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Automatic TLI Recognition System Beta Prototype Testing

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**Automatic TLI Recognition System
Beta Prototype Testing**

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ABSTRACT

This report describes the beta prototype automatic target recognition system ATR3, and some performance tests done with this system. This is a fully operational system, with a high computational speed. It is useful for finding any kind of target in digitized image data, and as a general purpose image analysis tool.

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Automatic TLI Recognition System

Beta Prototype Testing

INTRODUCTION

The purpose of this project is to develop both the hardware and the software for an Automatic Treaty-Limited Item Recognition system, or an automatic target recognition (ATR) system. We have tested and compared three different hardware systems¹, all with the same software, and we have selected the system ATR3 as being generally preferred. This report describes the beta prototype system ATR3 (with software version 14) and some test and evaluation results.

FUNCTIONAL DESCRIPTION

This ATR system is a computer designed to find targets in digitized image data, in a very general sense. We present the ATR system with one or several images of a scene, and the ATR system tells us whether there is a target in the scene and, if there are any, where each target is. The following paragraphs describe some of the features of this ATR system:

Targets

The targets could be traditional military targets, such as airplanes or trucks. In this ATR system, the word "target" has a broader meaning: a target is anything that is potentially recognizable in the image data. A target could be, for example, a physical object, like an airplane or a golf ball or a river; a structure such as a crack in a surface or a hot spot detected by an imaging heat sensor; an area of chemical contamination on the ground; a particular combination of types of vegetation growing in an area; a certain type of terrain, such as gently rolling hills; or any other pattern that is distinguishable in the image data.

Images

By "image" data, we mean an array of digital data values versus position in two dimensions. A standard digitized video picture, with brightness versus x and y coordinates, is such an image. Instead of brightness, the image data for this ATR system could be any quantity such as temperature, ground surface elevation, ultrasonic reflectivity, eddy current readings, radar range readings, Raman scattering intensity at a particular wavelength, optical emissivity, mechanical strain, etc. The only requirement is that the data be in the form of a two-dimensional array of values.

Image Data Fusion

This ATR system is designed to produce one result ("target" or "no target") from the simultaneous analysis of several images comprising different types of data, such as radar reflectivity, infrared emission, and surface altitude, all versus x and y position, all for the same scene. That is, this ATR system uses *image data fusion*. The presumption is that a target can be recognized much more reliably if we have several different types of image data instead of just

one type. However, this ATR system is still fully functional with as few as one image per scene.

Uncertainty Estimation

No one expects that any ATR system will be perfect at recognizing targets. This ATR system tells us about its own imperfections and limitations for any application, by giving an *uncertainty* estimate. That is, this ATR system tells us how well it can do at recognizing the specified type of target in the given type of data. In some applications, the given data is simply not adequate to distinguish between the specified targets and background. This ATR system's uncertainty estimate is actually a prediction of the rate of errors in target recognition, a prediction of the fraction of pixels that this ATR system will incorrectly call "target" or "background". The uncertainty is very strongly dependent on the specific application, and it is estimated separately for each application.

Error Minimization

An ATR system can make two types of errors: incorrectly calling a background region a target, or incorrectly calling a target background. The rate of either type of error can be made as small as we would like, if we are willing to tolerate a very large rate for the other type of error. In practice, we choose a coefficient indicating the relative importance of the two types of error. Normally, we say that it is much more important to not miss any targets than to not have any false indications of targets. This approach can make this ATR system a very effective screening tool: it can be used to discard scenes that definitely do not include targets, and to flag for expert human inspection those scenes that might possibly contain a target. Such an approach can greatly reduce the amount of human labor involved in searching for targets, without any significant risk of missing targets.

Training Process

This ATR system uses a training process. For training, an operator gives the ATR system a set of data in which the operator has marked some regions of some scenes as targets and some other regions as background (that is, definitely not targets). Some regions of the training scenes may be left un-marked, and these regions are ignored by the training process. The training data set should be similar in character to the surveillance data that will be analyzed later, having both similar targets and similar background regions. Normally, better results are expected if the training data set is large, including many scenes with many (tens or hundreds) targets and many background regions marked by the operator.

