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The Track-segment Generator*

R.C. Strand

Brookhaven National Laboratory

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Introduction

In this paper we will describe the generation of track segments by use of a rotating comb histogram technique.

First we will review our understanding of the track recognition problem in road guided systems, and explain why we decided to use a track segment generator. Then we will outline our track segment generator. We will go over the steps leading to the definition of a pulse or track segment candidate. This section will conclude with a discussion of the pulse quality tests. Then we will mention the more significant strategies employed for the roads, the slices, and the pulses. We will conclude with some observations on the performance of our track segment generator.

I. Track Recognition and Track Segments

First we will review some high precision geometrical properties of bubble chamber track images. We want to evaluate the best use of road guidance to solve the track recognition problem.

Precision measurement of some track images reveals irregular curves. We mean that they are not well approximated by smooth curves at the micron level of precision. As a class, the lower momentum tracks often show kinks due to multiple scattering.

A further property of track images is non-circularity. Tracks that are not circles, show up with "S" amplitudes in their "roads" as illustrated in Figure 1. The roads are provided by the three

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rough digitized points per track. Data within plus or minus 200 microns of the road circle are transformed into road coordinates by subtraction of the lower road edge from each point. The "S" amplitude to first order is proportional to the sagitta of the track image. Noncircularity is caused by the slowing down of particles and by the dip angle of particles. Due to these properties of tracks it is not easily possible to use the full precision of the individual digitizings to solve the pattern recognition problem for the track as a whole in one step.* We mean that at least a four parameter search is required in general to "find" the smooth tracks to full precision. In the case of pronounced multiple scattering the integral search does not apply to full precision.

However, track images are precisely approximated by simple functions over shorter portion of their length. This suggests that full digital precision can bear on the recognition of partial segments of the whole track. The recognition of whole tracks by association of their segments must face the problems of track irregularities, and competing noise. (This will be discussed in the next paper of this series.)

Digital track segment recognition is aided by road guidance because precision segments of the road curvature are longer than straight segments can be in film coordinates. Longer segments have a better signal to noise ratio in the presence of crossing tracks. Track segments must be as accurate as possible so as not to confuse the later recognition of whole tracks. The track segments must not alter the accuracy of the digitizings by including points that do not belong to the track, or more importantly by omitting points that belong to the track as, for example, in the case of a track with many kinks due to multiple scattering.

Failure to use the full precision of the digitizings weakens the pattern recognition reliability and efficiency. Stated another way one expects to impose a mask upon the data to its full precision.

*This method is known as the integral method.

Anything less than full precision results in the loss of information.

Looking ahead to the solution of the segment linking program, we feel that all "segments" in the road must be found in order to bring maximum information to bear upon the more complex roads.

II. Outline of the Track Segment Generator

The search for segments occurs in road coordinates. The road is divided into a number of slices in which the signal is expected to be well approximated by a straight line. The recognition becomes a two parameter search for the slope and the intercept of the track segment, this is called the rotating comb histogram method. When the correct slope is found the track points are all close to the line. They are recorded for geometric reconstruction. The line parameters are recorded for the linking of segments into tracks. Also, bubble density data are recorded.

Road coordinates, X , DW , are obtained from film coordinates as illustrated in Figure 1. The function $R(X)$ is the lower road edge defined by displacing the road circle down in W by one-half the road width. The road has been divided into five slices. The slice length is the maximum length over which the track segments are linear. Our current slice length is about 2mm on the film.

The x -coordinate origin is shifted to the middle of the slice as shown in Figure 2. The rotating comb will be defined next. A series of angles for the track segment are tried up to $\theta_{\max}$ the maximum angle as shown. The first angle is parallel to the road edge, the second is rotated one angle step from the road edge in a clockwise sense; the third is rotated one angle step from the road edge in a counter clockwise sense. The fourth is two angle steps from the road edge in a clockwise sense etc. The angle step is defined in terms of the track's digital width. The change, $D\theta$, is taken as the track width divided by the slice length; this is

about one-third of a degree for our tracks.

The angle search is carried out by computing, I , the DW intercept of each slice point if it were on a line of slope, $\tan\theta$, as shown in Figure 2.

