360 facilities to the programmer with respect to diagnostics, editing capability, control card usage, etc. Programs 1 and 2 run in the 44, while the loader runs in the 40.

4. PL1 compiler, to run on the 44 and compile Supernova code. This program, scheduled to run this month, will remove the assembly-language-only restriction under which we have been operating.

5. A Supernova simulator was written a year ago to run on the 44. It has proven effective in program debugging, and has permitted us to write and debug code in advance of hardware device completion.

Figure 3 shows the I/O organization of the Supernova with respect to the actual POLLY devices. Programmed I/O controls the teletype, real-time clock, button-board, film-drive controller, and the optical display controller. It also starts the High Speed Data Channel (HSDC), and checks status of devices on the channel. On the Supernova under programmed I/O one has available three sixteen-bit read/write registers per device, start and clear levels, a pulse line, a maskable interrupt line, and testable busy and done levels.

Four devices are connected to the HSDC. These are the channel-to-channel connection to the 360/40, the circular shift-registers, the display controller, and the programmable POLLY digital controller. The last

Fig. 1 Present Purdue Measuring and Data Analysis System, showing point at which POLLY is connected.

Fig. 2 POLLY computer Control System, showing relationship to present 360 system.

Fig. 3 Supernova Programmed and HSDC I/O to POLLY Devices and 360 system.

of these, called the μ PUP, is the subject of a separate paper, and will not be described further here. Data rates on these four devices have been estimated, and will probably total in the neighborhood of 0.3 to 0.5 Mwords per one-event triad. Each of these devices reads its command words (command, flags, addresses, data lengths) through the channel, having been given the address of the first channel command word in a programmed I/O register. Small differences exist between devices, but where appropriate we have implemented: the commands READ, WRITE, NOP, and TRANSFER-IN-CHANNEL; the flags COMMAND-CHAINING, DATA-CHAINING, PROGRAM-CONTROL-INTERRUPT, and SUPPRESS-ILLEGAL-LENGTH-INDICATION; and the returned status indicators DEVICE-END, PROGRAM-CONTROL-INTERRUPT, ILLEGAL-LENGTH, COMMAND-MISMATCH (on the CTC only), and UNIT-EXCEPTION.

The CTC device is hardware symmetric: either side of the channel can be master or slave, and each is provided with a SENSE command to let the software determine an appropriate response to an interrupt. Channel speed is determined by the selector channel on the 360/40, and is 200 kW/s in the absence of channel interference.

The shift registers operate both as extended, relatively rapid-access storage, and as refresh memory for the display controller. Their functional relationship is indicated in Figure 4. The shift registers operate with a 4 MHz clock. If one considers them as a form of disk memory, then the average wait time to read or write is about 64 μ sec, unless the display controller is accessing a shift register, in which case the wait may be several milliseconds. The current status of this hardware is as follows: the display and display controller have been implemented, but data for display are temporarily being sent from Supernova memory rather than from the shift registers. The shift register system is designed, and is under construction. If it functions with very high reliability, the shift register auxiliary memory will be expanded and used for program overlays to the Supernova, a change that would free the 360/40 for a great deal more high-precision numerical computation back-up for the Supernova.

POLLY SYSTEM -- HARDWARE VIEW

The overall physical layout, plan view, is shown in Figure 5. The operator faces the display CRT, can see the optical display when it is called for on the large table at her left, and has immediate access to the ball and azimuth controls, a function keyboard and, farther to her right, an ordinary keyboard, and to the Supernova, which is immediately above the display CRT.

The precision CRT, lens, and platen are mounted horizontally, in line, about two feet off the ground, directly in front of the operator, with the CRT cathode towards the operator. The back electronics bay is lined up with the platen, and carries the film drives and associated hardware. Note that provision has been made for a second POLLY bay, although it is not being implemented at this time.

The optical projection is presented on a scanning table to the left of the operator. The ball and azimuth controls may be used to center a

Fig. 4 Auxilliary Shift Register Memory and CRT Display Controller

Fig. 5 Plan View of POLLY Main Frame

particular point on the image on a fixed (but turnable) cross on the scanning table. Image motion is obtained by driving small mirrors with stepping motors. The switch from slice-scan operation to optical projection is made by controlling shutters and inserting mirrors pneumatically on each side of the platen.

The first model film drive and platen system is for unsprocketed 46 mm single spool SLAC format film. The three views are presented on the platen, one above the other. Either the top pair or the bottom pair may be measured at one time; a pneumatic drive lifts or drops the platen to obtain the needed additional view. Conversion to some other formats (three or more strip 35 mm in particular) in the single bay POLLY has been planned.

The main POLLY (precision CRT, lens, and reference-light detector) is horizontally mounted, as has been noted. The CRT is a Ferranti 9B75Q4. The lens is a 1:1 Illinois DOLLY lens, designed and made by Optek. If a reference signal is used, it will be collected by a 45° mirror and fresnel lens system. This mirror is mounted on the precision lens, with a large elliptical hole to permit mounting. The fresnel lens is at right angles to the mirror, and focusses the light from any spot on the CRT onto a photomultiplier. Light-collection efficiency is uniform to about 20% over the usable face of the CRT.

Completion status is as follows:

Precision CRT: All components mounted, ready for test. DACs connected. Supernova-to-DAC temporary controls (for testing) under construction.

Lens: Ready to mount in place.

Platen and film drives: Ready to put in place. Supernova controls not finished.

Optical projection: Designed, partly assembled. Awaiting delivery of stepping motors. Supernova controls not finished.

Display CRT: Operating. Vector generator not tested.

Circular shift registers: Under construction.

Channel-to-channel connection: Operating.

μPUP digital controller: Designed. First and second phase construction begun.

The authors wish to acknowledge the essential help of Messrs W. J. Franklin, E. F. Durr, and E. C. Beard.

A Microprogrammed POLLY Controller

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ABSTRACT

A microprogrammed controller for a POLLY automatic measuring machine is described. It offers great flexibility in sweep generation and data collection.

INTRODUCTION

The Purdue POLLY will be controlled by a microprogrammed control unit operating from a small fast random access memory. The motion of the spot on the CRT and the collection of data will be controlled by primitive commands stored in memory. This method has two important advantages: (i) the logical functions are simpler than for a hard-wired controller and (ii) there is a great deal of flexibility in the operation. All of the POLLY operations, including scanning patterns, data collection, averaging, histogramming, etc., are programmed in software rather than hardware. The registers and flags used by POLLY are all available to the program for testing or modification. It has the well-known disadvantage that operations are slower because of the need to fetch and decode the instructions. The first advantage is also partly negated by more complicated data switching logic required by a more general controller. The flexibility advantage is the more important one, and it justifies the time required to develop a new control unit.

In designing the controller great attention was given to the standard operations which are required to run a POLLY. These operations were made as simple and fast as possible at the expense of less flexibility and of a less general command set. More esoteric functions are provided which use the hardware required for the basic functions, but usually at the expense of more programming complexity and longer execution times than would be required by a more general controller. The command structure has been left open (less than half of the possible number of commands are used at present); thus other functions can be added as they are needed.

The organization and operation of the controller will be presented in terms of the normal DOLLY digital slice scan and a simple data collection and buffering scheme. These are illustrative examples of the use of the controller rather than a complete description of its operation. Fig. 1 shows the motion of the CRT spot. There are two independent digital to analog converters (DAC's) which control the current to the deflection coil. The coordinates u, v are in units of the main DAC currents and ξ, η in units of the sweep DAC current. I is the number of clock pulses along the sweep line (actually $-I_0 + \text{number}$) and J is the sweep line number $-J_0$. The slice is started by putting (u_0, v_0) in (u, v) and in the main DAC, $(-\frac{\xi_0}{2}, -\frac{\eta_0}{2})$ in (ξ, η) and in the sweep DAC, $-J_0$ in J , and $-I_0$ in I . At every clock pulse the sum $(\xi, \eta) + (\Delta\xi, \Delta\eta)$ is stored in (ξ, η) and the sweep DAC, and I is incremented. When $I = 0$ the sweep line is finished and a new line must be started. This is done by forming:

$$\begin{aligned}(u, v) &= (u, v) + (\Delta u, \Delta v) \\ (\Delta u, \Delta v) &= (\Delta u, \Delta v) + (\Delta^2 u, \Delta^2 v) \\ (\xi, \eta) &= (-\frac{\xi_0}{2}, -\frac{\eta_0}{2}) \\ I &= -I_0 \\ J &= J + 1\end{aligned}$$

The next sweep line is generated as described above. When $J = 0$ the slice is complete.

In the controller the sums are formed with a fast adder (ALU) which contains two registers for the arguments, the B and the AC. At the clock pulse the sum of B and AC is formed and stored in AC. The sweep circuit is hard-wired in the sense that once the sweep is started the ALU is dedicated to (ξ, η) generation. At every clock pulse the sum is formed, stored in the AC and the sweep DAC, and the I counter is incremented. The ALU is released only when $I = 0$. Other operations can proceed in parallel with the sweep but these cannot use the ALU. Once the sweep is started it runs at constant speed until it is finished.

Computing the parameters for the next sweep line is completely under microprogram control. The $I = 0$ condition causes a microprogram instruction to be fetched, decoded and executed. A series of instructions will form the new (u, v) and $(\Delta u, \Delta v)$, increment J , reload $(-\xi_0/2, -\eta_0/2)$ and $I = -I_0$, and restart the sweep. If the $J = 0$ condition is detected the microprogram can halt and interrupt the computer or it can transfer to a routine to process the data collected during the slice.

Track detection circuitry is active during the sweep and can cause execution of microprogram routines in parallel with the sweep and, in addition, can perform certain hard-wired functions needed to measure the parameters of the track. Fig. 2 shows a track detected on scan line J . When the discriminator fires, the contents of I are transferred to I_c , shifted 1 bit left, and W is set to zero. While the discriminator is on, I , I_c and W are incremented at each clock pulse. When the discriminator goes off, W is compared to width criteria. If they are satisfied there

Fig. 1 POLLY Slice Scan

Fig. 2 Hit Detection

is a transfer to a routine which stores I_c , J , W in memory, increments a counter for the number of good hits, etc. I_c is automatically shifted right one bit so that its value is $I_{edge} + W/2$. The routine exits to the sweep word, which is a wait state since the sweep is already running. The quantities stored are the coordinates of the hit in (I,J) curvilinear coordinates and the width.

At the end of the sweep the hit parameters can be read into the computer from memory and further processing can be done. For example the center of gravity of the slice can be obtained by adding (I_c, J, W) to a cell which contains $(\Sigma I_c, \Sigma J, \Sigma W)$. This would normally be done only for a sweep which contains a single good hit. In a confused region it may be preferable to form histograms of the I coordinate. This can be done by masking, shifting and adding, using the ALU.

At the end of the slice other parameters such as the number of scan lines with single hits, multiple hits, sums, histograms, etc. can be read into the computer. Normally at this point the microprogram halts, which interrupts the computer and allows the parameters for the next slice to be read out. Problems of transforming from (I,J) to (x,y) coordinates, extrapolating to the next slice, etc. are performed in the control computer.

ORGANIZATION AND STRUCTURE

The structure of the controller is shown in Fig. 3. The random access memory (RAM) contains the microprogram and general data storage. There is a section of storage marked "Counters, Registers and Flags" (CRF) which contains all of the counters used by POLLY, the registers which are connected directly to other hardware, and flags which contain the status of the machine. Both the RAM and the CRF are accessed by an 8-bit address (MAD) bus. The CRF is assigned addresses (00-0F) in hexadecimal code and the RAM is assigned 10-FF. There are four registers which have access to MAD: SNAR is part of the interface to the control computer; MPAR is the microprogram instruction counter which is used to fetch instructions; DTAR1 and DTAR2 are contained in the instruction register and are used for data fetch and store. All data are moved as 48-bit words.

A second addressing method provides access to a sub-set of 16 counters using either CTAR1 or CTAR2, which are contained in the instruction register. This allows counters to be incremented, etc. without the ALU. Eight of the counters are 16-bit and eight are 8-bit.

The arithmetic and logic unit (ALU) has two registers, (the AC and B) and a fast parallel adder. The adder has a delay of about 70 nsec for 24-bit addition, which allows a maximum cycle rate of about 10 MHz.

The Supernova interface provides communication with the control computer in which a channel command structure is used. A programmed I/O command loads the CCWAR which is used to fetch the channel command word (CCW) from memory. The CCW (3 16-bit words) contains the command, SNAR, the address of the first word (CAR) and the word count (WC). The CCWAR is incremented by 3 so that it is ready to fetch the next CCW. When the

Fig. 3 Block Diagram of Controller

CCW is loaded, the command is decoded and the CAR and SNAR are used to transfer data between RAM or CRF and memory. At WC = 0 the transmission is terminated. At this point three things can happen: (i) ending status can be presented to the control computer, (ii) a new CCW can be fetched to continue the communication, (iii) the interface can go into a wait state until activated by the microprogram. The last mode allows the microprogram to control the data transfer.

Although the physical organization of the data is 48 bits, the logical organization is different and depends on the function being performed. Fig. 4 shows the different formats as follows:

- (i) The data are treated as two 24-bit words.
- (ii) A quasi-floating-point format. Word 0 and Word 1 are two 16-bit numbers; Shift 0 and Shift 1 are two 8-bit shift words.
- (iii) Three 16-bit words.
- (iv) Six 8-bit words.

The quasi-floating-point format is required to avoid round-off errors for a curved slice scan. For example in the $(u,v) + (\Delta u, \Delta v)$ algorithm, (u,v) in format (i) is loaded into the B register. $(\Delta u, \Delta v)$ in format (ii) is loaded into the AC, shifted and added to B. In the $(\Delta u, \Delta v) + (\Delta^2 u, \Delta^2 v)$ algorithm $(\Delta u, \Delta v)$ must be in format (i) and $(\Delta^2 u, \Delta^2 v)$ in format (ii). The addition is over 24 bits.

Format (iii) is used primarily for processing hit coordinates (I_c, J, W) . For example to get the center of gravity of the slice, (I_c, J, W) of the current hit is added to $(\Sigma I_c, \Sigma J, \Sigma W)$ for the slice. At the end of the slice, $(\Sigma I_c/n, \Sigma J/n)$ are the coordinates of the center and $\Sigma W/n$ is the average hit width. Both numbers are in format (iii). (I_c, J) and $(\Sigma I_c, \Sigma J)$ are loaded into B and AC. To simplify the adder, an auxiliary 16-bit adder forms the sum of W and ΣW . The sum is stored in $(\Sigma I_c, \Sigma J, \Sigma W)$.

Format (iv) is used for address registers and for machine parameters such as the dynamic focus, astigmatism, etc. There is no 8-bit arithmetic, as such; however with the masking and shifting capabilities of the ALU, it is possible to program it.

INSTRUCTION FORMAT

The sweep is started by setting MPAR = 0, and once it starts it is latched on until I = 0. During the sweep, tracks may be detected and must be processed and stored. A sweep control word stored in location zero controls these operations. The first entry in Fig. 5 is the format of this word.

There are four flags associated with a hit: (i) HIT is the track discriminator output and is on for the entire track pulse, (ii) STIT is on for one clock pulse after HIT rises, (iii) GIT is set if HIT satisfies width criteria, (iv) FIT is set on the first good hit of a sweep line. Associated with each of the flags GIT, FIT and STIT are the first three exit fields. If the corresponding exit field is non-zero when the flag comes on, MPAR is loaded from this field and becomes the starting address of a subroutine for handling that condition. If the exit field is

Fig. 4 Data Formats

zero, this is a no-op. Subsequent exits are blocked until MPAR is returned to zero by the subroutine. Also associated with these flags are halt flags. When both flags are set the HALT latch is set, which interrupts the control computer. This is primarily for debugging.

Several conditions associated with CRT safety can set the ABORT latch. If the ABORT exit is non-zero, it is taken; else the HALT latch is set. In either case the sweep latch is cleared. The I = 0 exit clears the sweep latch also.

The second entry in Fig. 5 is the format of instructions which use the ALU. If the sweep latch is set, this instruction sets HALT. If $M = 0$ the ALU is used as an adder; if $M = 1$ it is a logical function generator. The OP CODE field determines the function generated as given in the table. The field AD1 and AD2 are the addresses of the arguments. DTMD determines the data format to be used and STMD determines where the result will be stored. It may be stored in AD1 or AD2 and the main D/C.

The instruction also has two counter control fields which are executed in parallel with the ALU operation. The counters selected by fields C1 and C2 can be cleared, incremented or decremented according to the code in C1C and C2C.

Normally MPAR advances by one for each instruction executed. There are sixteen flags in the machine which can be tested; a successful test causes MPAR to be advanced by two. The flags to be tested are coded in fields SKP1 and SKP2. Field SKMD imposes additional logical criteria as follows: $SK1 + SK2$, $SK1 \cdot SK2$, $SK1 \cdot \overline{SK2}$, $\overline{SK1} \cdot SK2$. Most of the flags are associated with conditions in the hardware; however four are reserved to test the counters specified in C1 and C2 for zero or for negative.

The third entry is used for loading and storing specified counters. The counters are specified in fields C1 and C2 and the corresponding memory address by AD1 and AD2. The fields C1C and C2C determine the operations, which are: load, load immediate and store. The "load immediate" allows the counter to be loaded from the corresponding field of the instruction register. Note that if C1 or C2 selects MPAR, this is a transfer. This instruction can be executed in parallel with the sweep.

The fourth entry is used for moving data. Data at location AD2 are moved to location AD1. The BYS field allows masking of the data. $BYS = 0 - 5$ selects 8 bits to be moved, $BYS = 8, 9, A$ selects 16 bits, $BYS = 6, 7$ selects 24 bits. $BYS = B$ is a special code to allow quasi-floating-point results to be saved. The output of the adder is two 24-bit numbers which are usually needed in this format. $(\Delta u, \Delta v)$, is also needed in quasi-floating-point format. When this instruction is executed two 16-bit words starting at bits 0 and 24 of AD2 are moved to bits 0 and 16 of AD1; the contents of the 16-bit word at bit 32 of AD1 are not altered. $BYS = F$ moves 48 bits. Any other BYS code is a no-op.

Except for a few special cases there are no provisions for switching bits within a 48-word. In the move and counter load and store instructions, the desired data must have the same alignment in each word. An

ALU CODE	M = 0	M = 1
0	$B + 1$	$\bar{B}$
1	$(AC \circ B) + 1$	$\overline{AC \circ B}$
2	$(AC \circ \bar{B}) + 1$	$\bar{B} \circ AC$
3	ZERO	ZERO
4	$B + \overline{AC} \circ B + 1$	$\overline{AC \circ B}$
5	$(AC \circ B) + \overline{AC} \circ B + 1$	$\overline{AC}$
6	$B - AC$	$AC \oplus B$
7	$AC \circ \bar{B}$	$\overline{AC} \circ B$
8	$B + (AC \circ B)$	$AC \circ \bar{B}$
9	$B + AC$	$AC \oplus B$
A	$(B + AC) + \overline{AC} \circ B$	AC
B	$AC \circ B - 1$	$AC \circ B$
C	$B + B$	1
D	$(AC \circ B) + B$	$\overline{AC} \circ B$
E	$(\overline{AC} \circ B) + B$	$AC \circ B$
F	$B - 1$	B

$\circ$ = OR $\cdot$ = AND $\oplus$ = EXCLUSIVE OR
 $\bar{A}$ = 1's COMPLEMENT $-A$ = 2's COMPLEMENT

Fig. 5 Instruction Format and ALU Operation Codes

early modification will be to implement instructions which can rotate data and save them in a shift register.

An index counter is available for automatically storing arrays. It is addressed as a 16-bit counter (X), although it consists of two 8-bit counters - an address and a count. When an address (AD1 or AD2) references X, the address used is the contents of the address portion of X. After the reference, the address portion is incremented and the count is decremented. When the count reaches zero a flag is set which can be tested by a SK1 or SK2.

The long instruction length was dictated by three considerations: (i) the difficulty of fetching a smaller number of bits from a 48-bit word, (ii) the possibility of parallel operations, and (iii) simpler design in that most fields can have a unique meaning independent of instruction type.

STATUS

The construction is proceeding in at least two stages. The first, which is designed and under construction, will have the computer interface, adder, and sweep control. This will allow meaningful tests of both hardware and software. It will even be possible to measure, but very slowly. The second stage will be to complete the system as described here. It should be possible to program nearly everything that one would like to do, but some things may be very inefficient. Experience would then indicate the improvements to be added.

The system, excluding DAC's, TED's, etc. will be built on about 160 printed circuit cards. The RAM has 64 bits per chip and is packaged on 24 cards of 8 chips each (only 12 cards will be implemented at first). The counters and registers are all on standardized cards of 8 bits each. The control cards are all custom made. All cards are designed and fabricated at Purdue.

The author of the following paper, Robert O. Haxby, collapsed and died while attending this conference. There are no words adequate to describe the personal loss that we feel.

Bob came to Iowa State University in Ames, Iowa in 1965 to direct the design and construction of an FFAG betatron which was to be sited there. He had previously worked on the MURA betatron, and had also been completely responsible for the construction of the 300 MeV synchrotron at Purdue University. He was 59 years of age, and had undergone heart surgery a little over a year ago. His family consists of his wife, Mona and a son, David.

The dedication and sincerity which he gave to physics and his conscientious teaching, we shall all remember. But more importantly, we shall remember Bob as a kind and considerate person, ever helpful and generous of his time, and a valued friend.

(This note was contributed by William Higby, of Iowa State University) .

General Description of the Ames Laboratory POLLY

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ABSTRACT

A general description of the POLLY system (called "HOLLY" for various obscure reasons) is given, including reasons for some of our choices. The present status of the hardware is that one bay is operating well enough to test the software. Plans for the future are also discussed.

DESCRIPTION

In general, our apparatus is modelled after the "DOLLY" built at Urbana, Illinois. We decided to use four bays each with its own precision CRT, lens, film drive, photomultiplier, etc. The spot is moved on the CRT face exclusively by a digital to analog converter, including the fast sweeps. (There is one DAC for each bay.) All corrections for distortions, pincushion, etc., are done by software from the main computer which, in our case is an EMR 6050 (formerly ASI 6050). The principle reasons for our choice were that it was certainly necessary to have provision for 4-view film, each film on a separate reel. Although a mechanical scheme for interchanging platens was certainly a possibility, we felt that we could not spare the time (and we were not sure we had the ability) for a good mechanical design that would accurately register each of the platens and without damage to the film. Also, although it will be, at least for the foreseeable future, impossible to measure simultaneously on more than one bay, it is possible to go back and forth between bays, keeping the film registered on each bay, and hopefully, if the computer can handle it, use this feature to help match up tracks in different views, even with track shapes like those for the 12 foot chamber. In any case, it is possible to project to move film in other bays while measurements are being made in any desired bay.