This training process defines what a target is, by giving the ATR system examples of targets. It also gives the uncertainty estimate for this application. It also tells us the relative importance of each of the different types of image data given to the ATR system, so that we have the option of simplifying the overall process by not bothering with unimportant measurements (if there are any). Most importantly, the training processes gives values of coefficients to be used for *optimal* processing of surveillance data.

Surveillance Data Processing

After the training process is finished, this ATR system is used in a production mode, in which it simply looks at the image data for a scene and tells us whether there is a target in that scene. Using this mode to process surveillance data is very simple, requiring only that the operator tell the program the names of the computer files containing the image data. There are

several options for displaying the ATR system's results to the operator, including one as simple as printing "YES" or "NO" on the computer display, and another in which the scene is displayed with color coding to show the locations of targets.

Ease of Use

In the production mode, for processing surveillance data, this ATR system is very easy to use, requiring only very basic knowledge of how to operate a personal computer.

In the training process, certain expertise is required. A skilled operator must give the ATR system a list of local features to be extracted from the images and used in recognizing targets. These features might be such things as a measurement magnitude, smoothness of a measurement versus position, the presence of a step change in a measurement versus position, and a multitude of other local structures in the measurement versus position maps. The ATR system will select the important features from the operator-supplied list, and in effect ignore the unimportant features, so it does not matter if the operator specifies superfluous features. However, the ATR system cannot invent its own features, so the operator must supply a feature list that includes enough features to distinguish between target and background. This can require some understanding of the nature of the targets and of the measurement systems. Note, however, that the operator only has to supply the ATR system with a sufficient set of features, a set of tools that will enable target-background discrimination. The operator does not necessarily have to understand how these tools will be used, or exactly how a target will be recognized, or even which tools will be important. This allows the ATR system to effectively implement target recognition procedures that are very complicated, much too complicated to be used in practice by even expert data analysts.

Size of Data Sets

This ATR system analyzes one scene at a time, so there is no practical limit on the number of scenes that can be processed. The number of images per scene, and the number of pixels (sample points or measurement points) per image, are limited only by the memory in the parallel processor nodes, which is 80 megabytes in ATR3. In the event that this memory is inadequate for a particular application, this ATR system can analyze each scene in parts, effectively dividing each scene into several smaller scenes, and thereby circumvent any memory limitations.

System Hardware

The unique aspect of this ATR hardware is the use of small, low-cost parallel processors to give a lot of computing speed in a small, cheap package. It is easy to add more processors to this type of system and thereby increase the speed, for most operations, proportionately. The parallel processors for this beta prototype system ATR3 are Alta Technology AL/V66 processors, and the host computer is a DEC 2000 AXP. This system hardware is described in more detail later in this report.

System Software

This ATR system does use such basic, standard software as the operating system normally supplied with the host computer and a host-network interface normally supplied with the parallel processor network. Other than this, all the software was developed by the Idaho National Engineering Laboratory for the Department of Energy, so it has no licensing restrictions. The

source code can easily be modified to include additional functions or non-standard image manipulations. The software is discussed in more detail in a later section of this report.

Other Uses

As with any automatic target recognition system, this ATR software includes a lot of general-purpose image analysis capability, and the system can easily be used for image manipulations other than target searches.

The presence of the ATR-related hardware and software does not prevent the host computer from being used for any other normal application, such as running other data analysis programs, word processing, spread sheets, etc. Other software and hardware (within the normal limits) can be used freely on this ATR system computer.

Summary

We have developed an Automatic Target Recognition system designed for rapid screening of large amounts of multi-image data. This system is versatile and broadly applicable, and capable of implementing very subtle and complicated target recognition procedures. It incorporates optimal image data fusion and uncertainty estimation. It is reasonably low cost, fast, and not subject to license restrictions. The software is easily expandable to incorporate new capabilities, and the hardware is easily expandable to increase the speed.

HARDWARE DESCRIPTION

The ATR3 hardware comprises two major parts: the host computer, and a daisy chain of five parallel processor nodes. The bulk of the computation is done by the parallel processors, and the calculation speed of the system can easily be increased by simply adding more nodes to the chain. Adding more nodes also increases the total memory of the system, since each node has its own memory; the nodes do not share memory. This arrangement allows the user to easily tailor the ATR hardware system to suit his own calculation speed requirements and budget constraints.