The intercepts are collected in a histogram whose bin width is about one-half of the digitized track width as shown in Figure 3. The histogram bins appear as parallel lines on the slice plot. Four histogram bins are examined together in search for the pulse. An example of the four bin-pulse is shown in Figure 3. In other words, the basic histogram pulse we seek is about two tracks wide.

The quality of each pulse is evaluated as follows. We require the track segment to be separated from neighboring signal by about a track width. It must be narrower than the known width of real segments and it must be within in $3/2 \times D\theta$ (about one-half degree) of the current search angle.

If the pulse passes these tests its points are coalesced by averaging them in small groups for geometry. The pulse position and slope are recorded for the segment linking program. Bubble density data are collected for the segment. This consists of the total number of acceptable hits, misses and gaps for the segment. A gap is composed of one or more consecutive misses.

The track segment generator routine has the three-loop summary flow chart shown in Figure 4.

III. More Details about Track Segment Generator Strategy

1. Road Strategies

Next we will discuss the special strategies that have been introduced and applied to the road contents as a whole.

We planned to use all of the digitizings found on the track. The track segment generator averages the individual pulse points so as to produce at least twenty resultant average points for the track assuming that 75 percent of the slices contain a good segment.

We permit 5 to 10 slices for a road so long as the number of road points is consistent with our minimum pulse threshold. This algorithm tends to make the slices as long as is possible for our mix of tracks. We found that the standard two millimeter slice was too short for the longer high momentum tracks and too long for the shorter low momentum proton tracks that show multiple scattering kinks.

We use the known beam track curvature to "re-gate"* the road points so that the track is straight over its entire length. This enables us to obtain more accurate extrapolated end points in order to select the correct beam track from two or three candidates by using a vertex matching procedure.

Because the Track Segment Generator frequently picked up points from competing tracks at the vertex, all secondary track roads are terminated ten scan line separations from their vertex.

We ignore slices that contain fewer than 5 points. If a slice contains fewer points than our pulse threshold we set the threshold to 80% of the slice points. This enables us to take geometry points into the region where the track image has faded.

The 20-inch chamber bubble images are oblong. The long axis of the bubble images is parallel to the x-axis for all of the bubbles. For this reason, the tracks which make larger angles

*The DW coordinate of each point is recomputed from a road circle through the first and last rough digitized points with the known beam track radius of curvature.

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with the x-axis present a "stair case" structure to the flying spot. Consequently the w-coordinate setting error is a function of the angle between the track and the local direction of the track. The expected setting error is computed for each slice to be used as an upper limit for the track segment rms deviation from a straight line. Also, the calculated setting error is accumulated and averaged for the road as a whole. The Harwell geometry program has been modified to accept one setting error for each view of a track.

2. Slice Strategies

We found it very useful to vary the histogram bin size according to the expected track width which is a function of the track angle. This enables us to define the segment in terms of its natural width for slices at all angles.

3. Pulse Strategies

The pulse strategies are most numerous. The pulse threshold requires one hit per four scans. We next require that the pulse be narrow enough so there is a valley on both sides that contain no more than about one-tenth of the number of points in the pulse. The valley is about one track width wide. Since we search for a pulse that is two tracks wide, on the average we can detect segments that are separated by $1\frac{1}{2}$ track widths.

The valley requirements accomplish two related tasks. First, they prevent us from fabricating track segments out of random noise. Secondly, they quickly line up the comb at the correct angle. We decided not to employ the technique of looking for a maximum signal as the comb swept through the correct angle. Coding for this method seemed somewhat complicated. We do require that the comb be aligned with the least square line for the pulse points.

A least square fit is made for the pulse. The DW-rms must be

less than the expected track rms for a track at this angle. The least square slope must be within $3/2$ of one comb angle step from the slope of the comb. This is about one-half of a degree.

The distance of each slice point from the least square line is computed. Final points for geometry are gathered according to their distance from the line being less than threshold. This threshold is the larger of three times the DW-rms or two times the external track rms at this slice angle. Groups of pulse points are averaged and recorded for geometry. An individual group may have from 0 to the order of 10 points.

Bubble density data, hit, miss and gap totals, are collected from points that lie further from the least square line. In this case the gather threshold is the larger of four times the DW-rms or three times the external track rms. Bubble density data accumulation occurs so long as the points lie within the bubble density boundary and so long as no gap is greater than 6 scan line separations long.