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A general block diagram of the equipment is shown in Fig. 1.

The cables in the figure have EMR drivers and/or receivers at both ends. The rest of the "interface" consists of EMR logic boards to recognize the various HOLLY addresses and to connect data line between the computer and HOLLY. The level shifters are necessary because the 6050 used negative logic (True = -4, False = 0 volts) while the "digital electronics used positive logic (+5 volts and 0). (I have to be careful here not to encroach on Bill Thomas, who will describe the digital electronics.)

The mechanical arrangement of each bay is shown in Fig. 2. (I have taken liberties in this drawing: The pellicle is actually rotated 90° about the optic axis of the system so that the reference photomultiplier is behind, and the projected image comes out forward. This image is again reflected to be imaged on the screen.) Four shutters are used on each bay, one for each photomultiplier, one in front of the projected light source, and the fourth to shut off light reflected into the system at the pellicle when the bay is not projecting. Microswitches on the photomultipliers are used to interlock them so that the projector shutters cannot open unless the photomultiplier shutters are closed. The shutters are driven by air cylinders energized by 110 AC solenoids. These, in turn, are energized by 24 volt dc relays driven by relay drivers from logic signals. With the air on and no ac available for solenoids, all shutters are closed. If the ac for the solenoids is on, the "default" condition is to have the photomultiplier shutters open and the projection shutters closed.

Only a minimum of power interlocking is used. (Actually, I think it is less than the minimum necessary for reliable operation with inexperienced personnel). A row of 10 circuit breakers control power to various parts of the machine. Any of these may be on without any of the others. A pair of push buttons is used to turn on and off a 3-phase solenoid which energizes these circuit breakers. A time delay, started by the 6.3 volt CRT filament circuit, holds off the CRT (and photomultiplier) high voltages for about three minutes. The same circuit prevents the control grid from being positive with respect to the cathode. After the high voltage on the first anode is on, a self-bias circuit protects the cathode from excessive current. Also, focus power cannot be turned on until the power to the digital to analog converter is on. When the "off" button is pushed, the high voltages are turned off immediately but a time delay keeps everything else going for another 2 or 3 minutes. An "emergency off" button is also available (in case of smoke or something), but it cannot be reset except from behind a panel which will be locked. Power for the interface is part of the power turned on and off by the push buttons, and it has been found that strange signals go down the cables to the 6050 computer when this power is turned on or off, so that it is necessary to halt the computer at these times.

A logical interlock is provided so that if, for some reason, the computer calls for film movement on a bay which is in the process of measuring, the measurement will be completed before the film is released. Another logical interlock does not allow the operator to move the film manually unless that bay is projecting. We plan to

Fig. 1 General Arrangement of HOLLY

Fig. 2 Precision CRT and Arrangement of Optics for One Bay

have four controls, one for each bay, for manual movement of the film.

The circuits used are mostly copies of either POLLY II or DOLLY circuits. The discriminator is from POLLY II; the film drive and reticle drive are from old versions from DOLLY, etc.

PRESENT STATUS

At present only one bay is operating. Essentially all parts for the other three bays are on hand and most of the mechanical work has been done. We have been spending some time measuring a precision grid and have found some peculiar difference between the x and y calibrations. The statistical errors in y (North-South direction) seem to be considerably larger than those in x and take several hours to settle down to reasonable values. At the same time there is a drift in y which also seems to settle down after a few hours. Whether these are connected or not we have not yet determined. In order to keep at least one bay operating while trying to locate the source (or sources) or this difference, a second bay is being assembled. Since the principle part of our effort lately has been with the software, I will leave that up to Bill Higby.

PLANS FOR THE FUTURE

So far we are using a pellicle to sample the light through the lens in to the reference photomultiplier and also to reflect the projector light out. For the first purpose, this seems to be reasonably satisfactory, although it does lose some light and also is very expensive, but the material which we have is not a very satisfactory mirror. It requires a low humidity (less than about 50%) in order to keep taut. We are planning to install a moving mirror for the projected image and have not yet decided what to do for the reflected light to the reference photomultiplier. We are also starting the design of a new discriminator. We plan to use some kind of operational amplifier to take the ratio of the signal/reference and use this for the discrimination. At the same time, we plan to design the circuit so that it can be used both for dark tracks on light film and light tracks on dark film.

We also plan to connect more microswitches to the photomultiplier shutters to signal that they are open and we also plan to interlock the room lights so that they can only be turned on when the photomultiplier shutters are closed. Also, the combination of 24 volt relay drivers and 110 volt ac solenoids produced a considerable amount of electrical noise in the system, particularly in the reticle registers. So far, this has been "fixed" by software, that is, by reading the reticle registers into the computer before operating the shutters and reading these values back to the registers after the shutters are moved.

Of course our most important improvement is to get all four bays working, and I am sure that this will give rise to many other problems.

The Ames Laboratory Interactive Hardware
Programmed POLLY

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ABSTRACT

This paper presents operational concepts concerning the amount of computer control required to select, gather, and display data in a POLLY System. An attempt is made to minimize computer interaction by incorporating outboard parallel processing function controllers. These function controllers are hardwired program subroutines to which the main software program can pass the desired parameters.

Necessary system status information is presented to the operator through a lighted panel as well as a video display. A built-in computer simulator is used to facilitate checkout and maintenance.

Logic design of the digital controllers and video display will be discussed.

The High Energy Physics Group of the Ames Laboratory, Iowa State University, is currently measuring bubble chamber film using three independent manually controlled film measuring machines. These machines are interfaced to an ASI 6050 computer. The computer system includes 16K core memory, a 5 megabit drum, 9 track magnetic tape unit, card reader, and a model 33 teletype at the console. One prerequisite in changing to a POLLY type measuring system was to use the above hardware and hold additions to a minimum. The expansion of the computer system is in secondary memory, a 10 megabit drum to replace the 5 megabit drum. Using the drum as secondary storage for incoming data and as a program file, a core overlay technique will be employed to expand the capabilities of this computer system. Channel assignment of peripherals and HOLLY control hardware is shown in Fig. 1.

With the system configuration finalized, a hard look at system performance revealed the fact that the computer is extremely compute bound. The scanning method employed by the POLLY system requires the computer to direct a scanning spot across a track while at the same time collect information resulting from that scan. Controlling spot programs and data stuffing robs the computer of required computing time and it is obvious that the scanning hardware would be sitting idle while computational needs are carried out. To relieve the computer of input/output requirements, as many scanning and gathering operations as possible were transferred to controllers external to the computer.

The method of scanning is shown in Fig. 2 and is called a slice-scan. By supplying a set of parameters to an outboard scan-controller the computer is freed from the task of actual spot deflection and a complete slice-scan can take place independent of computer control. The parameters required to perform a slice-scan are as follows:

function	number of bits
major axis x starting point	24
major axis y starting point	24
major axis x stepping increment	23 + sign
major axis y stepping increment	23 + sign
number of base line steps (slice-scan length)	8
major axis x pincushion correction increment	16 + sign
major axis y pincushion correction increment	16 + sign
minor axis x stepping increment	12 + sign
minor axis y stepping increment	12 + sign
number of sweep steps (slice-scan width)	9

These ten parameters specify the slice-scan raster and they are presented to the scan-controller in ten computer words in sign magnitude form.

The desired result of a slice-scan operation is the center of gravity of the bubble track within the scanned area. To supply this information using outboard hardware is a considerable duplication of computer capabilities; however, a summation of bubble crossing information is realistic. Much like the scan-controller solution, a data-summing-box is placed outboard from the computer and as the slice-scan proceeds the data-summing-box collects the track crossing data and condenses the hundreds of data words into five computer input

Fig. 1 HOLLY Film Measuring System

Fig. 2 Slice-Scan Raster

parameters. These five data parameters, as shown in Fig. 3, are then used by the computer to determine the center-of-gravity of the previous slice-scan.

parameters
summation of valid track sweep numbers
number of valid track crossings
number of invalid track crossings
summation of valid track ordinate values
summation of valid track bubble widths

If the controlling programs so desire, the data-summing-box can be bypassed and a more detailed look at slice-scan data can be obtained.

Various additional functions are implemented by the data-summing-box such that controlling programs can specify acceptable bubble track widths, focus the spot, set discriminator levels, and set a noise filter parameter to compensate for poor film quality.

Now for each slice-scan the computer transmits 14 words over the channel and receives five words back at the end of the slice-scan. This channel communication proceeds on an asynchronous bases and reduces control requirements by two orders of magnitude for the average slice-scan.

A lighted display panel indicates the status of these outboard controllers. This display and a data channel simulator were invaluable aids in initial checkout and will be used to good advantage for trouble shooting in the future should hardware malfunctions develop. Both controllers are clock driven at 2 megahertz; however, a manually operated push-button clock is wired in for test purposes.

System overhead is further reduced in CRT communication. Outboard character and vector generators lower channel requirements to a minimum. Characters are presented to the outboard character generator in ASCII format packed three characters per computer word. These characters are unpacked and displayed by the outboard generator. A single computer word is all that is all that is required to draw a variable length vector, or to position to any point on the screen. The display data field in core is a variable length record with character and vector blocks intermixed. When the controlling program wishes to implement the CRT display a control signal is sent to the unit. If ready the display unit will answer with a refresh interrupt and the controlling program will assign the active display field to the I/O channel. When this field is exhausted the I/O channel will disconnect automatically. At refresh time the display will interrupt again. The controlling program has the freedom to change or update the display data within the field whenever it so desires.

The display of the cursor spot on the CRT screen appears as crossed straight line vectors and is implemented using the vector generator hardware.

This POLLY system is a four view system with control features which allow projection and film movement in all four views simultaneously; however, film measurement can only take place in one view at a time. A three speed cursor control and a 48 function lighted switch panel provide operator-computer communication.

Fig. 3 Slice-Scan Data Parameters

The Ames Laboratory HOLLY Programming System

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ABSTRACT

This paper presents some of the program development that we have done in connection with our automatic "POLLY-like" measuring system. Some features of our program overlay supervisor for a small computer are discussed. The operator CRT display system includes a control interface designed and built at Iowa State University and a computer controlled display file refresh logic. The bulk of software event measuring logic consists of the POLLY FORTRAN programming done by the staff at Argonne National Laboratory.

INTRODUCTION

The major programming tasks that we faced during our development of HOLLY were generated by "making do" with our present computer hardware. Financial conditions also required that we could not buy the entire CRT system "off the shelf".

In this report we will cover some of the major problems that we have encountered so far and the solutions which we have implemented or propose to implement. After the system is completely in operation we expect to prepare a more complete description of the supervisor logic.

The first part of this paper is a general description of some of the features of our system. The second part is a more detailed discussion of system concepts. No track following or measuring logic will be presented. We are not far enough along in the production development to add anything substantial to the state of the art on these points.

General Description of ISU System

Computer Configuration

The computer we are using is an EMR 6050 with a memory of 16K 24 BIT words. Figure 1 represents the channel layout of our external devices. The dashed lines indicate the channel communication to HOLLY. Both channels are completely buffered with each other and the CPU.

Program Overlays

Unfortunately, the standard EMR program overlay structure was not adequate for the type of system environment that we desired. Our main objectives in the design of a new overlay system were the following:

1. The conversion of a large programming system, such as the ANL POLLY programs ⁽¹⁾, to our overlay structure should be as simple as possible.
2. The system should have multiple job capabilities
3. System overhead must be kept to a minimum

Multi-Job Processing

We have been quite pleased with the operation of our current computer controlled on-line measuring system ⁽²⁾. So naturally, one of the design requirements of the system was to include the option of on-line measuring jobs running concurrently with HOLLY. With this requirement in mind, we have designed a general multi-job processing supervisor. There are many job configurations available with such a system. One option could be to structure the programming of HOLLY so that it looked like more than one job. This would allow the time sharing of the fiducial measurement in one view with the track following in another view.

Operator Display CRT

Cost factors made it a necessity that we both design and build the display CRT interface, rather than buying such a system off the shelf ⁽³⁾. As a consequence, we were able to structure the hardware design to meet the programming requirements as economically and efficiently as possible.

The display interface is designed as another external device that has access to a standard buffered word channel. There are three commands that the display will recognize.

1. Position beam to a point
2. Display character string
3. Display vector string

Since the interface logic has no automatic refresh capabilities, it is necessary to "slave" the CPU for a particular file display. Refresh logic is controlled by a 33 millisecond clock interrupt. For most displays, this is quite adequate to produce no visible flicker with a P7 phosphor.

OVERALL VIEW OF THE SUPERVISOR

The supervisor is composed of the following sections:

1. Segment CALL and RETURN
2. Memory allocation processor
3. Execution control and job selector
4. KUBER, the controller for conventional on-line measuring machines
5. Drum I/O stack handler and processor
6. HOLLY I/O processor
7. Display CRT command processor
8. Display file refresh processor
9. Teletype, tape, and card reader I/O processors

System control information exists in many data areas used by the supervisor only. We will list a few of the main data control blocks. The Segment Table of Contents contains information describing the status of all program segments at any time in the system. The status of a segment includes:

- a) Which job (if any) is using the segment
- b) Where in memory the segment is loaded
- c) Logical checksum, name, length, drum address of segment, etc.

Each job in the system has a current execution status. This status could be

- a) Job has called a segment and memory has been allocated for the segment load
- b) A segment load is complete

- c) A segment load is in progress
- d) No memory is currently available for the segment load
- e) A segment is being executed
- f) A segment has executed a RETURN

The EXECUTION SCHEDULER is the main controller of the system. It checks for any I/O requests pending in the respective stacks, and will start the selected request if conditions will permit this. By using the execution status of each job, memory conflicts (which will be discussed later) are resolved.

Structure of Program Overlays

Segment Definition

The 16K memory is considered as consisting of 96 word "pages". A program "segment" is a sequence of instructions and the associated local data areas. A segment could consist of only one SUBROUTINE or it might be some main SUBROUTINE and the associated called SUBROUTINES. Figure 2 is an example of a typical segment call structure. Segments can be viewed as operating similar to SUBROUTINES. They are called via a simple call statement. They execute and then return to the calling segment.

Multi-job Operation

When only one job is considered, it is easy to assign the appropriate memory pages for each segment. The addition of other jobs to the system introduces a serious problem when a small memory computer is used. Memory pages must be shared by all jobs in the system. Figure 3 is an example of memory allocation when the system is servicing two jobs.

Supervisor Segment Call Processing

The details of executing a segment call by the supervisor are quite complicated for a multi-job system. Certain conditions must be satisfied before a requested segment can be loaded from drum and executed. First of all, memory must be available. That is, the segment cannot be loaded if another job is currently using the same space for the execution of a segment. Once memory has been allocated, a drum I/O request cannot be executed if some other device on the same channel is busy. We are using a concept which we call "non-sequential processing" to take care of these conflicting situations. When a job encounters such a conflict, no specific action is taken by the supervisor at this point to correct the conflict. At some later time the supervisor can resolve the conflict and schedule the job for execution.

Multiple Copy Segments

In general, the problem of loading a particular program section in any system consists of the task of memory address relocation. With our computer there exists no hardware for automatic base register address modification. The possible choices that we had for segment loading were the following:

- a) Design and write the necessary compiler and assembler that would produce code which made use of some index register for relocatable instructions.
- b) At segment call and load time, one could relocate the necessary instructions before the segment was executed.
- c) Assign a segment to a particular memory page starting address prior to the loading of the system. Use the standard EMR loader to load the segment, and copy the memory used by this load to drum. When a segment call is processed, check the current memory status table. If the appropriate memory block is free, schedule the segment for loading.

Choice a) might be OK, but we do not have a large enough programming staff at this time to consider such a project. Our two-man staff has been tied up for some time on just the supervisor programming. We ruled out b) because of too much system overhead time for the relocation. Choice c) was actually used, with a slight modification for "multiple copies".

A multiple copy segment is one which is assigned to more than one particular memory page for the load and execution. It becomes a task of the memory allocation processor to "pick" which copy to load depending upon the current status of memory at the time the segment is called. Using this technique, it would be ideal to assign a particular segment as having multiple copies beginning at page 1, 2, 3, 4, etc. Unfortunately, our drum unit is not quite that big. During the supervisor testing period we ran a variety of job structures. One particular structure consisted of five jobs that used the same memory area for the segment loads. The introduction of just one segment consisting of two copies instead of one greatly increased the frequency of job execution.

Segment Preparation

When the HOLLY supervisor is loaded into memory, all job segments must exist on the mass storage drum unit. The method of preparing these segments is a topic for another paper itself. In a nutshell, what basically happens is this: The programmer must decide at what page in memory each segment is to start. This is rather a burden, but it is necessary. Arthur Klein has written a very clever program called "SUBVERSION". It subverts the standard EMR monitor, job processor, loader, etc. The action of this routine is to load a segment into memory

starting at the desired memory page, copy this section of memory to drum, and go onto the next segment. After all segments have been processed in this fashion, a table of contents is also written on drum.

Programming View of Display CRT

We were quite concerned about the demand on the CPU for CRT refresh and the visible flicker rate. When a display file consists of many characters, there is some flicker. This has not been a problem so far, since most HOLLY displays do not have a large amount of text to be displayed.

The refresh data file does take up much memory space for certain displays. The worst one is the display inMPOINT of the digitized area for the operator. This problem has been solved by building into the refresh logic the use of multiple areas for the particular data file to be displayed.

Use of Multiple Area Files

The CRT supervisor allocates a fixed amount of area for the display file. We are presently using about 200 words. If a given program segment needs more area, it can call a supervisor routine which will then use, in addition to its own area, the area specified by the segment.

CRT Subroutines

We have essentially duplicated the types of subroutines that the ANL POLLY II software is using. In some cases we have added features of our own. In addition to the routines that build up a display file, we have added a feature called "Immediate display". For example, the "display vector immediately" routine will not add a vector data word to the display file, but instead it will execute the command to display the given vector on the tube.

This feature is quite useful when the HOLLY software is in the digitizing display mode. A refresh file is built that consists of a highly magnified view of a region of the film. While the refresh logic is displaying this file every 33 m sec, the joy ball position is displayed by calls to the "plot vector immediate" subroutine.

Current Programming Status

HOLLY FORTRAN Programming

We have not yet completely measured an entire event in one view, but we do have some bits and pieces running. The following major routines are now running with our system:

1. Fiducial measuring with FIDS
2. Track finding with FINDTKS

3. Track following with PHOLLOW

When the new supervisor is completed, we will be ready to add TVERT (the vertex calculation and track association routine) to the system.

Slice Scan Usage

From a programming point of view, the ability to specify the slice scan mode by one parameter has been a definite advantage. Fiducial and track finding are both done in the "data dump" mode, while the measuring of fiducials and tracks are done in the "center of gravity" mode. In order to keep the conversion problems of the ANL software to a minimum, we have not at present made use of the variety of slice scan possibilities available to us. Figure 4 illustrates some of the different slice scans that we can implement by simply changing a few of the specification parameters via the software.

Supervisor Status

All coding and debug is essentially complete, but no test runs have been made with the HOLLY software using the new supervisor. We hope to get the final system running by the end of January. The job structure will consist of one job assigned to HOLLY and three jobs controlling the current on-line measuring system. With this environment, we will be able to make the necessary changes in the ANL software for 35mm film without disrupting the present on-line production.

A Look at the System in Retrospect

We consider our approach to the HOLLY hardware design quite adequate for the current and future programming demands. It would, of course, be very convenient to have a larger and faster computer. Discussions relating to this question include the concept of adding another small computer to the system. Such a hybrid system might give one more power than a single large computer. Obviously this question requires a considerable amount of study.

The programming effort required for the multi-job supervisor was approximately one man year. We were fortunate to have an indirect addressing and indexing hardware feature on our computer. With clever use of this feature we were able to keep the amount of supervisor code less than 3K words.

Acknowledgements

We would like to thank the ANL High Energy Physics staff for their help during our program conversion stages. We also thank our hardware staff, in particular, W. D. Thomas, John Homer, Robert Haxby, and Charles Fullhart for their patience and understanding during our program debug.

References

1. W. W. M. Allison, F. Beck, and J. G. Loken, "POLLY II, A Complete System Incorporating Facilities for Measuring Bubble Chamber Film Without Prescanning," ANL/HEP 6916 (July, 1969)
2. W. J. Higby and A. H. Klein, "Ames Laboratory On-Line Control System for Bubble Chamber Film Measuring," IS-2228 (December, 1969)
3. William D. Thomas, "The Ames Laboratory Hardware Programmed POLLY," ANL - Proceedings of the Informal Collquium on POLLY and POLLY-like Devices (January, 1972)

Fig. 1 Hardware Configuration

Fig. 2 Single job Memory Allocation

Fig. 3 Multiple job Memory Allocation

STANDARD SLICE SCAN NOW USED

A POSSIBLE TYPE

ONE THAT MAY BE USEFUL IN TRACK FOLLOWING

Fig. 4 Slice Scan types

MOLLY - A Progress Report

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ABSTRACT

We have built and tested the basic components of a POLLY type automatic scanning and measuring machine, to wit: CRT yoke mounts and controls, optical frame, and Digital to Analog Converter. The DAC is free of oscillation, settles in 12 μ sec, and is linear over times of the order of weeks. The CRT spot, focussed on a film platen shows a full width at half maximum intensity of 14 μ at center screen and 20 μ at the edge.

I. General Description

We are building at UCLA a simplified POLLY type machine. This report summarizes the first six months of our work. Our machine, called MOLLY, will be controlled by an IBM 360/44 computer, the configuration of which is shown in Fig. 1. The computer currently is dedicated to the operation of five scanning and measuring projectors (SMP). In principle it is possible to operate both MOLLY and the SMP's simultaneously, but in practice we do not expect this to be desirable. The I/O paths for MOLLY are two half duplex lines of which one will serve an operator's console, mainly sending data to it and the other will mainly read track hit data to the computer from the video channel of MOLLY. A small fraction of the capacity of this path will be required to initiate a slice scan. Both paths operate asynchronously and simultaneously into the 2701 data adapter; they are then multiplexed into a 360 multiplexer data channel. The MOLLY data rates are limited by the MPX data channel, to 1 word/30 μ sec on either path.