The host computer is the interface between the parallel processor network and the peripheral devices including the operator's console and any data storage and display devices. The ATR3 host computer is a DEC 2000 Model 300 AXP. A VT510 monochrome monitor and keyboard, connected to a serial port, are used as the operator's console. The high-resolution RGB monitor, with the ATR software in its normal mode, is used solely for displaying the images being processed. When the ATR software is being debugged with TCP/IP support, the RGB monitor is used with the second keyboard and the mouse to manipulate and observe the parallel processor nodes.

Each ATR3 parallel processor node is an Alta Technology AL/V66 which includes a DEC Alpha 21066 processor and 16 Mbyte of memory. Each node also includes a T425 transputer to facilitate inter-node communication and control operations such as booting the network, but the transputer's operation is transparent and the user does not need to explicitly address it. The nodes can communicate via the standard four 20 Mbit/second (about 1.8 Mbyte/second in one direction) transputer links, or T-links, and also via four 250 Mbit/second (at least 17 Mbyte/second) A-links. The parallel processor nodes can be accessed using the TCP/IP model, in which case each node's T-links 2 and 3, and one host T-link, are used by the system and are not available explicitly to the user; the other T-links and the A-links are available at the user's

discretion. This TCP/IP access is very useful for debugging the software that runs on the parallel processor nodes, as it allows each node to be monitored in a separate window of the user's display. The parallel processor network can also be used, more simply and efficiently, without TCP/IP support, in which case all the links are at the user's disposal. The parallel processor nodes are mounted in a VME chassis, separate from the host. The ATR3 vendor recommends leaving one or two vacant slots between nodes in the VME chassis.

For historical reasons, three of the five nodes in this particular system have a clock speed of 166 MHz, and two run at 233 MHz. The current version of the ATR software cannot allocate computation tasks to the nodes differently depending on their different speeds. Therefore, the system speeds that are discussed later are determined by the speed of the 166 MHz nodes. A system using all 233 MHz nodes would presumably be proportionately faster.

Figure 1 indicates schematically the ATR3 hardware system. The present system does not include A-link connectors on the host; these will be supplied later by the vendor, as specified by the original purchase agreement. The details of the inter-node connections are indicated in Figure 2. The node T2 and T3 connections are used for TCP/IP support. The ATR software uses either T0 and T1 or A0 and A1 for inter-node communication. (T-links cannot be connected to A-links.) The UP and DOWN connections are always required for system operation. It would be possible to use several links in parallel; for example, we could connect the A2 and A3 links just as the A0 and A1 links are connected, and thereby double the potential inter-node data transfer rate. However, this would substantially complicate the inter-node communication part of the ATR software, and the overall ATR software is such that it could not significantly benefit from the additional parallel links.

Figure 1: ATR3 nodes.

Figure 2: ATR3 inter-node connections.
The HOST A-links are not yet installed.

Figure 3: ATR3 host configuration.

SOFTWARE DESCRIPTION

The host computer operating system software is OSF/1. The ATR software is written in standard C augmented with a small library of functions to allow inter-node communication. The software is designed to allow easy addition of new image manipulation functions as the need arises.

There are three programs, called E, F, and G. The three programs have many functions in common, but they also have some differences associated with the different operations they perform. Appendix A lists the functions currently included in the ATR software.

Surveillance Program E

The surveillance program E is the production program, used in the field to analyze a set of one or more images of a scene and report on whether there is a target present in the scene. Program E uses a set of three control files: a .sl file, which specifies the names of the files that hold the image data to be analyzed; a .fc file, which includes a sequence of image manipulation instructions that is a recipe for determining whether a target is present in the scene; and, a .cmd file, which contains primarily just the names of the .sl and .fc files. Program E is used very simply, by typing "em" and then, when asked, the name of the .cmd file to be used for this application. Thus, using program E is trivial after the three control files are ready. Preparation of these files is not trivial; it will be discussed in more detail in a separate report. For the present, we note that the .fc file may use the values of coefficients determined by program F.