When a pulse has been accepted as a valid track segment its points are removed from the slice. If too few points remain to form another pulse, an exit to the next slice takes place. This obvious strategy saves running time.

A more detailed flow chart of the Track Segment Generator is shown in Figure 5. This chart is designed to appeal to those who speak FORTRAN. The corresponding FORTRAN statements of the Track Segment Generator dispatcher fall exactly in this sequence.

IV. Performance of the Track Segment Generator

1. Track Segment Generator Running Time

The most obvious objection to the use of a rotating comb histogram is its potentially long running time. However, most often the track segments are found on the first step when the comb is

parallel to the road edge. This is illustrated in Figure 6, which is a histogram of the number of tangent steps required per slice for eighty three slices. About 80% of the slices take only the one comb angle.

2. Track Segment Generator Efficiency

The track segment generator misses some information because the location of the slice boundaries may be out of phase with noise. A case of this occurs in the slice plot of Figure 7. In the slice plots the x-axis points down and the DW-axis points to the right. The x least count is one scan line separation. The DW least count is about 4.2 microns. No track candidate was found in the slice plot of Figure 7. However eight points near the top of the Figure clearly form part of a track segment. In this case we have lost some useful information.

3. A Case History

Last of all we will go through the slice plots from a seven slice road whose secondary track falls within one degree of the beam tracks and is crossed by many beam tracks.

The first slice appears in Figure 8 where one track segment was found. The set of points belonging to the segment are plotted as the character, S. Two dots mark the points where the least square line intersects the slice ends. An arrow at the bottom of the Figure points at the position of a track segment in the next slice. The first slice is at the end of the track which is away from the vertex. In this area of the photograph the track image is faded. No bubble density data was collected for this slice because it lies outside of the bubble density boundary.

A track segment generator error occurs in the second slice shown is Figure 9. Bubble density data is now being collected as indicated by the point plotted as the letter "B". This point is only used for bubble density purposes. The track segment generator first found the correct track segment under the arrow at the top of the Figure. However this candidate was found to be too broad so it

was rejected. At a higher comb angle the program fabricated an incorrect track segment from most of the real track points and one noise point. The wrong point is about thirty microns from the center of the track whereas the natural spread allows points out to about sixteen microns. Bubble density data would not be seriously effected because the gaps introduced are mostly greater than the six scan line separation cut off.

Slice three contains two segments which are correctly found in Figures 10 and 11. Notice in Figure 11 that the points from the first segment are removed before the rotating comb continues its search.

Slice four contains two segments that are found in Figures 12 and 13. Located in slice four are two tracks that we might expect to merge in slice five, although the program does not use information from pervious slices. Properly, no segment is found in slice five as shown in Figure 14. The signal was rejected because it is too broad. The width of the signal in this case is partly due to the resolution of our Mark I FSD which is able to resolve two bubbles that are separated by about thirty microns in the w coordinate. This resolution is better demonstrated if at least one dark track is involved in the merge.

After the merge there are again two segments in the next slice. Two segments are found in slice six as shown in Figures 15 and 16.

The last slice, number seven, is honestly the perfect typical slice.

The best way to evaluate track segment generator performance is to feed its output to LINKUP and DIAG of the Brookhaven FILTER Program. The next two papers will explain how to find track segment mistakes.

Figure Captions

1. Film coordinate (X,W) system road coordinate (X,DW) system.
2. Slice coordinate (X,DW) system.
3. Definition of a track segment histogram pulse in the slice coordinate system.
4. Summary flow chart for the track segment generator subroutine.
5. More detailed track segment generator subroutine flow chart.
6. Histogram of the integral number of tangent steps taken per slice for a sample of 83 slices.
7. No track segment was found in this slice although eight useful digitizings appear at the top of this slice plot.
8. Slice one, segment one.
9. Slice two, segment one with one point about 30 microns off the track.
10. Slice three, segment one.
11. Slice three, segment two.
12. Slice four, segment one.
13. Slice four, segment two.
14. Slice five.
15. Slice six, segment one.
16. Slice six, segment two.
17. Slice seven, segment one.

Figure 1

Figure 2

Figure 3

Figure 4

TRACK SEGMENT GENERATOR FLOW CHART

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

Figure 11

Figure 12

Figure 13

Figure 14

Figure 15

Figure 16

Figure 17