We have adopted a philosophy embodying simplicity, stability, and high resolution. Accordingly, our machine will scan a single view and the path from CRT to film will be free of mirrors and beam splitters. An overall diagram of MOLLY is shown in Fig. 2; a photograph of the main-frame as it now exists is shown in Fig. 3. The planes of the CRT faceplate and a film platen are adjustable for parallelism to each other and for perpendicularity to the main lens' optic axis. The lens mount has x, y, and z motion so that the lens can be focussed and its optic axis can be made to intersect the undeflected CRT spot. The framework consists of nonmagnetic stainless steel tubes compressed by tension rods

and is virtually immune to vibration.

An optical display will be provided off axis, as indicated in Fig. 2, by means of a wide angle projection lens (Schneider componon 210 mm) which gives good quality up to 50° off axis. We will use an angular range from $\approx 15^\circ$ to $\approx 35^\circ$. To provide a reference PM signal, we will collect light which would miss the main lens. We expect to use a light pipe for this although we have not tested our design yet.

II. Critical Components

- 1) Cathode ray tube: Ferranti microspot 9B75 with A phosphor.
- 2) Lens: Custom built by Optek Incorporated. The aperture is $f/4$ at ∞ ; $f/6$ in our system. Object size = 7.5" diameter circle. Limiting resolution ≈ 300 lp/mm, resolution at 75% mtf is 48 lp/mm; demagnification is 2:1. The optical path include the CRT face plate and the film platen.
- 3) Yokes
 - a) Deflector. Celco type HAD428-P530. $L = .5$ millihenry. Residual magnetism = 50 ppm.
 - b) Magnetic lens. Celco type NCJ334-379/530-401-530 having static and dynamic focus and astigmatism.
 - c) Alignment. Ferranti FC 10A.
 - d) Back focus. Ferranti FC7A.
- 4) Accelerating potential. Computer power systems model 1300PBF. $V = 25 \text{ kv} \pm .3v$.
- 5) Digital to analog converters. We use a modification of the University of Illinois, DOLLY circuit design and have made our own physical layouts. Both X- and Y- DAC's will occupy about 1 ft² of space including a precision resistor box. We have built our X- DAC and it is visible in Fig. 4. We will generate slice scan lines with ramp generators, one of which has been built and used as described below.
- 6) Beam control. For all yokes other than the deflector we are using single current sources. The circuit cards occupy about a 6" cube (see Fig. 4) and all manual controls are located on a single 5" x 19" panel.

III. Performance of Components

- 1) DAC. We have cycled our DAC between the bit patterns 1000..... and 0111.....continuously for periods up to 20 hours. To our ability to measure, about 1/4 Least Significant Bit, there was no change in the ratio of currents delivered to the two yoke windings in this length of time. Settling time to 1/2 l.s.b.

for the one l.s.b. transition above is about $20\mu\text{s}$ with our present choice of switching transistors.

The DAC was aligned by first doubling the current of the l.s.b. (bit 16). Bits 9-16 are fixed, so that bit 8 controls the smallest adjustable current. Bit 8 is balanced against the sum of bits 9 through 16, then bit 7 against bits 8 through 16 and so on until bit 0 is balanced against bits 1 through 16. In fig. 5A we show the voltage across 2 ohms in series with the two halves of our yoke, as seen with a differential amplifier. For comparison, fig. 5B shows the same voltage when bit 16 is switching its normal current, $13\mu\text{a}$. This alignment did not change over about three weeks preceding this colloquium during which there were approximately 100 power on-off cycles.

Settling time is seen in fig. 6. Here again the DAC is cycling the patterns 10000--- vs. 01111----. We estimate the current change between $t = 15\ \mu\text{sec}$ and $t = 20\ \mu\text{sec}$ using

$$V = L \, di/dt$$

where $V < 10^{-3}\text{v}$ (see fig. 6), $L = 5 \times 10^{-4}\text{h}$, $dt = 5 \times 10^{-6}\text{sec}$ giving $di < 10^{-5}\text{ampere}$. We have found that resistors of $560\ \Omega$ in parallel with each yoke half adequately damp any oscillations without the addition of any capacitance.

- 2) Spot size. To measure spot size we have built a two slit analyzer consisting basically of a 20x microscope objective lens, a reticule having .001" slits separated by .09" and a photomultiplier tube. We sweep the beam, using a ramp generator and beam gate, at a rate of 2.5 m/s at film platen. By measuring at the film platen we test several components: CRT, beam control, and main lens. Moreover, we measure resolution under conditions closely approximating final operating conditions. Our FWHM at platen center is 14μ and at platen edge, 20μ when focus and astigmatism currents are optimized. Fig. 7 shows photomultiplier signals of a sweep across one of these slits. The signals at the platen edge show more noise for two reasons: 1) loss of light due to vignetting in the microscope and 2) pickup of stray 60 HZ magnetic fields since this picture was recorded when the CRT was unshielded.

Another check of resolution was made by scanning two crossed .001" diameter wires. The traces are shown in figs. 8 A-F for three positions and two speeds of the sweep. The wires are evidently resolvable at a separation of $10\text{-}13\mu$ with either speed. Finally we tested our ability to see narrow tracks by sweeping across tracks in pictures taken of the ANL 30" bubble chamber with demagnification about 30:1. The bubble images are about 12μ in diameter and are clearly detectable in the oscilloscope traces of fig. 9.

Conclusion: The spatial resolution of MOLLY appears to be good enough over the whole platen to measure most track chamber films in current use. Initial tests of stability have revealed no drift problems and our yoke driver circuits, both deflection and focus-astigmatism are free of oscillations. Our DAC settling time of $20\mu\text{sec}$ to $1/2$ l.s.b. for the transistion 10000---- to 01111---- while useable for test runs is expected to be cut significantly by replacing the DAC switching transistors.

Fig. 1 MOLLY Computer Configuration

Fig. 2 MOLLY Plan

Fig. 3 MOLLY Mainframe in Checkout

Fig. 4 MOLLY Electronics Showing DAC and Beam Control

Fig. 5a Bit 0 balanced against bits 1-16 with bit 16 doubled

Fig. 5b Same as (a) but bit 16 Normal

Fig. 6 dI/dT in Deflection-Yoke for transition 10000000000000000 to 0111111111111111

Fig. 7 Slit Analyzer traces at (a) center screen, (b) edge of screen. Writing speed was 2.5 meter/sec on platen.

Fig. 8 Sweeps across crossed .001" diameter wires. Writing speed = 2.5 m/sec for (a, c, e) and 5.0 m/sec for (b, d, f). Wire separation edge to edge was 25μ (a, b), 13μ (c, d) and 10μ (e, f).

Fig. 9. Sweeps across 12μ wide tracks for 35mm pictures of ANL 30" chamber.
 (a) Two parallel beam tracks, (b) Saturated track

Discussion

H. Walz (SLAC) How are you going to install your reference multipliers without putting anything in data path and optical path?

W. Slater We're planning to use a light pipe which will mount right next to the main lens. We plan to collect light from outside the main lens.

STATUS OF NAL SAMM

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SAMM is an abbreviation for Semi-Automatic Measuring Machine. In this paper we will discuss 1) the basic design of the NAL machine, 2) progress on the construction of the NAL SAMM to date, and 3) some of the reasons behind our choice of the particular designs utilized in this machine.

1. Design Parameters of NAL SAMM

SAMM is a three view system. The three measuring stations are independent to the extent that there are three CRT measuring stations. Each CRT is driven by its own set of magnetic deflection and focusing yokes. These yokes in turn are driven by independent DAC (digital to analogue converter) networks. There is however, only one digital control system which is switched, under on-line computer control, from the DAC input register of view "i" to view "j". Therefore, measuring under computer control may proceed in only one view at any given instant in time.

The tube that we have chosen for the operation of SAMM is the Ferranti Ltd. 9 inch tube, with the 9B/75 electron gun and Ferranti P16 equivalent phosphor. For early testing, we have also acquired a Ferranti tube with a 9B/71 electron gun. The 9B/71 is inherently capable of a smaller spot, without "back focus" coils, but at a considerable loss of light. We now feel, based upon reports that we have received from other institutions with experience with Ferranti tubes, especially Oxford and the University of Illinois, that the 9B/75 gun, coupled with a "back

focus" system can be made to perform with a sufficiently small spot size and at an innately higher intensity to warrant its use over the 9B/71. We will study the performance of both tubes in the forthcoming months and will report our experiences at an appropriate later date.

The deflection and focus system for the NAL SAMM is based upon CELCO (Constantine Engineering Laboratory Company) coils. The coils we have chosen to mount, in order from the bulb end of the neck, are: Deflection Coil, Irrotational Focus Coil, Diquadrupole Coil, Centering Coil, "Back" Focus Coil (not irrotational) and Aperture Flooding Coil. To date, we have not had any operational experience with the behavior of 9 inch tubes at NAL, so we cannot comment on whether this selection of coils and the planned mounting arrangement are optimum. Since the Ferranti tube is similar in geometry to the 5 inch DuMont tube, with which some of the NAL staff have had considerable experience, we do not anticipate unusual difficulties. Questions such as the usefulness of a dynamic astigmatic corrector coil, such as that recommended by Oxford, can only be answered by research. We believe that the present selection of coils should be capable of achieving a spot size of 14 microns at the tube center, with some growth, perhaps 50%, to the tube edge. This growth may be amenable to further reduction with the introduction of astigmatic correction, as mentioned above.

The relay lens we have chosen is the OPTEK design 1093, originally designed for Argonne, and now fairly widely used. This lens is a 2:1 demagnifier with a 6 inch field on the CRT. We are designing our system for a 75 mm circular aperture at the film plane, so the lens is quite adequate. Also note that spot sizes in the range of 14 to 20 microns on the CRT tube face are reduced to between 7 and 10 microns. It is hoped that the NAL 15 foot bubble chamber will not produce bubble images on the film substantially less than 10 microns in diameter, so the lens should match the CRT to the film we intend to use. (The image of the 15 foot chamber is a 75 mm diameter circle.) The phototube we have selected for signal gathering is the RCA 4501.

The basic frame and optics layout of the NAL SAMM is very similar to that of the Illinois DOLLY, which however is a 1:1 system, and to the Iowa POLLY, which is a 2:1 system as is SAMM. We acknowledge the design help we have received from both of these groups. "Unwrapped", the optics layout may be seen in the schematic presented in Fig. 1. This schematic is of course similar to that of any POLLY-like machine with operator intervention. The pellicle between the relay lens and the film has been built into our first view. We are aware of information from the University of Illinois with respect to excessive loss of light with the use of an essentially identical pellicle; a factor of three being mentioned to us. Engineers from Illinois have suggested the use instead

NOTE: SHUTTERS 1 AND 2, AND
SHUTTERS 3 AND 4, ARE
DESIGNED TO OPERATE
IN TANDEM; AND WHEN
ONE PAIR IS OPEN THE
OTHER PAIR IS SHUT

Fig. 1 Schematic of One SAMM Measuring Station

of a pivoting mirror, removed during the measuring sweeps. Reference signals may then be obtained by surrounding the OPTEK lens with fiber optics and collecting off-axis light. We could change our system to such a design if we were to find it necessary, but we wish to obtain some experience with our tube and yokes first, especially since Oxford reports a factor of eight increase in light with the introduction of the "back focus" system.

The image of the film projected to the operator is magnified by 13:1. This should be adequate for general intervention by the operator. For the 15 foot chamber, it is possible that a TV type display at a higher magnification may be made available to the operator as well. The operator may also mark points on the display screen utilizing a reticle mark driven by a track ball. This reticle system has been copied in its entirety from POLLY III.

The computer driven display obtained for SAMM is manufactured by Digital Equipment Corporation, the builder of the PDP-10 computer available for the on-line operation of SAMM. The display is essentially a peripheral processor sharing core with the PDP-10. A "display file" is composed by a program resident in the PDP-10. Then the PDP-10 issues one command to start the display processor at the first location in the display file. The display then runs independently leaving the central processor available for other work. The display has hardware vector and character generation, and plots points in these modes at the rate of 600 ns/point.

The SAMM digital controller is essentially a special purpose computer designed and under construction "in house" at NAL. It communicates with the PDP-10 both via the I/O bus and the data channel. The slower I/O bus is used essentially to initiate requests by the controller for the data channel for the purpose of the transfer of data to and from registers in the controller.

The principal parameters transferred to SAMM as input are the following:

(M)	the number of sweeps (minor scans)
(A, B)	the initial center of the first of M sweeps
(dA, dB)	first order changes to (A, B) to be made after each of M sweeps
(d^2A , d^2B)	first order changes to (dA, dB) to be made after each of M sweeps, (second order to (A, B))
(K)	pincushion correction constants.

The above parameters determine the locations of successive centers of sweeps. The sweep pattern itself is specified by: (da, db, N) where N steps are made of size (da, db) from $(A-(N/2)da, B-(N/2)db)$ to $(A+(N/2)da, B+(N/2)db)$. This information is actually transmitted as $((N/2)da, (N/2)db)$. Each step is taken every 100 nanoseconds.

Note that there is no one sweep speed: rather the sweep speed is a variable dependent upon the size of (da, db) . The registers for (A, B) are 16 bits long and are called the major DAC registers. The sweep pattern is generated in a 12 bit register called the minor DAC register. Sweep lengths are also variable, the length being dependent on the number of steps of the minor scan, N .

Finally, to complete the generation of a swept light pattern, we may energize the diquadrupole yoke to distort the spot into a line up to 2 mm long on the CRT face. This is of course similar to the operation of a PEPR system. The necessary information is then θ , $d\theta$, and L the line length. This is transformed into currents proportional to $L\sin 2\theta$ and $L\cos 2\theta$, and θ is incremented by $d\theta$ every sweep.

Thus the NAL SAMM has some rather versatile sweep pattern possibilities. For example, if one sets $(d^2A, d^2B) = 0$ and $L = 0$, then one generates a standard POLLY "slice scan" with a spot with the successive centers of the slice scan on a straight line with a slope given by $\tan \phi = dA/dB$. Another limiting possibility is to set $(dA, dB) = 0$ and $(d^2A, d^2B) = 0$, $L = 2$ mm, and $d\theta = \text{one degree}$. This would generate a typical PEPR scan. However, we are not limited to either of these two extremes. For example, using a spot, one can generate a curved slice scan by setting (d^2A, d^2B) non zero. Note that (da, db) are not changed between minor scans (sweeps) and therefore the sweep is always run in the same direction. Another pattern now possible is a further extension of the idea of a curved slice scan. One can actually make the successive centers of the slice scan about 1 mm apart on the film and use a line. To show the utility of this approach, consider that one was scanning for beam tracks and had done a search across the chamber window and had recorded candidate hits for beam tracks. One now wishes to ascertain, over a fairly long distance, if this hit might correspond to a beam track. We assume that we are dealing with a very well defined beam in this exercise, whose parameters are well known. One then simply calculates the turning angle for the length of beam track one wishes to examine and divides that angle by the number of slices to obtain $d\theta$. One sets up dA , dB , d^2A , d^2B , and $d\theta$ according to this scheme and then one should be able, with only one call to the hardware, to perform an extensive scan for a beam track. Similar scans under road guidance are possible.

The detection system envisioned for the NAL SAMM is based upon clocking the beginning and end times of the crossing of a threshold by the PMX signal. This system obviously will require some feedback on background levels and also computer adjustment of threshold levels. We have made provision for four sets of threshold crossings (4 tracks) in one minor scan. Therefore the possibility of handling multiple hits is present. We actually will use two clocks, both summing in a register, until the first threshold crossing turns off one clock, and that value is saved in the first of two registers. Then, only the second clock continues to sum in a second register until the threshold is crossed in the opposite direction. Then the second clock is stopped, yielding in the second register the center count of the pulse, with the difference of the pair of registers yielding the half width of the pulse. This system does not at this time include any peak detecting circuitry.

The NAL SAMM will be driven by a devoted on-line computer given to URA by DEC. This computer is a PDP-10 with 64K of core, a 5 million word disk, line printer, card reader, DECtapes, 7 and 9 track standard drives, and other features. At present this computer is one of two PDP-10's on the NAL site. Both are being extensively used by other groups than those associated with SAMM. It has been scheduled that as the construction of SAMM proceeds, the other usage of the devoted PDP-10 will be phased off that machine.

2. Progress to Date

Actual physical construction of SAMM began about January 1, 1971 with the acquisition of the temporary building now housing our Film Analysis Facility (FAF). We determined to build up the mechanical design of the first of the three views immediately, with the other two measuring stations to follow. At present, we have in fact finished the mechanical work for the first of the three measuring stations, the frame work, and the electronic racks to hold the printed circuits for the controller. We have projected bubble chamber film through our projection optics onto the operators screen. The PDP-10 display has been delivered. Film drives have been mechanically fabricated for all three views, and mechanical construction on the second and third views is proceeding. The basic design of the electronics for the controller and yoke drivers has been completed. Boards for IC packs have been laid out and "stuffed" in sufficient quantity to run the fundamentals of the controller and DAC circuits. Inter-connector wire wrapping has proceeded based upon computer generated wiring lists. Still to be designed are visual registers for the presentation of input and output quantities for SAMM to engineers and programmers. We estimate that we may be able to energize the CRT and yokes for the first measuring station this

Spring. Then, large scale research programs of tube performance may commence. Software techniques have been extensively studied using a software simulator to be reported by the next speaker.

3. Questions of Philosophy

The NAL SAMM is a three CRT machine because we felt that certain advantages of multi-measuring stage capacity were worth the extra cost and effort. Fast electronic switching is possible between views, rather than moving the film. The automatic scanner may access the film in one view while the operator studies another view of the same event. All these ideas seemed to point to three CRT's rather than one with an indexing mirror. The nature of our controller seemed indicated by the increased capabilities made available to the design engineer by IC packs, at little extra cost. Building an "in house" machine seemed indicated because of the general need for familiarity with a system such as a POLLY by the engineering staff to adapt to changing conditions on the film presented to the measuring machine. Study of the programs of other institutions is natural, and the simulator described in the next paper gave our programming staff an introduction to many problems in a realistic, but reproducible fashion.

We believe that the capability of handling multiple hits on a single sweep is necessary to eliminate some additional confusion. The fact that in the new large chambers it is not possible to specify a single bubble size for the entire chamber has led us to rely on the two clock detection system, rather than some fixed delay acceptance schemes, especially as the TED's in PEPR rely upon. Once one abandons a fixed track width, then sweep speed variations are meaningful and useful. Also, since we anticipate that many events at the higher energies to be investigated at NAL in the 30 inch and 15 foot bubble chambers will have several prongs in a single 'forward jet', track width information may actually be useful in scanning for events in a bare chamber configuration.

THE NAL SIMULATOR

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ABSTRACT

The exercise of adapting the Argonne POLLY programs to run with a simulator has proved extremely useful as a learning tool. Also, we believe we now have software that will at least follow clear tracks when our hardware comes up. This software is of sufficiently advanced form that going from simple track following to measuring at least an event should proceed quite rapidly.

INTRODUCTION

As part of the NAL program to develop a Semi-Automatic Measuring Machine we have written a film and hardware simulator. This simulator has allowed us to proceed with software analysis in conjunction with hardware construction. To gain an appreciation of the difficulties involved and the state of the art we chose to begin with the POLLY software (version PONG83). During the process of forcing the first event through a measurement a much deeper understanding of PONG83 was achieved. We then proceeded to develop our own software through the expedient of modifications to PONG83.

SIMULATOR

Before delving into the details of the simulator we should re-emphasize those aspects of our hardware, previously discussed, that directly effect the structure of the simulator. 1) We allow a maximum of four (4) hits per minor scan. 2) Our sweep is generated by a fast

adder in the hardware adding δa and δb to the present A and B values for the spot coordinates. Since δa , δb and the number of such additions are loaded from the computer the sweep speed and length are under software control. 3) The values ΔA and ΔB , defining the distance between minor scan centers, are also under computer control. 4) We will have a diquadrupole on the tube neck to produce a line element if desired.

The simulator has two distinct functions; it must set up equations defining tracks and events on film, and it must simulate the slice scan desired and return the information on hits and misses.

At the present stage the routines which set up tracks contain virtually no physics. The beam track curvature was chosen to look like our 15 GeV/c $\bar{p}$ exposure in the Brookhaven 80-inch Chamber. Charge conservation is demanded. All parameters are chosen by a random number generator with the exception of the number of beam tracks, the bubble density, and the interaction probability.

The first step in setting up a frame is to choose the entry coordinates of the beam tracks. With this information and the coordinates of the center of curvature (the radius of curvature has a uniform distribution $\pm 5\%$ about a central value) we define the coefficients in the track equation;

$$\Theta = \sum_{i=1}^n (\alpha_i A^i + \beta_i B^i) . \quad (1)$$

The track is characterized by Θ , α_i , β_i , and the beginning and end coordinates. At present only α_2 and β_2 are non-zero, i. e. circles. To find the end coordinates of a beam track we must first determine whether an event did or did not occur. This decision is made by comparing a random number to the event probability. If we have no event we simply compute where the track left the frame. If an event occurred we decide where by assuming that events are uniformly distributed over the center 80% of the frame.

For an event we randomly chose 2, 4 or 6 prongs and proceed to determine the constants in Eq. 1 describing each track. The random radii of the outgoing prongs are chosen so as to insure that each track leaves the frame before turning 180° . Charge conservation is obtained by using the same radius of curvature for paired tracks with the B coordinates of the center of curvature symmetrically placed about the event. End coordinates of all secondaries are determined by where they leave the frame.

The values of Θ , α_i , β_i , beginning and end coordinates are stored for use by the hardware section of the simulator. A few examples of events generated in the above fashion are shown in Figs. 1-3. From these figures and the above discussion we are obviously dealing with a highly idealized situation. We have no stopping track, no fiducials, and no extraneous background (such as delta rays, scratches, coat hangers, etc.). Also it should be noted we have only one view.