Training Program F

The training processes is implemented in program F. The training process is optional. In some applications, the analyst may know by other means how to manipulate the image data to find targets, and he can build this procedure into the program E .fc file without ever using program F.

The training process in program F is used when the target/no target decision is expressed as a linear combination of the raw images or any other images that may be derived from the raw images. Program F gives the optimal values of the coefficients in the linear combination. This is a surprisingly versatile process. Even though the optimized combination is linear, the overall target detection process is not restricted to linear combinations of the raw images, since any of the images in the linear combination can be constructed by any arbitrary non-linear process from the raw images.

In addition to the optimal coefficient values, program F gives a predicted error rate for target detection based on the present training data. Program F also indicates the importance of each of the images in the linear combination, so that the analyst can simplify the target detection process by eliminating the unimportant parts.

Program F uses training data, in the form of sets of images in which the analyst has marked some areas as targets and other areas as background. This marking of training scenes is done using program G.

Mask Creation Program G

For each training scene, a skilled operator must create a mask that indicates which parts of the scene are targets, which parts are background, and which parts are not designated as either target or background regions. Program G is a tool to help the operator do this task. G creates a mask, an "image" that contains the operator's target/background designations, and makes the mask available for program F to use along with the raw training scene images in the optimization process.

Unlike program E and program F, program G does not take its instructions from control files; program G takes instructions from the keyboard. Program G includes all of the image manipulation functions that are in program E and program F (but not the coefficient optimization procedure used in the training process), so program G can be used as an interactive version of the software, which some users might find convenient for experimentation when developing a target recognition process.

SYSTEM TESTS

The three programs E, F, and G have been verified as being functional on the ATR3 hardware. They are generally faster, and is some small ways slightly easier to use, than they are on the other two hardware systems we have tested.

An important aspect of this ATR systems is its speed, primarily the speed of the parallel processor network. We have done direct measurements of speeds for certain typical image analysis operations, and we have done comparisons with two other ATR systems using essentially the same software on different hardware systems (ATR1 and ATR2). ATR1 uses T805 transputers, and ATR2 uses T9000 gamma transputers. The results of the measurements reported here are in some cases different from similar measurements reported earlier¹, primarily because of improvements in the ATR3 system software and also because of changes in our own software. For these timing measurements, ATR3 was used with only 3 daisy nodes, to make it more directly comparable with ATR2. The times quoted here were measured with the echo turned off, using images with 512 columns by 480 rows of pixels. Some explanation of these times follows:

COMMAND, comments

ATR1 seconds

ATR2 seconds

ATR3 seconds

This is the format for the following entries. The command, capitalized, and a comment in italics are in the first line; the execution times for each of the three hardware systems, in seconds, are in the second line; discussion is in following lines. The $\pm$ values given with the times are not statistical uncertainties; they are absolute limits on the accuracy of the time measurements, imposed by the limited resolution of the accessible clock.

;remark, remark with leading semicolon

< 0.0001

< 0.0001

< 0.0001

This is the time required for the master to read a command from the feature calculation file and dispose of it without any attempt at command interpretation. The times listed here are for a remark of minimal length, ";" with no real remark text. These times are strongly affected

by the time required to read a line of ASCII characters from a disk file; the times will be greater for longer remarks.

REM, remark without echo

0.0003 ± 0.0001 0.0001 ± 0.0001 < 0.0001

This is the time required for the master to read a command from the feature calculation file and do minimal command interpretation. Command interpretation times are different for different commands and they are generally greater for greater numbers of parameters. The time will of course increase if the echo is turned on. The times listed here are for a remark of minimal length, "REM" with no real remark text.

SET_AB, set scale factors

0.0076 ± 0.0001 0.0031 ± 0.0001 0.0003 ± 0.0001

The master sets the values of two variables in a table in the master program, without interacting with the slaves.

CLEAR, clear memory, with no memory de-allocation

0.0019 ± 0.0001 0.0008 ± 0.0001 0.0017 ± 0.0001

The master writes values to a table in memory and sends a short message to all the slaves (daisy chain nodes), so this example includes minimal one-way master-to-slave communication. Each slave also writes a table in its own memory and, if images or kernels (operators) are defined, frees those memory blocks. No memory de-allocation was done in this test.