Track detection along a minor scan is done in the hardware simulator by calculating

$$\Theta'_S = \sum_{i=1}^n (\alpha_i A_S^i + \beta_i B_S^i) \quad (2)$$

where A_S and B_S give the present spot coordinates. If we then define

$$\begin{aligned} A_{S+1} &= A_S + \delta a \\ B_{S+1} &= B_S + \delta b \end{aligned} \quad (3)$$

we can determine the fact that we have crossed the track at A_S and B_S when $\Theta - \Theta'_{S+1}$ is of a different sign from $\Theta - \Theta'_S$. Once we have found a hit we compare a random number to the preselected bubble density to determine whether it is to be sent to the hardware simulator. This procedure obviously does not clump hits as in real film.

For the case of circles the above scheme is slower than actually computing the intersection of the minor scan and the circle. Several additional tests have been incorporated into the simulator to speed up track detection. These tests are designed to determine whether or not the track falls within the bounds of the slice scan before proceeding to the addition stage. We have stayed with the above scheme even in face of its inherent lack of speed for several reasons; it more nearly mimics our hardware, pin cushion effects are easily included, and non-circular tracks are easily included. We feel that allowing non-circular tracks will be very important for studying the large chamber film.

MODIFICATIONS TO PONG83

Since our hardware is designed to operate on 24-bit words our first change was to perform all calculations in a 24-bit system. This change naturally produced a large number of overflows which are of little interest here but took considerable time and effort to overcome.

During this exercise we found a large number of chamber dependent constants buried in the programs. Without a simulator with its reproducible results we feel that finding all such constants would have been a monumental task. It should be pointed out that all of our work with the simulator has been in the automatic scanning mode.

As the film we expect to measure will have track widths on the order of 10μ our slice scans have smaller dimensions than those in PONG83, namely 50 or 100μ wide and 100 to 200μ long. This smaller size implies more slice scan and coupled with the leisurely nature of the simulator led us into having gaps several slice scans long between slice scans. With the addition of algorithms to sneak up on a vertex this procedure has worked well on our idealized situations. The real world will quite likely force us to retreat to more densely packed slice scans.

The few major changes the simulator has demanded are caused by the small sagittas on the beam tracks and the forward nature of the secondaries. We found that for close or crossing beam tracks we had to make use of the predication method described under Subroutine CIRCLE in Argonne's PONG50 writeup¹, as opposed to an approximate method used in PONG83. Otherwise it was not uncommon to switch beam tracks in midstream. Again it is doubtful that anything like the present methods will work when dealing with the distortions present with large chambers.

We also found that the success of the measuring phase was very sensitive to the approximate vertex published by the automatic scan. With our tracks and the simple straight line method used in PONG83 the approximate vertex found can be many millimeters and in the extreme centimeters off. The objection that the vertex variation is due to the large gaps between slice scans is one reason for the vertex sneaking algorithm. Since wide variation was not uncommon (effecting between 10% and 20% of our events), we used a circle intersection method coupled with a cluster analysis to find an approximate vertex. We did not go all the way and use the circles for the beam tracks as they are quite linear in our model. Since the outgoing tracks also tend to be quite linear at times, some care needs to be exercised in the cluster analysis to pick the correct intersection of the two possible intersections. This particular problem becomes quite severe on very forward two prongs.

¹POLLY II: A Complete System Incorporating Facilities for Measuring Bubble Chamber Film without Prescanning. Vol. I; W. W. M. Allison, F. Beck, and J. G. Loken, ANL/HEP 6916.

CONCLUSION

Our present software effort is directed towards incorporating a Digital Equipment VB 10C display into the system for use with the simulator. Other than part time effort to write a film simulator that contains some $\bar{p}p$ physics we are working hard on the hardware. The goal is to be able to try our software on real film at the earliest possible moment so that we can tackle the problems the real world presents.

The success rate of our software with the model film is on the order of 90% with about 220 events attempted. However it should again be mentioned we have no physics in the model so the 90% tells us very little. The nice feature of the simulator is that failed events may easily be studied in great detail. Looking at our 10% failures we find that they fail almost exclusively because of their very forward nature. Since we have yet to make use of the availability of information on more than one hit we cannot say how useful such information will be in untangling these events. We have as yet made no use of the line element possibility either, although we have identified areas where it might be useful. These are during searching for either beam track or outgoing prongs, as the angle information is available from one set of sweeps. The line sweep also seems promising for rapidly following beam tracks while hunting for events.

The major benefit of the simulator is that we have some software we believe will at least follow clear tracks. Also we have learned a great deal, which should allow the software development with real film go much faster. The simulator has allowed us to define the nature of the hardware specifically in discussions with our engineers, and to prepare programs whose response to a given situation is understood and debugged. This procedure should minimize disagreements between people having hardware and software maintenance responsibilities.

Fig. 1

Fig. 2

Fig. 3

Discussion

J. Phillips (Toronto) Why bother going through the trouble of generating fake events, when you could give a real event to Don Hodges and have him digitize it on ALICE and give you just a bank of data?

B. Chrisman That possibility was discussed. This gives us somewhat of a cleaner thing - we can change the events then to look more like what we want them to. Also, the major problem is, the events that are available here are not high enough energy - they're not forward enough for what we expect and we did at least want to tune on something like what we would expect. We haven't beaten over the head the events that fail in the simulator because we do realize we're not dealing with physics - this is highly ideal.

P. Connolly (BNL) I have a question that really should have been asked right after Bogert's talk. It would seem that at the NAL 15' chamber non-distorting lenses might have two useful properties. It's certainly going to be easier for human scanners to look at, at least in the beam point and they might even be easier for track following routines. Does anybody care to comment on the relative difficulty of CRT techniques with six micron and ten micron bubbles?

D. Bogert (NAL) I can expand on this somewhat. Not myself, but Russ Huson and Bill Fowler from NAL, who have been working on the 15' chamber held a number of meetings on the subject of the lenses. There was apparently, from the CRT world in general, sufficient feeling that any bubble size on the film smaller than 10 microns was not really something that they wish to handle. Now I will say that my personal feelings are along that line, but my feelings were not responsible for the choice of the lenses at NAL. In fact, I'm not sure that the choice of lenses (the final lenses that were chosen) reflected at all the considerations of whether CRT people liked these lenses or not. I think that financial considerations had a great deal to do with the choice. That's a personal feeling. With regard to the spot size, I don't particularly want to attempt a bubble size smaller than 10 microns with a CRT device. Now we have heard various comments from Argonne concerning their spot sizes and we've also heard some comments from UCLA. As far as I can tell, obtaining a 14 or 15 micron spot size at the center of a 9-inch tube is a real art and a two to one demagnification without any loss is essentially impossible. So you don't really get a seven micron spot size when you demagnify two to one, you get something ideally maybe 10. But, anyway, the big point is that even with astigmatic correction, you grow toward the edge, so your real spot size starts out 20 to 25 microns on the tube. The problem is that you'd say bring in the lens 3 to 1 or 4 to 1; but very soon you are in the stage where you have

to step all over the place on the film because your visual aperture is just too small. The problem is that you must ask someone then to design a lens that is actually a 9-inch lens. If you want it with a high F number, the costs are very large. This is probably enough on the subject, but at any rate, those are my feelings on it.

After-Dinner Speech

Richard Royston
Argonne National Laboratory

I feel a little bit like a lion in an ancient Roman circus. In the days of the Roman Empire they used to feed Christians to lions. At one of these circuses the Christian who was being fed to the lion went and said something to the lion and the lion didn't eat him; the lion looked rather worried, put its tail between its legs and walked off. The patron of the festivities ordered another lion into the arena, one who had not eaten so many Christians and would obviously be hungrier and better able to dispatch this rather tiresome man. As the lion approached the man he said something to it and that lion, even though he was hungry, looked rather worried and turned away. At that point Caesar sent for the man who was supposed to be eaten and said, "Whatever was it you said to the lion?" The man replied, "Well, I told him that if you get a free dinner, you are supposed to give a speech afterwards." So, I didn't pay for my dinner tonight and that's why I'm giving this speech.

I have a second and slightly ulterior motive in giving this talk. In April there is a meeting on "The Machine Perception of Patterns and Pictures" which has been organized by people who could be described as pattern recognizers. I was asked to give a talk on Image Processing in Nuclear Physics. It seemed to me that I would need to do a fair amount of research into how this developed since it had started before I became involved in it, and it appears that it will continue long after I have departed. It's obvious that that amount of work shouldn't be wasted on just one presentation. One of the things I hope is that tomorrow anybody who is able to fill in any of the glaring blanks in my narrative will do so, which would improve my next talk on this subject.

So I went to my bookshelves. Owing to the fact that I've only recently moved back to Argonne, there is nothing actually on my bookshelves, it's all in an attic of an apartment building in Wimbledon. So, I went to various other places. I went to the High Energy Physics Library and I went to visit various friends. The first recorded reference to a POLLY-like device, if not to a POLLY, I found in 1958 in the report of a conference on instrumentation at CERN where Bruce McCormick reported on a development he was working on at Berkeley called "The Spiral Scanner." That was 14 years ago.

The Spiral Scanner and Bruce McCormick have gone separate routes since 1958, both in their own different ways. The next entry in the record was the following year in 1959 when a fellow at The University of Michigan by the name of Paul Hough wrote a paper on the

enormous difficulties of trying to analyze bubble chamber photographs automatically because of the very large quantity of information contained in them. He said that one might possibly get round some of the difficulties that this presented by dividing the picture into framelets. It took him about a year, during which time he was at CERN, to come up with his first scheme for a flexible scanning device, the flying spot digitizer (FSD). The big breakthrough which was made was the realization that in fact most of a photograph consists of empty space and the amount of information in it is not a billion bits but much closer to a million bits. This is clearly a quantity of data that it's possible to think of processing in a finite amount of time, even on the computers existing 12 years ago.

The other, I think, big breakthrough that was made at that time, at least conceptually, was the idea that you could have some interaction between the machine and the people who were interested in it. That came from Lou Kowarski at CERN who was very actively interested in these devices. This idea is now known as "roads"; a few points on the photograph are indicated before the measuring process is started and they are used to guide the measurements and to throw out the grossly irrelevant data. At that point there was still quite a long way to go before physics came out of the FSD, and in fact I think the first man who actually got physics out of a POLLY-like device was Martin Deutsch of MIT. He performed the first physics experiment I know with his device which he called SPASS. SPASS was actually a Tektronix scope connected to a PDP-1 with a lens, a film platen and a photomultiplier. It was a very simple device, very inexpensive and very successful. In fact, within a year of his first appearance in public in 1961, he was producing physics.

It was in 1962 that Deutsch made a remark that I consider a rather memorable one. It was, like all profound remarks, both brilliantly illuminating and stiflingly boring. He said, "If you are trying to process pictures, it's a hell of a lot easier if you can see what you're doing." Now think back to the early '60's and what people were doing with the automatic devices that they were building at that time. They reckoned that filtering was something that would be simply accomplished by the computer. You would simply debug your program and you'd be away. Deutsch was one of the few people who didn't believe that looking at what you were doing was some kind of cheating. He actually believed that it would help and if it helped, it was clearly a good thing to do.

It was about that time in 1962 that PEPR got under way. A whole lot of devices were starting then, PEPR was starting and the SMP had been under way for a little while but it wasn't yet producing. The Spiral Scanner turned into a Spiral Reader and it was coming along rather well. It was also a memorable year because work was starting here at Argonne! CHLOE was being built by a gentleman who is sitting very

close to me at the moment (D. Hodges). To start with, the CHLOE device was not very closely coupled with physicists and so it didn't produce physics, although it did produce some other things in other areas quite as quickly as it had the potential for doing. It was in 1964 that the first of what I think of as the classical devices, the flying spot digitizers, started to produce results that, if you were thoroughly optimistic, you could call physics. It was probably true at that time, however, that people who were working to produce immediate results were still doing their physics using manual measuring machines. It was in that year that Don Hodges wrote the first document proposing a POLLY type system, so we at Argonne have probably just passed our 7th birthday on some scale.

By 1965 people were producing real physics, so you didn't have to be too optimistic then. Automatic devices were now recognized as a good way of measuring film. The Spiral Reader was producing a lot of physics and the Hough-Powell devices were producing some physics. The first bits of POLLY were being designed and few of them were being put together.

It was in 1966 that I arranged a wedding between the Applied Mathematics Division and the High Energy Physics Division here at Argonne. In fact, the collaboration started before POLLY was complete. I don't know how many people realize that a small number of bubble chamber pictures were actually measured on the original CHLOE device, which it was initially believed had obviously insufficient resolution even to see the tracks, let alone to measure them adequately. The developments proceeded from there through the three versions of POLLY that most of you have probably seen. POLLY I was an entirely electronic device. The display and the measurement were both done with a Cathode Ray Tube. The display was nonetheless of the complete picture just as we have in the present systems. The first physics was produced from POLLY I which ran, believe it or not, on a PDP-7. The entire filtering and control process was accomplished on that machine. I think sometimes people feel that they need a SIGMA 7 or even a CDC 6600 to do any useful work on filtering at all. I don't think that we should forget that in fact if you discipline yourself or get disciplined, perhaps is a better way of putting it, by only having 8K of memory, it is wonderful for what people, like Don Hodges at least can do. So, while POLLY was coming along the techniques of using the other devices had not changed very much, namely the HPD's were still relying on roads, the Spiral Readers were still looking for a person to locate the vertex for them and POLLY was still looking for somebody to indicate to it where the vertex was. One of the advantages that POLLY had was that it was an infinitely flexible device. One day you could say, "Well, we're pointing out where the vertex is" or "we're doing pre-scanning" and then the following day you could say, "Well, it's finding the vertices and we're just pointing

out the ones it's missing." It was in 1969 that POLLY II flipped over from being a system in which the operator more or less as a matter of course found the vertex of the event and identified its type, to a situation in which the system itself was doing most of the scanning with some help from the operator.

Progress in automatic measurement has been marked at intervals by what have been called the "Kowarski" meetings, at which the flying spot digitizer group at CERN and other FSD groups have always been represented. Three people were always present at them, the three being Paul Hough, Brian Powell and Lou Kowarski who were the 3 original people at CERN who realized what it was that they were trying to do. It was the custom at these meetings for Kowarski to give what he describes as "concluding remarks". It's a shame that the business is now so fragmented that the people are going to separate meetings and we don't have the benefit of Kowarski's concluding remarks here.

A number of years ago, Kowarski pointed out that there appeared to be two schools of thought, the so-called tricky hardware school and the tricky software school. He referred to tricky hardware as devices like PEPR or, to a large extent, POLLY, in which pre-arranged circuits are used to do rather clever things with the spot either in the way it is moved about on the face of the CRT or the way it is expanded into line segments. Tricky software is used to describe the sorts of things that people do, particularly at Columbia, to massage large amounts of undigested data by means of computer programs. For a long time there appeared to be a dichotomy and an opposition between these two approaches.

It has taken until a couple of years ago for people to stop feeling that those with the tricky hardware or those with the tricky software were competition that was going to show one up as having been wrong. Whereas in fact, maybe they just discovered something interesting that you didn't know that you could incorporate in your equipment. In the last two years there has been a good deal more "healthy plagiarism" than we used to see in the earlier days, when you joined one of the clubs and took the received wisdom as to what was the right way to go. You were a PEPR man or an HPD man or a Spiral Reader man. I think now we are at a point where there are some PEPR groups who have been happy to use the POLLY programs and there are now some routines in the POLLY programs which have names like PEPR and TED.

Well, an after dinner speech is like oil prospecting, you go on drilling for awhile and if you don't strike anything, you stop boring. Thank you.

A Progress Report on the BNL Vertex Guidance System*

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ABSTRACT

The bubble chamber film is scanned and vertices rough-digitized at tables connected on-line to an XDS Sigma 7. Accurate digitizing is done by the single-view HPD controlled by an IBM 7094. Tracks are initiated, followed and reconstructed in 3 views by programs operating in a CDC 6600. If errors are detected by the 6600 programs, the data is transferred to the Sigma 7 where a human operator, utilizing a TV display and tracking programs in the Sigma 7, can repair any deficiencies. In some months the HPD will be replaced by a Flying Image Digitizer connected to both the Sigma 7 and the 6600.

INTRODUCTION

I suppose one wonders why FSD people are participating in POLLY conferences. The original, and still the main purpose, of both devices is measurement of bubble chamber film, so we begin at the same point. We do diverge to different digitizers but the software problems in pattern recognition are very similar. Both POLLY and the BNL system rely on a human operator for help in this area. So there are many common areas of interest.

Outline of System

The system we have been implementing is outlined in Fig. 1. The film we are working on is from a 7.4 GeV/c K^- beam in the 80" bubble chamber. The number of tracks per frame is in the normal range (15-20) and no special procedures were used in the bubble chamber run. We are scanning for all events with the exception of elastic scatters

*Work performed under the auspices of the U. S. Atomic Energy Commission.

where the proton stops inside the chamber.

The scanner enters the frame number, topology code, and a request for orthogonal scan, if one is required. Then, in each view, one fiducial and each vertex of the event is digitized. Special points may be entered for stubs, range points, and short tracks. At the completion of each event the Minimum Guidance Acquisition (MGA) program checks the formats and the vertices are reconstructed in space, checked, and projected back to the film.

Our main interest at the moment is in 2-prong plus anything events, so the 6600 program, which orders the events and creates a bookkeeping tape, selects only those events which have two prongs at the primary vertex. Decays, secondary interactions, and neutral V's are allowed. Multiple primary vertices have been entered if a neutral V has an ambiguous origin.

The film and the scan data then go to the single-view Mark II HPD for digitizing. All events in one frame are done in a single normal scan. The film (Fig. 2) is from one of the first experiments in the 80" chamber with bright field illumination on 35mm film. Double pulsing was also used. The illumination is very non-uniform in some rolls, chamber conditions vary rapidly and there is an additional phenomenon of the "shadow" tracks from the scotchlite. These problems have been overcome and the digitizings are written onto tape by the Minimum Guidance Bubbles (MGB) program at the rate of 300 views per hour. About 100 frames in one view fit on a tape. The bubble density of beam tracks is monitored during film advance to the next frame to be digitized.

The tapes are then brought to the 6600 computer where the executive program (TR4) runs for each frame.

1. The CERN Minimum Guidance Filter program.
2. A conversion program (SLOG) which also eliminates duplicate tracks and makes associations of tracks with range points and other vertices.
3. MATCH and TVGP.

If there is a good 3-view reconstruction of all tracks the output is preserved on a disk. If there is something wrong with the event, the found tracks, whatever diagnostic information is available, and all the bubbles for three views are sent to a disk.

This disk can be read by the Sigma 7 over the Brooknet link. The operator and the LOTUS program cooperate to fix up the event, check it with TVGP reconstruction and ship it back to the 6600.

The last step is a full TVGP and merge of the events from the two streams.

LOTUS Displays and Operations

Figure 3 shows the latest version of the LOTUS station, with a function keyboard (heavily influenced by POLLY II), 2 teletypes to provide program initiation and a hard copy record of what is being done, and a TV screen where the operator sees the diagnostic prompter blocks, event identification, the bubbles, and the tracks found by the TR4 program. A "track ball" enables the operator to point to any part of the picture. Note that we are now getting along without the film. Stub tracks have been measured at the MGA table with a special cursor.

Figure 4 shows the digitizings of the same frame as Fig. 2. The digitized picture appears quite noisy but this is due to the low resolution of the TV which tends to overemphasize any background noise compared to the true tracks. Later figures at higher magnification will give a truer feeling of the digitizers capability.

Figure 5 shows the region around the vertex of the 2-prong event in Fig. 2. The "shadows" of the fiducials are seen clearly.

Figure 6 shows the corresponding digitizings. These displays are occasionally useful and are available from the function keyboard. We use information from TVGP to construct what we call a "prompter block" which informs LOTUS that it should present specialized displays and messages to the operator. The two displays currently used are the "window" and "beam" displays.

We have found that it is helpful to program in some extra horizontal magnification to discriminate between beams and to spread out the secondary tracks. Figure 7 shows the "window" display and is distorted 5 to 1. The width is 1 cm on film. The total range on the screen is the area enclosed by the 4 points shown in Fig. 4.

If the geometry program in the 6600 has determined that there may be a problem with the beam, then the operator is presented with the display shown in Fig. 8. This is a circular road adjusted to a "typical" beam track. In an r.f. separated beam there are really 2 bunched beams with a small angle (≈ 10 m. r.) between them. This can really cause many problems in the forward direction. The beam display has a magnification ratio of 45-1. As well as resolving problems with the beam, the display has sufficient range to decide difficult problems in the forward direction.

The "beam" and "window" displays are the only ones which are automatically presented to the operator. Others are available through

the function board. Figure 9 shows the commonly used "road" display. This is a parallelogram around the end points of the track and hence is of variable magnification. Figure 9 shows the master points of track 5 as crosses, and the master points of track 4 as brightened dots and illustrates the problems which can arise with the optical shadows. The distance between the two tracks is about $80\ \mu$ on film. These shadows have several properties compared to the parent track --

1. The spread of the digitizings is larger.
2. The bubble density is equal or lower.
3. They are nearly parallel.
4. They do not intersect the vertex.
5. They usually are at large angles (slow protons).
6. They are always closer to the camera axis than the parent track.

None of these properties by itself can eliminate these shadows, but in some (as yet unknown to us) combination we hope to get rid of them in the programs. They cannot be removed by adjustment of the HPD without loss of bubbles on real tracks.

The function board can also be used to change magnifications, move displays, cut tracks followed around kinks, delete extra tracks, etc. Most importantly, it is used to request the Sigma 7 to begin tracking at the point on the screen indicated by the track ball. This would be the procedure for the track shown in Fig. 10. The forward secondary was not found in this view by the pattern recognition program. Two other events are seen in the same figure. Two of the primaries are totally merged. In another view, a track from the first vertex exactly passes through the third vertex. It is frames like this which confirm our belief that human fixup is necessary if we are to be able to process the general event type.

On completion of fixup in the displays presented to the LOTUS operator, TVGP is called for confirmation and the event is shipped back to the 6600 and the bubbles discarded.

Current Performance and Plans

The final output, either processed completely by TR4 or fixed up by the LOTUS operator, has proven to be of high quality. In samples of a few hundred events, we can find NO physics errors in a comparison with our RG system. We do lose a few percent of events due to problems like wrong frame numbers entered by the MGA operator, non-beam events, and parity errors on all that tape, but these do not bias the physics. The peak of the distribution for RMS deviations on film after

3-view reconstruction is under $3\ \mu$ for tracks with momentum above 1 GeV/c.

The only problem is that the system operates too slowly. We require 3-view reconstruction for all tracks with no view allowed to be short. With this condition, the reject rate of TR4 is about 2/3, and it takes about 2 minutes to fix the rejected event. We therefore do not yet have a viable production system.

We are taking certain steps to try to improve the situation.

1. We must improve MG filter performance on beams and shadows.
2. We are implementing a "stop point" facility at MGA time so that the scanner can indicate the end of a truly difficult track. Filter can then make a second attempt to find the track if necessary. We estimate a 25% loss in scan rate.
3. We are implementing a tape interface between TR4 and LOTUS to minimize LOTUS downtime. The closed loop operation sketched in the bottom part of Fig. 1, while efficient in many senses, is vulnerable to the "for want of a nail" problem.

If we can achieve these 3 goals in a short period, then we will be ready to tackle the challenges offered by the Flying Image Digitizer.

The Flying Image Digitizer

The Flying Image Digitizer (FID)¹ will replace the HPD as the digitizer in the system. It will connect with both the Sigma 7 and the 6600. In its first version it will have 32 detectors and 1 view will be measured (both scans) at a time. A lateral slide will then move the 2nd and 3rd views into measuring position. Some elements of the production system have had preliminary tests. A new film transport system, with some unique properties (no vacuum columns, no capstans), has been partially tested. A single detector has transmitted coordinates, and the data path to the 6600 has been tested. All the optics, 32 detectors and corresponding electronics are expected to be in place by the end of March with the intention of replacing the FSD by July 1.

The FID will be capable of digitizing 300-600 triads/hour to match with current or possible speeds of 6600 processing. If faster computing facilities become available, the digitizer is readily expandable. Increasing the number of detectors to 128 can yield a factor of 4 in digitizing rate; or, alternatively, 3 projector stations yield a factor of 3. These two options are compatible, and, if both are implemented, yield a measurement rate of 3600-7200 events/hour. The estimated incremental cost by either route is in the neighborhood of \$30K for each

additional 1000 events/hour.

It is clear that many people have contributed ideas, time and productive talent to this effort. In the interests of time and space they shall not be named here. However, we would like to acknowledge and thank one of the major contributors - the CERN Minimum Guidance team.

REFERENCE

1. "A Proposal for a New Digitizer of Bubble Chamber Photographs", M. Kawaguti, Nuclear Inst. and Methods 63, 57 (1968).

Fig. 1 Schematic of System

Fig. 2 80" bubble chamber in bright field illumination on 35mm film.

Fig. 3 LOTUS Station

Fig. 4 LOTUS version of Fig. 2. The full TV screen is not shown in these or succeeding figures. The master points and prompter information is displayed at a brighter intensity than that of the raw bubbles. In these figures we have attempted to retain the discrimination between the master points and the bubbles. Unfortunately, this badly blurs the alpha numerics in these reproductions. The human eye is not aware of the problem with the real-life TV screen.

Fig. 5 The region around the vertex of the 2-prong event in Fig. 2.

Fig. 6 The LOTUS view of Fig. 5

Fig. 7 "Window" display of same event (see text)

Fig. 8 "Beam" display of same event (see text).

Fig. 9 "Road" display of track 5 (shown as crosses).
Its optical shadow was found by the 6600 program as track 4.

Fig. 10 A difficult case where the forward secondary leading to the 4-prong secondary was not found.

Discussion

R. Burnstein (Maryland) Is this flying image digitizer a variation of the scheme that Kawaguti was working on several years ago?

P. Connolly Exactly. Reference in the paper will be to Kawaguti.

R. Burnstein (Maryland) In this conference, will there be a paper on that or some other paper?

P. Connolly No, just only what I've said. Other than Kawaguti's original paper in Nuclear Instruments, there's little published information yet.

R. Burnstein (Maryland) I see, OK, thank you.

R. Royston (Argonne) You said the pictures were taken without any reference to the problems of measurement - how did that happen?

P. Connolly They were taken by a group of physicists prior to the BNL bubble chamber group reorganization. This group rough digitized on conventional measuring machines and turned the film over to the HPD team for road guidance. This method had been quite successful and presented no problems, so they optimized film conditions inspite of the fact that it was bright field film.

THE BRUSSELS ON-LINE SYSTEM - BROL
PROGRESS REPORT

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ABSTRACT.

The design of an integrated on-line system for the analysis of film from giant bubble chambers is described. This system is built around a PDP-10 computer and is intended to simultaneously support both automatic (POLLY-III) and manual devices. The reasons for the choice of the computer are briefly mentioned.

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1. INTRODUCTION.

The Brussels bubble chamber group has recently ordered both a SEACO-POLLY-III device and a DEC system 10 computer, which equipment will be interfaced and installed on site within the coming months.

Our choice of these devices is motivated by the general option to furnish our laboratory with scanning and measurement equipment adapted to the requirements of the new giant bubble chambers. With this in mind, we also purchased new manual scanning and measuring tables suitable for the analysis of Mirabelle and Gargamelle film. Moreover, we possess equipment which can be adapted to the analysis of the single view films of BEBC and the Argonne 12' chamber. The optimal use of these classical devices requires the connection of at least some of them to a computer powerful enough to ensure on-line reconstruction of the measured events. Hence the idea arose to select a computer which would be dedicated to the simultaneous support of both automatic and manual analysis systems. The project was called the 'Brussels On-Line System' or BROL.

2. CHOICE OF THE COMPUTER.

The central computer facility at Brussels University is a CDC 6400 oriented to batch processing, which is not available for real-time applications. Hence the development of the BROL project required the acquisition of a dedicated machine.

As the POLLY software presents very few machine dependent features, there is no a priori reason to select the same computer as the one used in Argonne, i.e. an XDS-Σ7.

The choice of the computer type and configuration needed, was made in the light of the budgetary and manpower resources proper to our laboratory. Amongst those we may mention

- (i) the existence of a well-defined budget, specific to the computer
- (ii) the availability of a rather restricted staff to support the hardware and software applications envisaged. This led us to pay special attention to computer configurations which were or would be connected to other POLLY devices (i.e. XDS-Σ7, DEC PDP-10, IBM 360/44 ...)

An investigation of the computer systems available on the Belgian market led to the selection of the offers made by five different firms : CDC, CII (a French company selling the XDS-Σ7), DEC, IBM and UNIVAC. These offers were issued in response to a set of general specifications and their final form has been influenced by the knowledge of the available budget. One of us (P.V.B.) made a detailed comparative study of the proposed configurations, complemented by visits to a number of computer centres and the running of a series of benchmarks mainly consisting of

- (i) a compilation of the POLLY-II FORTRAN code
- (ii) a compilation of the FORTRAN code of LBCG, the CERN Large Bubble Chambers Geometry program
- (iii) a test of the efficiency of the software for mass-memory management, consisting in the determination of the average time required to load a dummy overlay of 10000 words

Table 1 presents the main characteristics of the proposed configurations, not mentioning the standard peripheral equipment (card reader, line printer, magnetic tape drives). Some results of the benchmarks are displayed in Table 2.

The proposal made by DEC was considered to present two major advantages :

- (i) the TOPS-10 monitor is the only one to give a simultaneous support to batch processing, time-sharing and real-time applications
- (ii) the memory size of 96 K of 36 bit words.

Notwithstanding the slight disadvantage of the inclusion of a slower memory bank, this proposal appears to be the best adapted to a simultaneous handling of the POLLY and manual devices.

Hence, the PDP-10 was selected. The complete configuration is represented in Figure 1.

3. THE ON-LINE SYSTEM.

Figure 1 also gives a schematic representation of the interface between POLLY and the computer : information will flow between the POLLY

Table 1.

Main Features of the 5 Configurations (Hardware)

	CDC	CII	DEC	IBM	UNIVAC
Model	CYBER - 72	10070	PDP - 10	360/44	418 - III
Core Memory	32 K 60 bits 1 μ s	64 K 32 bits .85 μ s	96 K 36 bits 1 μ s (32 K) 1.8 μ s (64 K)	32 K 32 bits 1 μ s	96 K 18 bits .75 μ s
Mass Memory Access Time	Disk 7.2 Mwords 300 ms	Fixed-head disk 1.6 Mwords 16 ms	Disk-pack 5.1 Mwords 62.5 ms	2 disk-packs 3.8 Mwords 87.5 ms	Drum 4.2 Mwords 17 ms
Operating System	SCOPE 3.4 + INTERCOM 6 K	SIRIS 7 18 K	TOPS-10 18 K	PS/44 + DAMPS 4 K	RTOS 12 K
Features	Multiprogram- ming batch - Time-sharing via INTERCOM - Real-time via PP programming	Multiprogram- ming batch - Data-base sha- ring - Real- time announced	Multiprogram- ming batch - Time-sharing - Real-time - Swapping	Real-time via foreground/ background organization	Multiprogram- ming batch - Real-time

Table 2.

Some Results from the Benchmarks

	CDC	CII	DEC	IBM	UNIVAC
POLLY	23 K	29 K	29 K	39 K	51 K
LBCG	30 K	37 K	37 K	60 K	70 K
Overlay	584 ms	951 ms	297 ms	411 ms	59 ms

- KA10 Central processing unit
- CTY Console and operator teletype
- PTR Paper tape reader, 300 cps
- PTP Paper tape punch, 50 cps
- 2 x ME10 Memory bank, 16 K, 1 μ s
- MD10 Memory bank, 64 K, 1.8 μ s
- DF10 Data channel, direct memory access
- RP10 Disk controller
- RP02 Disk-pack, 5.1 Mwords, 62.5 ms access time, 400 kc/s
- TM10A Magnetic tape controller
- 2 x TU20 Magnetic tape drive, 7 tracks, 800 bpi, 36 kc/s
- BA10 Hard copy controller
- CR10A Card reader, 830 cpm
- LP10A Line printer, 300 lpm
- DC10A Data line scanner
- DC10B 8 line group, 110, 300 and 1200 bauds
- 2 x LT33A Teletype, 110 bauds
- VT05 Display terminal, 300 bauds, 20 lines of 72 characters

Fig. 1 Brussels' PDP-10 Configuration

hardware and the computer via the I/O bus and the priority interrupt system, whereas the IDI display has a direct read access into the computer memory.

In this way we will be able to implement the Argonne software without any major modifications. Our immediate intention is to try to reproduce as accurately as possible the results obtained in ANL for a given sample of events.

Regarding the manual tables, we intend to couple them to time-sharing terminals like the VTO5 display. Hence they will look like normal users to the system and share its resources in the same way. In the software, reentrant coding will be used wherever possible; ideas will be taken from already existing systems, namely the one developed in CERN for Gargamelle film analysis. We will aim at an upward compatibility with the new CERN geometry and kinematics system, HYDRA.

The two applications (POLLY and manual tables) will be developed rather independently, but our hardware will allow us to run them simultaneously, and the final goal is an integrated system that will support the two tasks simultaneously, while optimizing response time for both.

4. POSSIBLE MODIFICATIONS.

Let us finally mention two aspects of the POLLY device, which could possibly be improved in the future.

The first one is the film transport. It is obvious that POLLY devices will be used for films from more than one bubble chamber. In Europe, Mirabelle and BEBC will provide us with light liquid film, and the possibility of automatic analysis of Gargamelle pictures will surely be investigated. All these chambers work with 70 mm sprocketed film, but with different camera layouts, and a larger viewing area than for the 12' chamber is needed to obtain all the necessary information.

The real urgency of this problem will however be subject to the possibility of starting our POLLY system in production with experiments using film from the 12' chamber, a possibility which undoubtedly looks very appealing.

The other feature which might be improved is the interface between

the POLLY hardware and the computer. In view of the fact that we will be running other on-line applications, it would be preferable for the POLLY scan data to flow in direct memory access, with a single interrupt occurring at the end of a whole slice-scan. This would simplify the hierarchy of the various devices and allow the central processor to do more calculations, better than I/O. With the present structure of the interface, which features already a direct memory read for the display file, such a modification should surely prove feasible.

Acknowledgments.

We wish to thank Professor J. SACTON for his participation in the elaboration of this project.

Discussion

J. Goldberg (Technion) What is actually meant by the core requirement you quoted for the POLLY II program? On one typical example you said that on IBM computers you need 39K for compilation. Does that include the linkage editor or the resident system routines or is it really only the compilation of the FORTRAN subroutines?

J. Lemonne It is without a system.

R. Glasser (Argonne) What were the problems with the Univac system? They had some very attractive figures on that diagram.

J. Lemonne Well, one of the main problems is the 18 bit word. Our first aim is to try and adapt the software for POLLY as closely as possible to that which is used here; and in general 18 bit words would have caused trouble.

ALICE
A General-Purpose Image Processing System*

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ABSTRACT

A general-purpose image processing system, ALICE, is described. A large influence in the system design was the concept of interaction between machine and human operator in simple yet convenient ways. Furthermore, the incorporation of a medium-sized computer (a PDP-10 with 32K core memory) allows significant data processing to occur whilst the image source is still available. The system is built in an open-ended manner so that a variety of image sources can easily be attached to the scanner controller interface. Currently, two film stations and an optical microscope are operating.

INTRODUCTION

The design and construction of the ALICE system in the Applied Mathematics Division has followed from eight years of experience in image processing work. The first general-purpose film scanning system, called CHLOE,⁽¹⁾ built in the Applied Mathematics Division, was a 4096 x 4096 point digitizer using a cathode ray tube light source and which could accept 35mm and 16mm sprocketed film. CHLOE was used primarily for the measuring of high energy physics spark chamber particle track data. However, CHLOE was found to have photointerpretation applications in the biological and medical areas as well as in the material science and nuclear engineering fields. The need to process types of data for which CHLOE was not suitable resulted in the construction of two special-purpose systems. These were a nuclear emulsion plate particle track counter,⁽²⁾ and POLLY,⁽³⁾ a high energy physics bubble chamber film scanning and measuring system.

*Work performed under the auspices of the U.S. Atomic Energy Commission.

The main lessons of the CHLOE development for scanning system design were the demonstration of the effectiveness of coordinate data compression and the importance of a general-purpose approach to aid in solving unplanned applications. Other important characteristics of this machine were the use of asynchronous buffered I/O and overlapped scanner control functions. In the POLLY development it was a basic principle to think in terms of a human operator on-line to the measuring system who was available to the machine whenever some higher level (usually global) pattern recognition decisions had to be made. All questions were eventually asked of the human operator in a graphical manner and were answered in a similar way by the operator. All of the hardware techniques necessary for these capabilities have been incorporated into the ALICE system.

The ALICE system carries the asynchronous control philosophy several steps further by incorporating more computational power into the scanner controller. The controller is designed as a second processor sharing the memory of the control computer via its own memory port, and is designed such that the scanning pattern can be virtually any subset of the basic 131072 x 131072 point raster that can be described in terms of areas, lines, or points. The controller output interface is multiplexed to several scanning stations so that although only one can be in use at any time, changeover is at electronic speeds. Controller operations are initiated by commands issued from the main computer. The computer can either monitor the controller status or request various program interrupts at strategic stages so that the programming system can be made aware of the completion of controller tasks. A new hardware feature of the ALICE system is the use of pure digital logic to compute any necessary pincushion and dynamic focus corrections for the scanning coordinates, a function which has usually been done by analog circuitry in previous systems. Presently, the system is equipped with three input stations; two are for conventional 35mm and 16mm film using a cathode ray tube light source, whilst the third station uses an optical microscope coupled to an image dissector tube which performs the actual scan.

SYSTEM DESCRIPTION

The equipment consists of three main elements: a digital computer, a general-purpose controller, and a variety of image sources which can be connected, one at a time, to the controller. The digital computer is a commercially available Digital Equipment Corporation Model PDP-10⁽⁴⁾ (36-bit word length), with the controller and scanning stations being built at ANL. The controller assumes that all scanning stations are completely digital in nature when specifying points to be examined on the image source. The controller provides an X,Y Cartesian coordinate (each 17 bits long) and expects in return a density value (maximum of 6 bits long) for each point examined. In order that the individual points do not have to be specified by the control computer, the controller can be provided with a specification of a set of points to be examined in the image. A simple example is a rectangular area in which the lower left-hand coordinate, the separation between points along a line and between lines, as well as the number of points along a line and number of lines are all variable. More complex sets of points can be specified by procedures to be described later. The returned stream of 6-bit density values can be dealt with in several ways

by the controller. The simplest way is to pass them back to the computer, packed six to a computer word. A more complex operation is to examine each density value as it is returned and to compare it with both a fixed computer-provided discriminator value and the value of the previously examined point. The current coordinate value is fed into the computer whenever a measured density value crosses the discriminator level. The most complex mode of operation is the ability to specify from the computer up to 15 density discriminator values at which a coordinate is fed into the computer whenever any one of the discriminator levels is crossed.

Operator facilities provided include a visual slave cathode ray tube (CRT) display whose deflection pattern is generated by the set of coordinates being issued by the controller. The bright-up of this slave CRT is governed by the mode of the information being returned to the computer. For example, in the boundary coordinate input mode, bright-up occurs only for those coordinates actually being sent back to the computer. A special mode is provided in which the bright-up occurs for each examined coordinate but without coordinates being sent to a scanning station. In this way the slave CRT can have computer-generated data superimposed on the normal slave display. A conventional computer-driven CRT display is also provided which is equipped with both vector and character-generating hardware. The actual display CRT is identical to the slave CRT, both being 21-in. flat-faced radar display CRT's provided with a P7 phosphor. Because of this use of similar tubes, the slave and display CRT's have identical deflection and appearance characteristics, which is very advantageous in terms of human engineering for an operator. Slaved to the computer display is a 5-inch precision CRT equipped with a 35mm camera having 100-foot film cassettes for obtaining film output if desired. An operator-controlled track ball is provided which is connected only to the computer and whose use is a function of the software. The entire set of 36 computer sense switches are duplicated at the operator's position as well as program-controlled display lights, which enables the operator to exercise program control without leaving the operating position. One scanning station is provided with the ability to present an optical display of the data film on a rear projection type screen. This optical display screen is provided with a sonic pen system (graf/pen) manufactured by Science Accessories Corporation⁽⁵⁾ for the rough digitizing coordinates of interest. This enables the operator to assist the computer with any scanning problems in difficult areas of interpretation.

SYSTEM ORGANIZATION

A schematic of the overall system is shown in Fig. 1, and a more detailed breakdown of the controller is shown in Fig. 2. Photographs of the overall system and the operator's position are shown in Figs. 3 and 4.

The basic function of the controller is to provide to the scanning station a series of points (in digital Cartesian coordinates) whose density is to be measured and returned to the controller. Any necessary digital-to-analog conversion or power driving capabilities for a deflection system are all provided in individual scanning stations. Previous film scanning systems⁽¹⁾ used counters for the X,Y positioning coordinates so that sub-set rectangular areas could easily be selected out of the total set of all

possible points. Furthermore, by injecting the advance counter pulse into other than the least significant bit position, variable point separations could be achieved. In the ALICE controller, the counters are replaced by adder circuits so that there is much less restriction on the size or direction of the interpoint and interline separation. The basic spot raster is set up to be 131072 x 131072 (i.e., 17-bit binary numbers); this large number enables lines at closely spaced angles to be constructed on most practical scanning stations, as usually only the most significant 10 to 12 bits of the controller-supplied coordinate is used. In the actual implementation, all registers are 18 bits long and use a two's complement representation of negative numbers. The actual X,Y generated position coordinate must be in the first quadrant if useful information is to be sent by the controller to the computer. One or both of the X,Y values will in effect go negative whenever there has been an under- or over-flow condition produced when constructing the next point to be examined, and this can be signalled to the computer if requested.

To define any parallelogram-shaped set of points, eight controller parameters must be set up with the following quantities: the starting (X,Y) coordinate, the (X,Y) increment between points on a line, the (X,Y) increment between the starting points of lines, the number of points in a line, and the number of lines. The number of points in a line defines how many times the (X,Y) point increments are added to (X,Y) position to form a line.

Individual point, line, or area specifications, referred to as scanner tasks, can be linked together so as to be executed without computer action. This so-called chaining is very useful in linking several lines together to produce irregular scans such as a straight line approximation to a circular scan.

The type of information to be sent back to the computer by the controller is governed by the setting of mode bits in a function register. If the density values are to be returned directly, they are assembled, six to a word, before being stored in the computer memory. The end of a scan may or may not cause a computer interrupt at the programmer's choice as indicated by masking bits in the function register.

When working in the line segment mode, the ALICE system makes use of the coordinate method of image data compression. The controller can detect the boundary coordinates of a figure utilizing a parameter-provided decision density level. Boundary (X,Y) coordinates (packed into a single word) are sent to the computer memory. The density value corresponding to each coordinate sent to the computer may or may not also be recorded. These density values are again packed six to a word so that only after every sixth coordinate is a packed density word sent to memory. There is also provision in the controller for using up to 15 density decision levels for generating coordinates. This has the effect of measuring 15 equal-density contour lines with a single pass of the scanner. Again it is possible to have, or not to have, density values accompanying the coordinate data. The set of coordinates in this mode would normally, however, be meaningless without the accompanying density values.

In order that a systematic set of coordinates be obtained, it is necessary for the controller to be aware of whether the image background is defined as white (black on white data, BOW), or black (white on black data, WOB). This is designated by a bit in the function register and is used by the controller to force its own density value for the pseudo point prior to the first point on a line and the last point on a line. The net effect of this logic ensures that an even number of coordinates are obtained during the examination of a single line when in the single density discrimination mode.

Many devices used for scanning stations are subject to a pincushion⁽⁶⁾ distortion whose positioning error equation is well known. The classical example of such distortion is obtained when a cathode ray tube is used as a scanner light source. It is possible to correct for this error with a program in the control computer. However, this is very wasteful of computer time, and it is usually more convenient for the control programs to assume that the coordinate data is nearly perfect and only apply the fairly elaborate correction on a few master coordinates. Previous work^(1,3) has always used analog circuitry to achieve a hardware correction of the pincushion distortion. However, with the decreasing price of integrated digital circuitry, it is now reasonable to perform this task with pure digital circuitry, which has been done in the ALICE controller.⁽⁷⁾ This method has the advantage that the correction parameters are specified as digital numbers and can thus be easily set by the control computer to the value required for the particular scanning station in use.

Five different conditions can cause an interrupt to be generated by the controller during the performance of its tasks. Each interrupt is individually enabled by a bit in the function register. The five interrupt conditions are:

1. The word count register is zero (i.e., buffer full).
2. Total end of all controller tasks.
3. End of a controller task.
4. End of line in area scan.
5. Scanning area overflow.