READY, wait until slaves are finished, with slaves not busy

0.0019 ± 0.0001 0.0004 ± 0.0001 0.0059 ± 0.0001

The master sends a short message to all the slaves. Each slave responds separately, and the master waits for all the slaves to respond. Thus, this command involves brief two-way communication between master and slave, with essentially no other operation.

For the three commands SET_AB, CLEAR, and READY, the ATR3 times are in the order expected when inter-node communication time dominates calculation time. For ATR1 and ATR2, the SET_AB command apparently requires more time to do less than the CLEAR and READY commands. This is believed to be because the SET_AB command requires a function call with three parameters, whereas the other two commands use function calls with no parameters. Times being dominated by calculation rather than communication would also account for the CLEAR time being greater than the READY time for ATR2.

DEFKERN, define a kernel (operator)

0.0132 ± 0.0001 0.0048 ± 0.0001 0.0100 ± 0.0001

This operation allocates memory for a local convolution type of kernel (operator), with the whole kernel being stored in each slave's memory. This operation does not set the values of the kernel. The master sends a short message to all the slaves, and writes a few values to a table in memory. Each slave writes a few values to memory, allocates a memory block, and sends a short message back to the master. If the kernel was already defined, the slave also de-allocates the old memory block; this de-allocation was done in this test.

DEFIMG, define an image, with no overlap rows

0.0114 ± 0.0001	0.0040 ± 0.0001	0.0098 ± 0.0001
-----------------	-----------------	-----------------

DEFIMG, define an image, with 10 overlap rows

0.0115 ± 0.0001	0.0040 ± 0.0001	0.0098 ± 0.0001
-----------------	-----------------	-----------------

This operation allocates memory for an image, with different parts of the image being stored in different slave's memories. This operation does not set any pixel values in memory. The master sends a short message to all the slaves and writes a few values to a table in memory. Each slave calculates which part of the image it should store in its own memory, allocates a memory block, and sends a short message to the master. If the image was already defined, as it was in this test, the slave also de-allocates the old memory block. Unlike an earlier version of this software, no significant difference in time is expected when the number of overlap rows is changed. This DEFIMG operation sends slightly shorter inter-node messages than the DEFKERN operation.

ZEROIMAGE, zero an image, with no overlap rows

0.0250 ± 0.0010	0.0580 ± 0.0010	0.0045 ± 0.0005
	calcs=1.44	calcs=18.52

ZEROIMAGE, zero an image, with 10 overlap rows

0.0350 ± 0.0010	0.0640 ± 0.0010	0.0045 ± 0.0005
-----------------	-----------------	-----------------

ADD, add two images

0.043 ± 0.001	0.124 ± 0.001	0.038 ± 0.001
	calcs=1.16	calcs=3.77

MUL, multiply two images

0.049 ± 0.001	0.117 ± 0.001	0.038 ± 0.001
	calcs=1.40	calcs=4.30

DIV, divide two images

0.239 ± 0.001	0.351 ± 0.001	0.066 ± 0.001
	calcs=2.27	calcs=12.07

SQRT, square root of an image

0.288 ± 0.001	0.286 ± 0.001	0.080 ± 0.001
	calcs=3.36	calcs=12.00

ABS, absolute value of an image

0.105 ± 0.001	0.159 ± 0.001	0.014 ± 0.001
	calcs=2.20	calcs=25.00

MAXCON, clip low end values of an image, if all pixels are clipped

0.055 ± 0.001	0.134 ± 0.001	0.014 ± 0.001
	calcs=1.37	calcs=13.10

MAXCON, clip low end values of an image, if no pixels are clipped

0.052 ± 0.001	0.119 ± 0.001	0.014 ± 0.001
	calcs=1.46	calcs=12.38

ADDCON, add a constant to an image

0.037 ± 0.001	0.096 ± 0.001	0.012 ± 0.001
	calcs=1.28	calcs=10.28

MULCON, multiply an image by a constant

0.042 ± 0.001	0.104 ± 0.001	0.012 ± 0.001
	calcs=1.34	calcs=11.67

DIVCON, divide an image by a constant

0.044 ± 0.001	0.120 ± 0.001	0.012 ± 0.001
	calcs=1.22	calcs=12.22

For each of these simple arithmetic image manipulation operations, the master sends a short message to all the slaves. Each slave does the indicated pixel-by-pixel operation for its part of the specified images. There is no inter-slave communication. The bulk of the time is for the actual image manipulation. These times should be inversely proportional to the number of slave nodes, except for the ZEROIMAGE operation with overlap rows.