SCANNING STATIONS

The first scanning station uses a CRT point light source system for the digitizing of 16 and 35mm sprocketed transparent film. From the block diagram (Fig. 5) it is seen that the light from the CRT is imaged both on the film being examined and onto a reference photomultiplier. By effecting a division of the signal from the signal photomultiplier to that from the reference photomultiplier, it is possible to make the resultant signal amplitude approximately independent of the brightness of the spot on the CRT. This signal is then digitized to provide the 6-bit digital density value required by the controller. This density number is related to the optical density of the film, with zero corresponding to no transmission loss through the film, and 63 representing an optical density of around 2.2 on the film.

The digital-to-analog current system to provide the deflection current for the deflection coils is very similar to that described earlier.⁽³⁾

The CRT is a 215mm Ferranti type 9/71 with a type Q phosphor. It is operated with a 114mm square raster which is optically reduced by a Wray copying lens by a factor of about 3, so that a 38mm square deflection is obtained at the film plane.

Interchangeable platens are available for 35mm sprocketed film, 16mm sprocketed film, or a fixed glass plate. For 35mm film the sprocket from a digital stepping motor is geared such that the least count of movement is one-eighth of a sprocket hole separation, and for 16mm film the unit of least movement is one-sixteenth of a sprocket hole separation. The film is held off the platen by a cushion of air when being moved, and is clamped down by a vacuum system when actually being scanned. The 35mm film frame that is four frames ahead of the frame under scanner examination can be optically projected onto the rear of the rough digitizer screen. The station is provided with automatic film reel spoolers and will accommodate up to 400-foot rolls of 35mm film. Mechanical sensing arms are used to control the spooling servomotors.

The second scanning station accommodates sprocketed 35mm film only, and is similar in mechanical design to station #1. It is, however, provided with features to improve the signal-to-noise ratio which improves the film density range that can be accommodated. These features include a movable aperture between the imaging lens and the film to cut out stray scattered light in the optic system.⁽⁸⁾ This actually consists of a narrow horizontal slit, the full width of the film aperture, which can be moved in a vertical plane in sympathy with the vertical scanning position when performing a horizontal TV-type scan. Further signal improvements are achieved by a much improved analog-to-digital converter circuit and the use of a solid state cooler device cooling the housing around the photomultiplier. Increased electrical and magnetic shielding is also incorporated in this unit.

The third scanning station consists of a standard optical research microscope with a conventional illumination source. The microscope is equipped with a dual imaging system, one of which is used for normal viewing and the other is provided with a scanning image dissector tube for converting the light image to an electrical signal. The microscope is equipped with a two-dimensional stepping motor-driven stage that is either manually or computer driven. The least increment of movement in each direction is 10 microns. All of the usual optical filtering and illumination techniques for improving the clarity of a viewed image can be used to improve the image dissector density signals.

SOFTWARE

A general-purpose approach to the scanning control and data reduction software programs has been found to be of great convenience.^(9,10) Such a program has two main modes of operation. First is a display mode in which a human operator may view data being continually rescanned and shown on the display CRT and adjust the current scanning conditions. This includes such properties as the size, position, point density, and orientation of the scanned area as well as the current density discrimination level. He may also call for other facilities such as film moving and a density

histogram of the current area of interest. The second mode is that of execution of a sequence of digitizing programs, each of which produces some useful output data, either in itself or for later programs in the execution sequence to use. Any of these programs may also use operator intervention for assisting the program in a difficult situation. In the case of execution sequence programs requiring parameters, a different set is usually required for each particular execution of the program, and these are entered when the sequence of execution programs is assembled by an operator using the console teletype. Only the actual interface driver and interrupt programs are written in machine language code with all normal programming being performed in FORTRAN. It has been found useful in some production programs to write the inner loop in machine language in the interest of significant increases in speed. The manufacturer-supplied FORTRAN compiler, library, and loader systems are used as well as the now unsupported Single User Monitor. This small monitor has been updated at Argonne to enable the use of the manufacturer's later FORTRAN systems programs.

Another software system⁽¹¹⁾ has also been written in which the scanner controller is operated via monitor control. This consists of a scanner service module which is part of the monitor and a "driver" program included in the FORTRAN library (LIB40). Interrupt processing is accomplished in the same way as for other I/O devices, and the standard double buffering scheme is used to transfer scanner data to user storage. Scanner control is effected by FORTRAN calls which look rather similar to those described in Ref. 10.

OPERATION

The first major use of ALICE was a high energy physics spark chamber experiment which involved three related frames on separate reels of film. The first was a photograph of a pair of four trace oscilloscopes giving time-of-flight data by amplitude and position coding of pulses on the traces. The second and third frames are two orthogonal views of an array of optical spark chambers. The oscilloscope film was measured automatically, but an interactive measuring system is used for the spark chamber film measuring in much the same way as bubble chamber film is measured on POLLY.

Non-high energy physics uses of the ALICE system for production measuring include:

1. Neutron hodoscope data obtained during nuclear reactor fuel pin meltdowns is recorded as light images of binary counters on 16mm film. There may be as many as 10,000 frames of interest which can be read by ALICE at a rate of up to 1800 per hour.
2. Size and number distributions of metallic particles.
3. Determination of the perimeter and area of complex bone cross sections.

4. Grass plot classification of regular photographing of the same area over many years.
5. The counting and size classification of individual nerve fibers within cross sections of complete nerves.
6. Counting and karyotyping of chromosome spreads.
7. Digitizing of mass spectrometer output pen tracings.

REFERENCES

1. R. K. Clark and W. F. Miller, "Computer Based Systems at Argonne," Methods in Computational Physics, Vol. 5.
2. J. Erskine and R. H. Vonderohe, "An Automatic Nuclear-Emulsion Scanner," Nucl. Instr. & Methods, 81(2), 1970.
3. R. G. Barr, et al.: POLLY I: Operator-Assisted Bubble Chamber Film Measuring System. Rev. Sci. Instr., 39(10), p. 1556, October 1968.
4. PDP-10 System Reference Manual, DEC-10-HGAC-D. Digital Equipment Corporation, Maynard, Massachusetts.
5. Science Accessories Corporation, 65 Station Street, Southport, Connecticut 06490.
6. R. D. Rawcliff: Cathode Ray Tube Displays. T. Soller, et al. Eds. (McGraw-Hill Book Co., New York, 1948), Vol. 22, Chapt. 9.
7. R. Barr and D. Jacobsohn, "Digital Hardwired Pincushion and Dynamic Focus Correction." Argonne National Laboratory, Applied Mathematics Division, Technical Memorandum No. 204. October 1970 (unpublished).
8. A. S. Weiss, "Optimizing Film Density Sensing," Electro-Optical Systems Design, November 1971.
9. Donald Hodges, "Spark Chamber Film Measuring Using the CHLOE System." Pictorial Pattern Recognition, Thompson Book Company. 1968.
10. D. Hodges, "Some Preliminary Support Programs for the ALICE System." Argonne National Laboratory, Applied Mathematics Division, Technical Memorandum No. 202, October 1970 (unpublished).
11. J. W. Butler, "FORTRAN and Assembler Level Programming of the ALICE Film Scanner under Monitor Control," Argonne National Laboratory, Applied Mathematics Division, Technical Memorandum No. 212, January 1972 (unpublished).

Fig. 1 Block diagram of the complete ALICE system.

Fig. 2 Controller block diagram

Fig. 3 Overall view of the ALICE image processing system.

Fig. 4 Operator working at the console of the ALICE system.

Fig. 5 Scanning station No. 1 schematic

Discussion

R. Glasser (Argonne) I wonder why you didn't use gradient-type edge analysis on those nerve bundles - it looked like a natural for that.

D. Hodges I am sure there is not a unique way of doing it. The only problem is that the pictures are so busy that regardless of the method you multiply things by many thousands in terms of time.

R. Brown (Illinois) What's the speed of your controller? What rate can you generate those points that you send out to the devices?

D. Hodges At present we are limited by the fact that we do the analog to digital conversion of the signal and come back with a six-bit number. The film scanning stations are five or six microseconds a point, the digital corrector takes about 1.2 microseconds to do all the various multiplies and things to compute the (U, V) value and the adders that compute the next point are 200 nsec resolution time. I do not think we can go faster than two microseconds a point, but we really haven't tried for speed.

University of Toronto POLLY Progress Report

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ABSTRACT

The University of Toronto has ordered the first commercial Polly, conforming to the ANL Polly III specifications from SEACO, to be used to measure bubble chamber pictures, and also large quantities of pictures generated in medical cell biology and chemical engineering research; delivery is scheduled for mid-January. A PDP-10 control computer has already been installed. Progress with the hardware, and conversion of the software, based on PONG 83 is described.

INTRODUCTION

In April 1970, funding for the Polly project at the University of Toronto was approved by the National Research Council; in that month, orders were placed with SEACO Inc., Garland Texas for a Polly III conforming with the ANL specifications, plus a film transport modification kit to handle 3 x 35 mm. and 1 x 16 mm. films, and with Digital Equipment Corporation, Maynard, Massachusetts, for a PDP-10 control computer. The Polly is to be used for picture measurements in two fields other than the conventional High Energy Physics, namely Medical Cell Biology, and Fluid Flow Analysis. The choice of a Polly rather than another type of machine was influenced strongly by the man/machine interactive operating capability of Polly, and the flexibility this provides for developing the new applications; also, the complete specifications, drawings and programmes for a working machine were available from ANL, and this, along with the excellent personal contact and advice we are receiving from the ANL team, indicated a considerably shorter time to achieve production status than by any other route. Clearly, we expect to begin production with bubble chamber pictures earlier than with the new applications; we have adopted a philosophy of minimum change to the ANL design for the sake of expediency. Our first experiment, in collaboration with Brookhaven National Laboratory, will be a 10 GeV π^+p exposure of 10^6 pictures in the SLAC 82" chamber of which we will receive 50%, scheduled to begin in March. To support existing work, three manual measuring tables, previously hooked up to a dedicated CDC 1700 for data acquisition, have been interfaced to our PDP-10 and the software satisfactorily rewritten; this enables us to measure 5,000 events per month until Polly becomes operational.

Administratively, we have set up a Polly Committee, chaired by Dr. K.C. Smith, Department of Electrical Engineering, and joined by one representative from each of the user groups, Physics, Biology and Chemical Engineering. Management of the project is handled by Dr. E.C. West.

The decision to buy Polly from SEACO was based upon their price quotation, but also their technical competence, particularly in the digital analogue circuitry and optics areas, as assessed by members of the ANL design team, and Professor Normal Gelfand from the University of Chicago. We acknowledge gratefully this assistance.

Our own workshops estimated they would need about 15 months to complete a Polly; however, they can perform the necessary hardware changes for the new applications at least as fast as the parallel software developments can be handled.

THE CONTROL COMPUTER

The PDP-10 has the following configuration and significant features:

1	KA10	Arithmetic processor (16 fast registers, dual relocation and protection registers, 7 levels of priority interrupt, real time clock, console teletype, extended instruction set).
3	MB10	Magnetic core memory units (16 k.words/unit, 36 bit words, 1.65 μ .sec./cycle, 0.65 μ .sec. access time, memory interleaving).
9	MC10	Memory ports (3 for KA10, 3 for DF10, 3 for Polly display).
1	RP10	Disk pack control.
1	RP02	Disk pack and drive (5.1 m.words, 14.8 μ .sec./word transfer rate, 80 m.sec. max. head positioning time).
1	DF10	Data channel (direct memory access for RP10).
1	TM10	Magnetic tape control.
2	TU20	Magnetic tape transports (7 channel, 36 k.word rate).
1	BA10	Hard copy control.
1	LP10A	Line printer (300 lines/min).
1	CR10	Card reader.
1	DC10A	Data line scanner (teletype terminal interface).
1	DC10B	Eight line group for DC10A.
3	KSR33	Timesharing teletype terminals (for control of manual measuring machines; may be used for programme development).

The computer has been installed and running since July. There is a tremendous advantage to having time sharing capabilities, particularly in our situation where programme development for H.E.P., Fluid Flow Analysis, Medical Cell Biology, manual measuring machine control and miscellaneous systems areas are proceeding more or less in parallel; also it is possible for other users to learn how to use the system

while this is going on. The price of this is the large core space taken up by the time sharing monitor("TOPS-10", level 5S03B, 25 k.words at present, though this can be reduced to under 20 k. words quite easily). We are confident that the Polly programme will fit, overlaid as necessary, into 26 k.words by comparison with the Sigma 7 programme; the extra word size and large instruction repertoire of the PDP-10 make the compiled code relatively efficient. Hence, even with 48 k.words of memory, we hope we shall be able to continue simultaneous programme development whilst Polly is in production.

POLLY/PDP-10 INTERFACING

The IDI display is interfaced directly to memory, via one port to each of the 16 k.word modules; the interface simulates a single user data channel, which does not require CPU intervention once started, and can access memory, remembering the current address; in other words, the mode of operation will appear the same as that used on the Sigma 7 at ANL.

Loading of hardware registers, transmission of control information, and transmission of slice scan data back to the computer is handled by the I/O bus. The slice scan will operate at interrupt level; the overhead to handle an interrupt with the fast BLOCK IN instruction is about 6.5 μ .secs; so we feel that by overlapping with the slice scan line flyback, we can, for the price of about 2 μ .sec. per line, avoid the cost of another channel, or special memory interface.

POLLY HARDWARE STATUS

The Polly/PDP-10 interface was ordered from SEACO as an integral part of Polly, along with the Polly controller, and the IDI display and its controller. In the design and testing phases, SEACO has received close cooperation from D.E.C.; for example a set of I/O bus cables has been loaned, and consultations have been arranged to familiarise SEACO with D.E.C. logic. The interface is clearly one area where we depart significantly from the ANL design; the PDP-10 is completely asynchronous which simplifies interfacing; T.T.L. integrated circuits have been used in place of the X.D.S. modules used at ANL and this required some changes in the Polly and IDI display controllers and the discriminator circuit, to accomplish the desired logic. During production, the critical path seemed to be dominated, strangely enough, by the digital circuitry, particularly as changes were made to the designs during production. Our electrical engineer returned from Garland on December 15 and reported the following status:

- i) All mechanical parts were complete and ready for operation; they have been tested; a problem caused by defective SCR's in the film transport servo loop has been solved. A modification to the ANL design was necessary to mechanically accomodate the IDI display.
- ii) The optical parts, including the projection path with all of its related shutters, the reticle system, and the precision CRT with all of its projection path accessories, have been aligned. Final adjustment of the mirrors, which depends upon the alignment of the CRT coils, occurred in late December.
- iii) The dynamic correction circuits (pincushion, focus, astigmatism) had not been adjusted; this procedure requires extensive optical measurements using an accurate glass engraved grid in place of the indexing mirror; we understand this has since been done, but will probably require readjustment after Polly's arrival in Toronto. The reticle will then be positioned to coincide with the film position of the CRT spot.
- iv) Earlier problems in the CRT focus power supply and main D/A converters were solved using a better grounding scheme; also, deflection coil ringing was damped by introducing parallel resistors.
- v) The digital electronics, including the computer interface, Polly controller, and IDI display controller were lagging behind the other parts. Also, it was not clear whether the minimum and maximum acceptable width (for a 'good' slice scan line) was working properly, due to difficulties in interpretation, and conversion to D.E.C. logical elements.
- vi) The discriminator circuit for the photomultiplier circuits was lagging, because design changes at ANL were still going on.

The current status (January 6th) is that Polly will be shipped from Garland on January 7th, although the electronics will probably be not quite complete. Upon arrival at Toronto, around a week later, some dismantling will have to occur to get the frame into the physics building, via a window. Reassembly will be followed by optical realignment and adjustment of the dynamic correction circuits. It looks as though the following areas of which the most significant are digital

electronics will be tidied up by SEACO after Polly's arrival in Toronto.

- i) We have requested SEACO to add two busy status bits (one for slice scan line busy, and one for slice scan busy) to the interface.
- ii) Only 28 buttons can be illuminated according to the original ANL design. We wish to illuminate all 32 (as is now done at ANL).
- iii) The minimum and maximum width circuits will most probably need debugging.
- iv) To incorporate the latest changes to ANL's design, a shield for the capstan motors' power supply will be installed later.
- v) The auxiliary 3 x 35mm. + 1 x 16 mm. film transport modification kit will arrive about the end of January.

We are optimistic that by early February, we will have a working Polly ready for acceptance testing.

SOFTWARE

We took a sample of film from the SLAC 82" chamber (35 mm. sprocketed film with one view/reel) to ANL and tried it on Polly II. The pictures have contrast, beam track density, and resolution characteristics similar to MURA 30" pictures; we found that PONG 83 was quite capable of following tracks and measuring a whole event. Hence we have taken PONG 83 and the changes necessary for Polly III as our starting point, and are attempting to convert the programme directly to work on our computer, with our hardware. The changes fall into several categories:

- i) Experiment and bubble chamber dependent 'strategic' features.
- ii) Fortran differences between the PDP-10 and Sigma 7 (36 bit words, entry points etc).
- iii) Assembler language I/O routines (Different instruction set, different interface responses etc).
- iv) Other assembler routines (circle fit etc).

These have proved useful areas for division of labour. The interface specifications were received from SEACO in December, and a set of I/O routines have been coded to conform to

these (on the assumption that there will be none of the spurious interactions between functions such as indexing mirror flipping, and film transport which required the building in of delays with ANL's Polly III); these specifications still require a few minor changes and additions to reflect the final state of the interface hardware. Nevertheless, the version from which we are currently working is given in Appendix I to indicate how Polly looks to the programmer. Up to the present time most effort, apart from the I/O routines, has gone into converting the CALIBrate branch of the programme, for reasons explained below.

ACCEPTANCE TEST PREPARATIONS.

When the hardware is ready, we will have the I/O routines ready to try the individual functions, such as loading registers, moving film, changing views, etc. This includes individual functions of the IDI display; however, we do not think that the complete display package will be ready for some time after hardware arrives, and we can debug the programmes on-line. This implies that we should be able to perform acceptance tests on the rest of the Polly hardware without relying upon the IDI display being available to run WORKER.

A satisfactory acceptance test (once the individual hardware functions are working) will be to run the CALIB programme, and show that the values obtained when measuring a 5mm grid are not significantly worse than those obtained at ANL. These values will indicate if there are hardware errors in sweep linearity, major and minor deflection, drifts with time, and hysteresis effects. We have visited ANL and set up a version of CALIB which runs automatically, without requiring the operator to find grid intersections using the IDI display; this is working satisfactorily; the results are output on the printer.

SIMULATOR.

We have modified the slice scan routine so that the data it returns to the computer is also stored on magnetic tape. This routine is to be used at ANL with CALIB on Polly III, and the resulting magnetic tape transferred to our PDP-10. Then we can do our last minutetuning to the PDP-10 version of CALIB so that it gives identical results whilst reading the simulated hardware response from tape. This should eliminate any chance that our programme is at fault during acceptance testing.

NON-HEP APPLICATIONS.

Ed West's talk will deal with our preliminary thoughts on how to use Polly to measure the DNA molecule and fluid flow pictures. The problem in both cases is one of following irregular lines in rather noisy pictures. As experience at ANL with 12ft. bubble chamber pictures is showing, this may not be a

trivial problem when a mechanism for predicting where to look for the next point on the line is not readily available. A number of line following techniques are being developed by the other POLLY users, and their graduate students, and the limitations of these examined, in order to identify features that occur frequently, and can be recognised reliably.

CONCLUSION.

The University of Toronto's POLLY will arrive very soon; preparations are well advanced for acceptance testing, and conversion of the software for measuring its first bubble chamber pictures, based as closely as is possible, upon the ANL system.

ACKNOWLEDGEMENTS

We wish to express our thanks to the designers and builders of POLLY at ANL, firstly for the design for POLLY, and especially for their continued interest and encouragement as our questions have become more numerous, and our request for time on their computer more onerous.

APPENDIX I

SEACO's POLLY/PDP-10 Interface Interim Description

The following three drawings do not exactly reflect the final interface format. A few bits have been added and changed. Once Toronto's POLLY is delivered, a final design can be obtained from SEACO.

CONI BITS TO CPU	BITS NOT READ BY CPU DURING CONI										1=ON	1=ON	C	0	1=SET	1=SET	1=SET		C	OD	E
	0	1	2	3	4	5	6	7	8	9											
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
STATUS DESCRIP- TION											Controller, Interface Face Power On	POLLY System Power On	Slice Scan Done	Slice Line Done	Slice Scan Done	Scan Line Done	Program Interrupt	NOT USED	PRIORITY	INTERRUPT	ADDRESS
TYPE OF SIGNAL											LEVEL	LEVEL	CLEAR	CLEAR	SET	SET	CLEAR SET		C	OD	E
SIGNAL SOURCE	CONO BITS FROM CPU												1=	1=	1=	1=					
	POLLY CONTROLLER										✓	✓			✓	✓			✓	✓	✓
	INTERFACE												✓	✓			✓				

NOTES: 1 CONO CLEAR BITS 27 & 28 = LOGICAL "1"
WILL CLEAR INTERRUPT

2 CONO SET BITS 29 & 30 = LOGICAL "1"
WILL SET INTERRUPT, THUS PERMITTING
A THREE WORD "BLOCK-IN" OF DATA
CONTAINED IN THE SCAN LINE REGISTER
(TRACK EDGE, WIDTH & DOUBLE HIT) AND
THE SLICE SCAN REGISTERS (1 WORD ONE
& 2 WORD TWO).

Applications of POLLY to Biology and Hydrodynamics

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ABSTRACT

The POLLY installation at the University of Toronto will be shared among the High Energy Physics group, which will be involved in the measurement of bubble chamber film, and two users from the departments of Chemical Engineering and Medical Cell Biology. The biological application of POLLY will be the analysis of electron micrographs of DNA molecules. Also, the measurement of certain flow properties of confined fluids, which is being undertaken by a chemical engineering group, will use the POLLY system very extensively.

INTRODUCTION

The POLLY installation at the University of Toronto is a multidisciplinary project funded directly by the National Research Council of Canada. The participating users include the High Energy Physics group of Professor J. D. Prentice, the hydrodynamics research team of Professors J. W. Smith, and R. L. Hummel in the Department of Chemical Engineering, and Professor L. A. Machattie's medical cell biology group in the Faculty of Medicine. The details of the POLLY installation itself and the progress made for bubble chamber applications have been covered in the progress report presented by Mr. Phillips. I will discuss here the two non-bubble chamber applications of POLLY which we plan to implement.

These apparently unrelated fields of research have one common characteristic: they all analyse scientific data obtained from photographs. Moreover, all the images obtained have a roughly similar structure which can be described as "line-like". It is this feature which leads us to believe that techniques similar to those used in the analysis

of bubble chamber film can be applied as well to the analysis of these other types of scientific photographs.

DNA MOLECULE ANALYSIS

The biological application of POLLY involves measurements of a large number of DNA molecules to obtain data which will permit biologists to make statistical studies of their lengths and other configurational properties. Figure 1 shows an electron micrograph of a particular type of DNA molecule. These are virus chromosomes which are of special interest to molecular geneticists because the genetic system they represent is the simplest which can be studied by both physical and genetic techniques. It is the analysis of this type of system which has provided our current concepts about the molecular basis of all genetic systems.

The cell biology research on POLLY is being directed by Professor L. A. Machattie. He expects the availability of such a programmable scanning device with its ability to make rapid assessments of molecular populations to dramatically widen the scope of possible experimentation in DNA sequence-complementarity. It will be possible to study certain statistical properties of these molecules in a fraction of the time required by manual methods.

Although the DNA molecules appear to be similar to the trails of bubbles in bubble chamber photographs, there are obvious differences. Most of the molecules form rather complex patterns which can cross over themselves many times. Having several branches of a molecule originate at the same point they can also have cusps or even discontinuities.

Several line following techniques suitable for DNA molecule images have been developed by Mr. Pierce Reid, an Electrical Engineering graduate student using a POLLY simulation program and data from DNA electron micrographs digitized at the University of Illinois. His results make us confident that POLLY is a suitable system for this type of analysis.

HYDRODYNAMICS RESEARCH

An exciting recent development in experimental hydrodynamics is a new method of measuring fluid motions without disturbing the flow itself. The Lasar induced, photochromic dye line technique illustrated in Figure 2 is being used by Professors R. L. Hummel and J. W. Smith of the Department of Chemical Engineering to study the motions of fluids in a variety of situations.

The figure shows four frames from a high speed motion picture. A photochromic dye dissolved in the downward moving liquid turns dark when irradiated by a Laser beam (Frame A). Flow characteristics can be analyzed quantitatively by determining the development of the dye line from measurements made in subsequent photographs (Frames B, C, and D).

For example, the time development of the dye line can be used to yield instantaneous velocity profiles. By controlling such factors as pressure, viscosity and the geometry of the experiment a great deal of data can be obtained. The fluid flow research project has already produced a large quantity of film to be processed by POLLY.

The results of a series of measurements will be a set of dye line contours. Since the precision required of this data is not great, the poorly defined edges and non-uniform dye line (resulting from absorption of the Laser light) should not be a serious problem. Mr. Reid's work on the following of line-like molecules appears to be applicable to dye-line following as well. The development of appropriate strategy programs for this application of POLLY has been undertaken by Professor Hummel and his students. At present their work is still in the design stage.

Eventually, we plan to expand the film flow analysis studies to include the more difficult problems of diffusion and turbulence. To make this possible, we plan to modify the POLLY hardware to make direct measurements of film density more convenient. We will also enlarge the area covered by the slice scan.

SUMMARY

The first application for the Toronto POLLY installation will be the bubble chamber film analysis since the development of the software is much further along than that of the other applications. However, we are hopeful that within a few months after bubble chamber production begins the biological and hydrodynamics applications will also begin. The simulations we have done indicate that these projects are definitely feasible for our POLLY installation.

Fig. 1 Electron micrographs reveal the complex patterns DNA molecules can assume even in simple systems like the virus chromosomes shown here. POLLY measurements will provide topological information which can be used to make statistical analyses of interesting molecular populations.

Fig. 2 The fluid flow analysis technique to be used in connection with POLLY is illustrated by these frames from a high speed motion picture. A photochromic dye dissolved in the downward moving liquid turns dark when irradiated by a Laser beam (Frame A). Flow characteristics can be analyzed quantitatively by determining the development of the dye line from measurements made in subsequent photographs (Frames B, C and D).

Discussion

R. Brown (Illinois) I missed why the hydrodynamic problems get into thousands of pictures. Is this a statistical problem, or are they investigating a large number of flows, or is it that they want to examine it in very small increments of time?

J. Deery They want to study it in small increments of time. Also, they vary things like temperature, pressure and viscosity of the fluids and the function of these things.

THE CALTECH POLLY: Status Report

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ABSTRACT

We present a report on the status of the Caltech Polly. The following topics are included:

- Considerations that led to the mechanical and optical layout.
- Description and performance of the various subsystems: measuring CRT, view selection, film transport, optical pointer, operator displays, etc.
- The electronic control of Polly: the Polly controller.
- The computer configuration: task assignment and communication between the PDP-11 and PDP-10 computer.

1. Introduction

The essentials of the Caltech Polly have been patterned after the successful Argonne Polly. In particular, we plan to start operations by using most of the Argonne software package. There are, however, many details in which our system differs from the Argonne system. One of the most important differences lies in the computer configuration. Rather than using a single large computer on line to Polly we have a small PDP-11 fully devoted to Polly linked to a time-shared PDP-10. There are also differences in the mechanical-optical layout, the electronic configuration used to drive the CRT, and the operator displays. In Figure 1 we show the block diagram for the Caltech Polly and in the following paragraphs we describe the system, the considerations that led to its particular design,

and the state of its development.

2. Mechanical and Optical Layout

The Caltech Polly layout is shown in Figure 2 and schematically in Figure 3. The components of the machine proper are built into two standing plates, one containing the measuring and projection apparatus and the second containing the film transport systems. The advantage of building Polly in these two plates is the easy and comfortable access to every mechanical and optical component of the system. Standing away from the plates, at an arbitrary distance, is the operator console containing the optical display screen, the Tektronix T-4002 memory scope and keyboard, and the various buttons and knobs through which the operator interacts with the system. Also separate from the plates are the racks containing all the electronic components including the PDP-11 computer and the TU-10 magnetic tape unit.

The main plate contains four measuring and projection stations. The face of the measuring CRT lies in the main plane; a rotating mirror placed at 45° relative to the plate deflects the CRT spot to any of the four measuring stations. The stations occupy 90° out of the full circumference on which the CRT image can be placed. In the unused region of the circumference specially designed stations can be used to study other Polly applications (biological, astronomical?). In particular, the region of the circumference opposite the present stations allows the use of the present projection system without any modifications.

One optical channel is shown schematically in Figure 4. Each channel has a 2:1 reduction measuring lens which images the CRT spot onto the film platten. A pellicle immediately after the "measuring" lens deflects approximately 20 percent of the light to a reference photomultiplier. A mirror placed behind the platten deflects the remaining light to the measuring photomultiplier.

By changing the position of two mirrors and two shutters the channel is used for projection. Each channel contains a projection lens which forms the image of the film on a plane containing the reticle crosshairs used for pointing. The images from the various channels are fanned-in

to the reticle plane by a rotating mirror. The image at the reticle plane is then projected onto the operator console. The projection system past the reticle plane is completely flexible; by changing a lens and the position of a couple of mirrors the image can be carried to an arbitrary location.

To date we have completed and assembled all the hardware for one station, so that we effectively have a one-view Polly. The remaining optical channels will be completed by the end of March.

3. Performance of the Hardware

The hardware components have been assembled and most have been tested. The tests have been made on individual components; since we are not in a production state, no overall reliability figures exist. In what follows we list some of the performance characteristics which are of general interest.

A. The measuring CRT and photomultipliers:

An extensive study of CRT and photomultiplier performance is being presented at this conference by John Power. A few parameters are listed below (all distance measurements are on the film plane):

Measured spot size.....	13 μ
Illumination along the long dimension of the platten (35").....	flat within 25 percent
Available sweep velocities.....	12 μ / μ sec, 24 μ / μ sec
Maximum length of the slice scan.....	400 μ
Possible orientations of the slice scan.....	64
Measured photoelectron flux under normal operation conditions.....	1000 photoelectron/ μ sec
Expected resolution.....	2 μ

B. Peripherals:

-The film transport can operate with any film format. Initial operation has been with sprocketed 70 mm film from the SLAC 40" chamber.

Accuracy in positioning the film is $1/50''$ in several hundred feet. For moving the film less than 3 ft., the speed is 1 ft/sec. For motions greater than 3 ft. the speed is ramped up to 6 ft/sec. The operator on manual mode has control of the film transport through a single knob. The full range of speeds is available to the operator from $1/5''$ sec to 6 ft/sec.

-The reticle, used for pointing in the optical display, is driven by two stepping motors, either under operator control (through a trackball) or computer control. The following measurements are all referenced to the reticle plane. The minimum step is approximately 1.5 mils. Typical speeds are $1''/\text{sec}$. Two knobs change magnification at the reticle plane from .75 to 1.5 to optimize the pointing for different film formats.

-The measuring rotating mirror and the projection rotating mirror can be moved by either the operator or the computer. In a mockup test typical time for switching views was $1/5$ sec. When measuring the DC motors are deenergized and the mirror is held in place by a mechanical detente.

-Switching from a measuring to a projection mode is accomplished by changing the position of two mirrors and two shutters (see Figure 4). This can be done under operator or computer control. Switching time is approximately $1/2$ sec.

-The computer displays information to the operator on the T-4002 memory scope. The operator communicates through the T-4002 keyboard, a button board and a joystick used for pointing on the T-4002 screen.

4. The Polly Controller

The Polly Controller performs all the control functions for the measuring CRT and interfaces the hardware to the PDP-11. Control of the film transport, reticle, shutters, rotating mirrors is done by the Peripherals Controller which receives computer commands (via the Polly Controller) or operator commands directly. (See the block diagram in Figure 1.)

The Polly Controller builds the slice scan by directing the CRT to

perform a series of line scans. All the delays necessary for the settling of the CRT spot as a function of the displacement of the spot are determined by the Controller. The Controller receives the line by line information from the CRT and performs the averages of the line information thus relieving the computer from the routine chore of obtaining the slice scan parameters from the line scan information.

Two modes of communication between the Controller and the PDP-11 are used. The direct word mode, which requires CPU intervention, is used for giving the Controller the parameters of the slice scan to be performed, or any commands to the peripherals. It is also used for receiving the slice scan information from the controller or information from the peripherals (e.g. reticle position). The direct memory access mode is used by the Controller to stuff the line by line information directly into the PDP-11 memory without operator intervention. The Controller can interrupt the computer through 8 priority interrupts.

5. Task Assignments for the PDP-10 and the PDP-11

The computer configuration for our Polly system is a PDP-10 linked to a PDP-11. In detail:

A. The PDP-11 system consists of:

1. A PDP-11/20 CPU with 8 K words (16 bit) of memory;
2. Extended arithmetic element;
3. Controlling teletype which can be either an ASR-33 or the Tektronix T-4002;
4. 9 track magnetic tape unit.

B. The PDP-10 system is the CIT time-sharing computer which consists of:

1. 96 K X 36 bit words or core memory;
2. 3 disks drives;
3. 3 9-track magnetic tape units;
4. Card reader and live printer;
5. 2 dectape units.

The PDP-10 has 30 time-sharing teletype terminals all of which connect to a DC-10 which handles the scanning of the teletype lines for data in and out of the PDP-10.

C. Presently the PDP-11 links to the PDP-10 through the DC-10. That is, the PDP-11 looks to the PDP-10 like another time-sharing terminal. In turn the PDP-10 interfaces to the PDP-11 as would a teletype. Motivation for making this the first link was that it involved minimal hardware modifications. Moreover, we can take advantage of the DEC interactive software with no changes on the PDP-10. As an example we do program development for the PDP-11 by typing programs through the Tektronix terminal using the full editing features of the PDP-10 software. Source code can then be assembled on the PDP-10 and the binary code loaded from the PDP-10 into the PDP-11.

The speed of the link is presently 7 kilo bits per second. We soon will be increasing this rate by a factor of ten. Since we are presenting data to the PDP-10 at a higher rate than other teletype lines, the hardware on the DC-10 has been modified to give us a signal whenever our data has been strobed onto the PDP-10 I/O bus.

We plan to run Polly with the PDP-10 in the time-sharing mode. In order to avoid the overhead normally associated with time-sharing systems which do extensive program swapping, we will be running in a special mode. One feature of the special mode is that we will be locked into 32 K words of core without being swapped out. Additional required core will be subject to swapping. Another feature is that the PDP-10 monitor will give us every other time slice as well as the unused portion of other time slices.

For the first phase of Polly operation, virtually the entire Argonne Polly Fortran source code will exist on the PDP-10. The PDP-11 will do direct hardware controlling. Shortly after that we will bring the entire graphics part of the Polly programs into the PDP-11. After that we hope to expand the PDP-11 system and do rudimentary track-following using PDP-11 software. Thus we hope to eventually reduce as much as possible the communication between the PDP-11 and PDP-10.

Fig. 1 The Block Diagram of the Caltech POLLY

Fig. 2 Photograph of the Caltech POLLY. It shows the operator console in the foreground and the plates that constitute the machine proper in the background.

Fig. 3 Layout of the Caltech POLLY

Fig. 4 The Measuring and Projection Apparatus. Only one of the four measuring stations is shown.

Transient Analysis of Deflection and Photomultiplier Circuits

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ABSTRACT

The transient response of CRT flying spot scanners is discussed in two separate contexts. Deflection circuit settling time is related to external capacitive loading, leading to the design used in the CIT Polly, in which the deflection switches and current generators are physically separated. Signal-to-noise ratio in the photomultiplier is analyzed for the purpose of choosing the best time constant for filtering the signal. Results indicate that a smaller aperture, and hence less expensive, measuring lens can be used.

Two important properties of a Polly system are speed of operation and precision of measurement. A fundamental contributing factor to measuring speed is the time required for the CRT deflection circuits to reach equilibrium after spot deflection has occurred. This in turn is related to the external capacity which loads the deflection coil. To minimize delays due to this capacity, special effort was made in the CIT Polly to design the deflection switches so that they minimally load the coil. The precision of measurement, on the other hand, is influenced in part by the method of processing the signal from the photomultiplier. In particular, it is the speed of the discriminator that is important, so the two topics of this paper are both concerned with the appropriate time response of the circuits involved.

Figure 1 shows the push-pull deflection coil and its equivalent circuit. All of the quantitative statements made from this point on apply to the CTF coil. There is a considerable amount of flux linkage between the two halves of the coil, as evidenced by the high value of the coupling coefficient k . As a consequence, the coil forms a transformer with unity turns ratio. The inverting box on the right of the equivalent circuit is added so that the relative polarity of voltages at points A and B will be correct. The following circuit diagrams will ignore this box, so to apply the results of subsequent analysis to the physical coil, it will be necessary to invert the relative polarity of any voltages at the "virtual" coil terminals.

Now consider the effect of loading the coil with capacity. The equivalent circuit, shown in Figure 2, has two normal modes of oscillation. The vertical arrows indicate the relative polarities at the ends of the coil and the curved arrows show the directions of current flow. Each mode has a symmetry which makes the circuit equivalent to the simpler circuit shown to the right. In push-pull operation, the voltages at the coil terminals will be out of phase, which, because of the inverting box in Figure 1, means that the low frequency mode will be preferentially excited.

The probable sources of parasitic capacity contributing to C are shown in Figure 3. Since the two modes of the coil can be excited separately, it is possible to measure C_{ex} , C_{ic} , C_{iw} independently. This is because the capacity C_{iw} will not charge if the voltage at the ends of the coil are in phase, so the high frequency period will depend only on C_{ic} and C_{ex} . We can then measure the period under three separate conditions: no external capacity, coil connected as in iii - this forces high frequency oscillation and allows a determination of $C_{ic} = C_{iii}$; no external capacity, coil connected as in ii - this allows low frequency oscillation and gives us $C_{ic} + C_{iw} = C_{ii}$; external capacity added (the current switches), coil connected as in i - this gives $C_{ic} + C_{iw} + C_{ex} = C_{iv}$. A fourth configuration, shown in i, gives a value of capacity intermediate between C_{ic} and $C_{ic} + C_{iw}$, since in this case, C_{iw} will charge but not fully. The important number to be measured here is C_{iv} which is the total value of C across the coil.

To see how the settling time depends on C , we should first look at the equivalent circuit with damping resistors. This circuit is shown in Figure 4 along with the low frequency equivalent which will be more convenient to use. The response of this circuit to a current step and a current ramp is shown in Figure 5. The bump and delay in the ramp response will cause difficulties on the line scan. An inspection of the Laplace transform of this response shows that it is the sum of three terms. The first term is just the desired linear response. The second and third terms are the responses to a step and a delta function. To restore the correct ramp, therefore, we can add a step and a delta function to the driving current. The line scan generator on the CIT Polly has been designed to generate such a waveform.

We should now make a quantitative inspection of the step response. This is shown in Figure 6. As the field approaches its asymptotic value, an exponential change in the field, which is probably due to eddy currents in the coil structure, takes over from the pole response. (The eddy current data in Figure 6 was measured by the coil manufacturer.) The two curves should be added in quadrature to give the total error. Minimizing settling time is equivalent to minimizing the width of the pole response, which in turn is equivalent to minimizing C . For the value of C which we have been able to achieve (650 pf) the settling time is dominated by the eddy current response for unsaturated switching greater than 100μ . We can now relate the actual deflection distance to the settling time by choosing an upper limit for the spot position error, and computing the fractional error that is allowed for a given deflection.

The smooth curve in Figure 7 shows the necessary delay for displacements less than 400μ , with an allowable error of 2μ . The hardware approximation is generated by digital circuits which are programmed with the deflection length. The straight line on Figure 8 takes into account the long linear buildup of current when the deflection switches saturate. The curved line is the necessary delay beyond the end of the current buildup.

In summary, minimization of capacitive loading on the deflection coil has reduced delay times to the point where they are limited by an

inherent exponential property of the coil itself. This exponential or eddy current falloff is approximately a two percent effect, and becomes important for displacements greater than 100μ . To keep the capacity low, the current switches were mounted as close as possible to the deflection coil. This necessitated a separation between the current switches and the current generators since there was not enough room in the CRT module to house a large amount of equipment. The precision currents are supplied to the switches via coaxial cables thirty feet long.

The second topic of this paper is the time response of the photomultiplier processing circuit. We can see how this response affects measuring precision by looking at the following model. The sketch in Figure 9 shows a photomultiplier signal which is typical of that obtained when the spot crosses a partially opaque edge on the film. The average intensity of the phototube signal when the spot is unobstructed is I , and the fractional decrease in light level is D . W is the "effective" spot width, and δ is the uncertainty in spatially locating the edge. The light signal will have noise on it, and we can call the amplitude of this noise ϵ . The noise comes primarily from graininess of the phosphor and from the statistical nature of the photon flux. We can then write equation 1, which is a simple but probably accurate relationship between ϵ and δ . Define an integration time τ , which is the "memory" time of the processing system, and let the spot velocity on film be v . Screen persistence time can be conveniently taken into account by adding it in quadrature to the time constant of the phototube electronics to obtain an effective τ . The value of W then depends on the actual spot diameter d , and on the apparent broadening of the spot due to the memory time τ . This relationship is given in equation 2.

We can now develop expressions for ϵ for the two different types of noise. Since the photon flux obeys Poisson statistics, the ratio of signal to noise is just the square root of the number of photons arriving in time τ (equation 3). The phosphor noise will depend on the RMS variation in light output from the phosphor, and also on the number of times the spot diameter fits into the distance $v\tau$. The net value of ϵ from this source is then given by equation 4. From the two expressions for ϵ we can then find two expressions for δ which can be added in

quadrature to give the final result, equation 5.

Two important results can be extracted from equation 5. The first is that δ has a minimum for $\tau = d/v$, and increases as the square root of τ for large τ . This means that excessive filtering of the signal to remove noise will only degrade the performance of the system. In addition to the τ dependence, there is also an important dependence on the light intensity I . In fact, we can set τ equal to its optimal value, choose a value for δ , and compute the light level needed to achieve this error. This value of I , together with the intensity of light leaving the CRT, allows a computation of the net transmittance required of the optical system, which in turn, forces a lower limit on the aperture of the measuring lens. It is convenient to measure the light intensity by giving the number of photoelectrons per microsecond leaving the photocathode of the tube, since it is this number that is measured directly. Thus, the quantum efficiency of the cathode need not enter the calculation, although a high efficiency will be important in using existing light to best advantage.

A calculation of expected light levels for the Litton CRT used in the CTT Polly was performed, and the results were consistent with the measured values given below. There are four light flux values that are important in this discussion. They are: f_1 , the calculated flux needed to keep δ below a certain value; f_2 , the measured flux leaving the CRT; f_3 , the measured flux at the normal phototube position; f_4 , the value taken by f_3 when film is in the platen. Clearly, f_4 should be at least as large as f_1 . The measured values of these fluxes are given below in Table 1 for the parameter values shown.

$\delta = 2\mu$	$v = 12\mu/\mu\text{sec}$	$d = 15\mu$
$D = 0.5$	$\tau = d/v$	
$\Omega = \text{solid angle of lens} = 3 \text{ milliradians}$		
optical system transmittance = 15%		
film transmittance = 5%		
$f_1 =$	300 pe/ μsec	
$f_2 =$	18,700 pe/ $\mu\text{sec}/\mu\text{amp/ms}$	
$f_3 =$	8,400 pe/ $\mu\text{sec}/\mu\text{amp}$	
$f_4 =$	420 pe/ $\mu\text{sec}/\mu\text{amp}$	

Table 1. Measured CRT light fluxes.

The value of Ω was actually chosen from the above considerations, and is equivalent to an f:6 lens. The use of such a small lens leads to a considerable economy over the f:3 lens that we originally expected to use.

To check the validity of the above theory, a simple experiment was performed. The photomultiplier was exposed to a fast, pulsed light source (a light emitting diode). The phototube signal thus approximated the signal for an edge crossing shown in Figure 9. The time between the beginning of the light pulse and a point half way down the trailing edge of the phototube signal was measured with an interval timer that was accurate to 0.1 μ sec. Several hundred measurements were taken and histogrammed for each of four values of electronic rise time in the phototube circuit. The histograms are shown in Figure 10, and their RMS widths are plotted in Figure 11. The square root of τ dependence is quite visible.

ACKNOWLEDGEMENT

I would like to thank Professor Alvin Tollestrup for proposing the theoretical models used in this analysis.

Fig. 1 Equivalent Circuit of Coil

Fig. 2 Normal Modes of Coil

Fig. 3 Parasitic Capacity

Fig. 4 Low Frequency Equivalent Circuit with Damping Resistors

Fig. 5 Coil Response to Step and Ramp

Fig. 6 Error in Magnetic Field for a current step switched into coil.

Fig. 7 Delay time between lines of slice scan

Fig. 8 Delay time between slice scans

$$\frac{\delta}{W} = \frac{\epsilon}{DI} \quad (1) \quad W^2 = d^2 + (v\tau)^2 \quad (2)$$

$$\frac{\epsilon_{\text{photon}}}{DI} = \frac{1}{\sqrt{DI\tau}} \quad (3) \quad \frac{\epsilon_{\text{screen}}}{DI} = \sqrt{\frac{d}{v\tau}} \left(\frac{\Delta V}{V} \right) \quad (4)$$

$$\left\{ \begin{array}{l} \text{-----} \\ \text{---} v\tau \text{---} \end{array} \right. n = \frac{vI}{d} \Rightarrow \frac{\epsilon}{DI} = \frac{1}{\sqrt{n}} \left(\frac{\Delta V}{V} \right)$$

n MUST BE ≥ 1 . $\left(\frac{\Delta V}{V} \right) \cong 6\%$ AND IS CHARACTERISTIC OF THE SCREEN

$$\delta^2 = d^2 \left[1 + \left(\frac{v\tau}{d} \right)^2 \right] \left[\frac{1}{DI\tau} + \frac{d}{v\tau} \left(\frac{\Delta V}{V} \right)^2 \right] \quad (5)$$

$I = \text{PHOTONS/SEC}$

Fig. 9 Noise considerations in Photomultiplier circuit.

Fig. 10 Simulated edge profiles as a function of filter time constant.

Fig. 11 Plot of RMS widths of edge profiles, showing dependence.

Progress report on the University of Michigan
CRT measuring equipment

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ABSTRACT

Progress on the construction of a CRT scanner patterned after the ANL POLLY III and the University of Illinois DOLLY is discussed. The connection of the scanner to the Honeywell model 124 computer is presented along with two features of the system that are specific to the Michigan scanner.

INTRODUCTION

In describing the U of M scanner, I can in many respects simply make reference to the work of ANL and the University of Illinois. We have constructed a copy of the ANL POLLY III as far as the mechanical and electromechanical systems are concerned. The optical stage, mirrors, lenses, film transports, and operators console are of ANL design. In general, the external appearance is that of an ANL POLLY III. The electronics are patterned after the Illinois scheme, i.e., the slice is digitally generated with adders. It can, as a result, be any sweep speed desired. The precision DAC we are building is of Illinois design with the modification that we plan to step the 16 bit register directly and no 12 bit register exists. If high order carries cause inductive ringing in the coils, we will probably suppress such carries by duplicating the highest bit into which a carry can be tolerated. Direct stepping of the one register has the advantages of simplicity and unlimited slice width. The specific circuitry to accomplish the digital slice, hit detection and computer control of the scanner are of local design with generous copying of too many sources to remember or acknowledge.

GENERAL FEATURES

Fig. 1 shows a block schematic of the U of M scanner

computer arrangement. The computer which is connected directly to the scanner is a Honeywell 124 with 8K of 24 bit memory, a card reader, disk, tape transport, and a typewriter. The machine has 8 levels of priority interrupts, 3 index registers, a direct memory channel, and can be expanded to 32K directly addressed core. The 124 is connected to the 65K PDP-10 which serves as the HEP computing facility. The scanner is shown in its various connections to the 124 via the I/O bus and the memory channel. The film movement, view selection, track ball communication, button board I/O, and scan parameters are all transferred along the programmed I/O bus. The digital controller will perform a single line generation with the computer providing the base point calculation. The base points for the lines are also transferred over the I/O bus to the line generator which accepts one advance load. A single word input transfer can be initiated through the I/O bus at the conclusion of the line generation if the sum of the hit transition addresses and hit count for that line are desired. These quantities are necessary for a calculation of the least square straight line fit to the hits. As is shown in Fig. 1, the remaining communication between the 124 and scanner is through the memory channel. The IDI display scope is driven through the memory channel for its refresh. The hit transitions are transferred into the computer by the channel if that option is selected. An automatic histogram of the hit transitions for a series of lines is performed as the scan lines progress and may be read upon selection via the memory channel. The reading of the histogram clears the histogram memory for the following accumulation. The histogram can be binned in 1, 2, 4, or 8 least count groups.

We are assembling a hit detection unit similar to the schematic of Fig. 2. (Fig. 2 is actually a simplified version which works for bright field film only.) The circuit accepts a 6-bit background level, a 6-bit threshold, and a 4-bit follow rate from the computer. Six-bit DACs convert the background and threshold signals to analog levels which are summed and compared to the filtered PM signal to determine the hit-no hit condition. If the no hit condition exists, the 6-bit background counter-register is stepped in the appropriate direction so as to follow the PM signal. If a hit is sensed, no background updating occurs. The rate at which update pulses are generated relative to the slice line clock is controlled by the four bit rate number sent from the computer. Rates from one update per clock to one update per 16 clocks are provided.

THE SCHEDULE

As of January, 1972, we have essentially all of the machine shop work done and all of the assembly except the optical stage and CRT. All of the electronic design is completed. The construction and testing is approximately

2/3 done. At the current rate we will have all components powered up within three months. Modification of the ANL programs to utilize the 124 as a controller only will begin soon, with summer 1972 as a target date for our first attempts to measure events. If we can be measuring events in a production way by January 1973, I personally will be satisfied. The earlier the better, of course.

FIG. 1 - CRT SCANNER CONNECTION TO COMPUTERS

FIG. 2 - SIMPLIFIED BACKGROUND FOLLOWER

Lens Resolution versus Field
as applied to the Polly Program

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ABSTRACT

Three topics are touched upon. MTF from spot size is the first topic. Resolution versus field size charts are presented for those interested in tradeoffs. Specific film formats are discussed with respect to lens magnifications for the POLLY III programs.

INTRODUCTION

This paper has arisen as a result of some questions, two general and one specific. The first question is how can the requirement for spot size be converted into a MTF requirement? The second question: how much loss or gain can be expected if the format size is changed? The third question: will the POLLY III be able to scan films larger than 75mm with different lens systems.

MTF - SPOT SIZE

The following is a direct way to find the required MTF of a lens when object and image intensity distributions are Gaussian with given half width:

Given, $O(x) = A_o e^{-x^2/\sigma_o^2}$ perfect image intensity distribution

and $I(x) = A_i e^{-x^2/\sigma_i^2}$ actual image intensity distribution

The Fourier transforms are:

$$G_o(y) = \int_{-\infty}^{\infty} O(x) e^{-ixy} dx \quad (1)$$

$$G_i(y) = \int_{-\infty}^{\infty} I(x) e^{-ixy} dx \quad (2)$$

Then:

$$MTF(y) = \frac{G_o(y)}{G_i(y)} \quad (3)$$

where $y = 2\pi f$ and $f = \text{cycles/unit length}$, and A_o and A_i are chosen such that

$$G_o(0) = G_i(0) = MTF(0) = 1 \quad (4)$$

To find $G_o(y)$:

$$G_o(y) = A_o \int_{-\infty}^{\infty} e^{-x^2/\sigma_o^2} e^{-ixy} dx \quad (5)$$

$$= A_o e^{-\sigma_o^2 y^2/4} \int_{-\infty}^{\infty} e^{-\left(\frac{x^2}{\sigma_o^2} + ixy - \frac{\sigma_o^2 y^2}{4}\right)} dx \quad (6)$$

$$= A_o e^{-\frac{\sigma_o^2 y^2}{4}} \int_{-\infty}^{\infty} e^{-\left(\frac{x^2}{\sigma_o^2} + i\frac{\sigma_o y}{2}x\right)} dx \quad (7)$$

$$= A_o e^{-\frac{\sigma_o^2 y^2}{4}} \int_{-\infty + i\frac{\sigma_o y}{2}}^{\infty + i\frac{\sigma_o y}{2}} e^{-u^2} du \quad \text{where } u = \frac{x}{\sigma_o} + i\frac{\sigma_o y}{2} \quad (8)$$

$$\text{Consider } I = \oint_{\Gamma} e^{-z^2} dz \quad \text{where } \Gamma \text{ is a rectangle} \quad (9)$$

$$\text{whose vertices are } \pm R, \pm R + ib, R, b \text{ real.} \quad (10)$$

Since e^{-z^2} is regular within α on Γ , $I = 0$.

$$\text{Thus } \int_{-R}^R e^{-z^2} dz - \int_{-R+ib}^{R+ib} e^{-z^2} dz + \int_0^b e^{-(R+iy)^2} idy - \int_0^b e^{-(R-iy)^2} idy \quad (11)$$

$$= 0.$$

The last integrals vanish and become

$$\lim_{R \rightarrow \infty} \left| \int_0^b e^{-(R \pm iy)^2} idy \right| \leq \lim_{R \rightarrow \infty} \int_0^b |e^{-(R \pm iy)^2}| dy \quad (12)$$

$$\leq \lim_{R \rightarrow \infty} \int_0^b e^{-R^2 + y^2} dy \quad (13)$$

$$< \lim_{R \rightarrow \infty} b/e^{-R^2 + b^2} = 0$$

Thus,

$$\text{so, } G_o(y) = A_o e^{-\sigma_o^2 y^2/4} \sigma_o \int_{-\infty}^{\infty} e^{-u^2} du \quad (14)$$

$$= A_o e^{-\sigma_o^2 y^2/4} \sigma_o \sqrt{\pi} \quad (15)$$

$$G_o(y) = e^{-\sigma_o^2 y^2/4} \quad (16)$$

where $A_o = 1/\sigma_o \sqrt{\pi}$ is chosen

$$\text{Similarly, } G_i(y) = e^{-\sigma_i^2 y^2 / 4} \quad (18)$$

$$\therefore \text{MTF}(y) = e^{-(\sigma_i^2 - \sigma_o^2) y^2 / 4} \quad (19)$$

$$\text{MTF}(f) = e^{-(\sigma_i^2 - \sigma_o^2) \pi^2 f^2} \quad (20)$$

If σ_i and σ_o are given in mm, f is in cycles/mm or lp/mm .

In addition the aberrated spot radius can be expressed as:

$$\sigma_i = \left((\ln \text{MTF}(f)) / \pi^2 f^2 + \sigma_o^2 \right)^{1/2} \quad (20)$$

For example the 2X scanner lens, (Optek 1093) has a resolution requirement of 60% MTF at 60 cycles/mm. Using (20) above, $\sigma_o = 3.125$ microns, σ_i gives a scanning spot diameter of 9.83 microns.

Admittedly this technique has shortcomings. It is based on a axially centered symmetric system and neglects diffraction effects. In the region of 20 to 80 cycles/mm when the aberrational correction is more than $1/2$ wavelength the prediction is quite good and tends to be conservative. More comments can be found at the end of the paper.

RESOLUTION vs FIELD SIZE

The following discussion may be helpful to those who either contemplate a change in POLLY III or are planning similar programs. One of the more difficult questions to answer for the optical designer is what happens to resolution when field size is changed. The following diagram, Fig. 1, gives image diameter versus resolution for many specialty and commercially available lenses. The lenses plotted are as shown in Fig. 2. These are lenses which: are all basically finite conjugates, of several different magnifications, focal lengths and even different spectral corrections. Many of the lenses have different apertures. With the exception of those near the origin most apertures are in approximately the $f/2.0$ to $f/4.0$ range. The lenses are used in many different applications, CRT scanning, CRT recording, camera lenses and relay lenses.

Despite the many differences of the lenses, they do have certain things in common. The lenses are all considered high quality and as represented here the resolution is plotted at approximately the 50% MTF point.

Of particular interest is to note the general slope of the line when plotted through the steepest angle which connects most of the points. Those lenses which are to the right of the line could be considered of inferior quality. Those lenses on or to the left of the line are the best obtainable.

Fig. 1 Image Diameter versus Resolution

FIG. 2
LENS PROPERTIES

<u>No.</u>	<u>Mfg.</u>	<u>Designation</u>	<u>Focal Length in mm</u>	<u>Reduction</u>	<u>Min. Cycles</u>	<u>Line Pair Width (microns)</u>	<u>Image Diameter (mm)</u>
1	Optek	1132	256	1.73x	10	(100)	365.0
2	Optek	1077	217	1x	30	(33)	179.6
3	Optek	1038	245	2x	40	(25)	114.3
4	Optek	1109	267	1x	60	(17)	107.95
5	Optek	1170	227	2x	60	(17)	95.25
6	Optek	1093	197	2x	60	(17)	76.2
7	Optek	1055	117	1x	200	(5)	63.5
8	Optek	1036	178	4x	60	(17)	57.15
9	Wray	Spec MIC	127	10x	45.6	(22)	53.88
10	Optek	1185	93	3x	120	(8.3)	38.1
11	Nikon	U.MIC. NIK	105	30x	114	(12)	27.71
12	Zeiss	Spec. S-Planar	-	10x	164	(6.1)	26.94
13	Baush & Lomb	Super - Bal	50	60x	140	(7)	21.55
14	Optek	1127	80	5.6x	200	(5)	19.05
15	Optek	1102	26	10x	500	(2)	8.00
16	Nikon	U.MIC. NIK	28	10x	394	(2.5)	5.03
17	Zeiss	Planapochromate		20x	492	(2.0)	2.69
18	Zeiss	Planapochromate		25x	820	(1.2)	.718

This study is by no means to be taken as the final word and it should be used merely as a guideline. It is after all merely empirical data which is plotted and interpreted. It is interesting that there may appear to be a relationship when so many of the inputs are of a different nature.

POLLY III LENS TRADEOFFS

The more specific question regarding POLLY III lens changes for various films can now be discussed. The present system of course has a 152.4mm CRT and a 76.2mm scanning plane, i.e. 2.0X reduction. This is apparently suitable for ANL 56.7 cm a NAL 11.81 cm chambers. The NAL 70.86 cm, Gargamelle and mirabelle require a 1.5X reduction lens the BEBC requires a 1.35X reduction lenses. These assume the same 15.24 cm CRT is used and gives scanning diameters of 10.16 cm and 11.29 cm, respectively.

It has been noted, however, that the CRT could be rotated 45° and the lenses reduced two (2) reduction ratios 2.0X and 1.5X.

There are, of course, more considerations to be taken into account. Assuming the signal to noise of the present system is adequate the additional lenses will have a smaller numerical aperture than the existing system. The aperture of the present system is $f/3.0$ or N.A. of 0.166. The N.A. at the film plane is 0.111 but at the CRT plane is 0.0555. Since it is this N.A. that determines the collection angle of light of the CRT, then all other reduction ratios should have the same input collection cone. The corresponding image cones for 1.5X and 1.35X are N.A. of 0.0833 and N.A. of 0.0750. The corresponding apertures at infinity then are $f/3.6$ and $f/3.82$.

The ideal situation would be to merely change lenses to cover a larger scanning field, in the same overall dimensions and with the same overall performance. This, however, is not so easy to do in practice. First of all two out of these variables; overall object to image length, object distance, or image distance; must be changed to achieve a magnification change. Holding the CRT to objective lens distance to a constant of 43.38 cm results in an EFL change from 19.70 cm to 25.4 cm for a redesigned 1.5X lens. This changes also results in an overall object to image change from 81.28 cm to 90.16 cm or an extension of approximately 8.88 cm. For the 1.35X lens the EFL changes to 28.26 cm when maintaining the 43.38 cm CRT to lens distance. One of the factors which allows the position of the lens to be shifted with respect to its thin lens placement is the position of the nodes with respect to the glass surface giving rise to the so called "telephoto" affect. The final placement of the nodes, however, cannot be easily moved, since it is the optimization which determines their final placement. The above represents the best compromise between nodal point positioning and aberrational correction.

The term "same degree of correction is desired" needs to be amplified on the basis of this context. The present system provides approximately 60% MTF at 60 cycles/mm, at 2.0X reduction. (The diffraction limit at this aperture is about 84% MTF at 60 cycles/mm.) Changing to 1.5X and the image N.A. from .166 to .111 the corresponding 84% MTF theoretic limit is found at 45 cycles/mm. Hence to achieve the same results 60% at 45 cycles/mm is required. Even at 60 cycles/mm the theoretic MTF is 81% and hence might be achievable.

The 1.35X lens would have a corresponding 60% MTF at 40.5 cycles/mm to have the same degree of correction in the film scanning plane. The real question is does the term "same degree of correction" refer to the lens criterion or the fact that the same information density over a larger film format is desired to be scanned? Presumably the geometric considerations are greater.

It is noteworthy to expand the previous chart about the point of interest. As we might expect as the image diameter varies from 76.2mm (for the 2X), to 101.6mm (for the 1.5X), to the 112.89mm the resolution does in fact decrease as expected.

The calculation of spot size based on equation (20) gives:

<u>Magnification</u>	<u>Scanning Diameter</u>	<u>Spot Diameter</u>
2X	6.2mm	9.82 microns
1.5X	101.6mm	13.10 microns
1.35X	112.89mm	14.56 microns

which all assumes a CRT diameter of 152.4mm and a spot diameter of 12.5 microns, and the 60% MTF criterion at 60, 45, and 40 cycles/mm.

The image resolution also correlates rather well with the theory that the image spread function is the convolution between the object function and the lens point spread function. No matter how good the lens is, it cannot counter the geometric spreading.

CONCLUSION

For the POLLY III scanner, larger film areas can be scanned if the degradation in resolution can be tolerated and the mechanical accommodation can be made.

The art of lens design is becoming more of a science. As the various techniques are cataloged, software is improved, new materials and manufacturing techniques evolved, new and better systems will come into being. As the complexity of the system escalates so also the price increases. The

future will be in making wider bandpass lens systems over larger fields. That is, the line showing image area versus resolution will be improved.

ADDITIONAL COMMENTS

Subsequent to the presentation of the paper additional comments were made as follows.

The first comment has to do with the relationship between scanning spot size and scanning system resolution. It should in fact be obvious that the spot size determines the system resolution. This can be visualized by thinking of the spot as a kind of slit. When the information to be scanned is smaller than the slit, indeterminacy of position results, i.e. the signal does not change all the while the information is being scanned except for the leading and trailing edge of the spot. In another extreme there would never be a signal if the scanning spot were infinitely wide.

Another comment has to do with the geometric relationship $MTF = \exp - (\sigma_i^2 - \sigma_o^2) \pi^2 f^2$ as can be seen when the aberrated spot is perfect, i.e. same size as the geometric spot, the MTF is 100% for all frequencies. It is obvious that there should be another factor in the equation describing the diffraction part of the aberrations.

$$\text{Hence the total OTF } (f) = (MTF(f))(DF(f))$$

where

$$DF(f) = 2/\pi (\text{Arccos } (f/2b) - f/2b (1-f/2b)^2)^{\frac{1}{2}}$$

where $b = \lambda a/R$, λ = wavelength, a = radius of aperture, R = focal length of lens. However, as previously mentioned in the region of 20 to 80 cycles/mm the $MTF(f)$, expression (20), is a good model for rapid calculation.

List of Attendees

INFORMAL COLLOQUIUM ON POLLY and POLLY-LIKE DEVICES

Name	Affiliation
Alyea, E. D., Jr.	Indiana University
Ammann, A. C.	Purdue University
Beck, F.	Argonne National Laboratory
Blin, M. J.	Institut de Physique Nucleaire
Bogert, V. D.	National Accelerator Laboratory
Brown, R. M.	University of Illinois, Urbana
Burnstein, R. A.	University of Maryland
Canter, J. M.	Tufts University
Chapman, J.	The University of Michigan
Charlton, G. R.	Argonne National Laboratory
Chrisman, B. L.	National Accelerator Laboratory
Connolly, P. L.	Brookhaven National Laboratory
Deery, B. J.	University of Toronto
Deutschmann, M.	Technische Hochschule Aachen
Downing, R.	University of Illinois, Urbana
Dzierba, A. R.	California Institute of Technology
Ellis, C. R.	Indiana University
Engelmann, R.	Argonne National Laboratory
Equer, B.	College de France
Fong, D.	Brown University
Glasser, R. G.	Argonne National Laboratory
Goldberg, J.	Israel Institute of Technology
Guignard, C. F.	LPNHE
Hanft, R. W.	National Accelerator Laboratory
Haxby, R.	Iowa State University
Higby, W. J.	Iowa State University
Hodges, D.	Argonne National Laboratory
Hough, P. V. C.	Brookhaven National Laboratory
Jacobsohn, D. H.	Argonne National Laboratory
Johnson, G. C.	National Accelerator Laboratory
Kikuchi, T.	Carnegie Mellon University
Kosner, C.	Argonne National Laboratory
Kroupa, B., Jr.	Argonne National Laboratory
Lemonne, J. L.	University of Brussels
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McNeal, D.	SEACO Computer Company
Marema, R.	Argonne National Laboratory
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Oren, Y.	Argonne National Laboratory

Name	Affiliation
Palfrey, T. R., Jr.	Purdue University
Peeters, P.	Argonne National Laboratory
Pevsner, A.	The Johns Hopkins University
Phillips, B.	Argonne National Laboratory
Phillips, J. S.	University of Toronto
Power, J.	California Institute of Technology
Rangan, K.	Purdue University
Shapiro, A. M.	Brown University
Shelman, C. B.	Argonne National Laboratory
Slater, W. E.	University of California
Steele, D.	SEACO Computer Display
Stern, M. A.	Argonne National Laboratory
Sunde, R. A.	Argonne National Laboratory
Tenner, A. G.	University of Amsterdam
Tezzuto, A.	Photo Digitizing System
Thomas, W.	Iowa State University
Timm, R. E.	Argonne National Laboratory
Troyer, J.	Argonne National Laboratory
Walz, H. V.	Stanford Linear Accelerator Center
Wehman, R. H.	Argonne National Laboratory
Wolsky, G.	Tufts University
Wray, J. J.	University of Illinois, Urbana
Zahn, C. T., Jr.	Stanford Linear Accelerator Center
Zander, D. R.	University of Illinois, Urbana
Zivkovic, D.	University of Birmingham, England