CONVOLVE, correlate an image with a kernel (operator), for a 5x5 pixel kernel

1.56 ± 0.01	3.09 ± 0.01	0.30 ± 0.01
	calcs=1.68	calcs=17.33

The master sends a short message to all the slaves. Each slave does the correlation calculation directly (no Fourier transform) for its part of the image. This operation normally must be preceded by the OVERLAP operation to set the values of the pixels in the overlap rows. This time should be inversely proportional to the number of slave nodes and roughly proportional to the size of the kernel domain.

SSQ, local sum of squares, for 5x5 pixel kernel

1.97 ± 0.01	3.43 ± 0.01	0.37 ± 0.01
	calcs=1.91	calcs=17.75

The master sends a short message to all the slaves. Each slave calculates a weighted sum of squares of values of the pixels in the local region indicated by the domain of the specified kernel, with weights equal to the kernel values. This operation normally must be preceded by the OVERLAP operation to set the values of the pixels in the overlap rows. This time should be inversely proportional to the number of slave nodes and roughly proportional to the size of the kernel domain.

OVERLAP, set pixel values in overlap rows, for 2 overlap rows

0.0169 ± 0.0001	0.0076 ± 0.0001	0.0300 ± 0.0010
	comms=2.22	comms=0.56

OVERLAP, set pixel values in overlap rows, for 10 overlap rows

0.0604 ± 0.0001	0.0303 ± 0.0001	0.0800 ± 0.0010
	comms=1.99	comms=0.755

The master sends a short message to all the slaves. The slaves exchange the values of the pixels in the overlap rows; thus, there is a lot of inter-slave communication, with one long message in each direction for each overlap row. This time is expected to be roughly proportional to the number of overlap rows and independent of the number of slave nodes.

SMTHX, smooth in X direction, for 5 passes

0.720 ± 0.010	1.140 ± 0.010	0.105 ± 0.001
	calcs=2.11	calcs=22.86

The master does a short calculation and sends a short message to all the slaves. Each slave smooths its own part of the indicated image without communication with other slaves. The smoothing function is more Gaussian for more passes, with 5 passes being a good approximation to a real Gaussian and 1 pass having a sharp cusp in the smoothing function. The time is proportional to the number of passes and inversely proportional to the number of slave nodes.

SMTHY, smooth in Y direction, for 5 passes

1.87 ± 0.01	2.08 ± 0.01	9.10 ± 0.10
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This is like SMTHX, X direction smoothing, except that this Y direction smoothing requires significant inter-slave communication. Two short messages per image column per pass are sent by each slave. This time should be roughly inversely proportional to the number of slave nodes only if the calculation time dominates the communication time. The disproportionately long time required by ATR3 for this operation is believed to be due to communication overhead.

MEDIAN, two-dimensional median filter, for a 21-pixel window

11.7 ± 0.1	17.9 ± 0.1	1.8 ± 0.1
	calcs=2.18	calcs=21.67

The master sends a short message to all the slaves. Each slave does the calculation for its part of the image without inter-slave communication. This operation normally must be preceded by the OVERLAP operation to set the values of the pixels in the overlap rows. This time should be inversely proportional to the number of slave nodes.

UNDERSAMPLE, decimate (undersample) an image, for decimation by a factor of 2 in each direction with a pre-defined destination image

0.019 ± 0.001	0.114 ± 0.001	0.010 ± 0.001
	calcs=0.555	calcs=6.33

The master sends a short message to all the slaves. If the destination image is not already defined, this operation defines it; in this test, the destination image was already defined. This time should be inversely proportional to the number of slave nodes. For unknown reasons, ATR2 seems to have an anomalously low speed for this operation.

SCALE, scale an image

0.175 ± 0.001	0.354 ± 0.001	0.037 ± 0.001
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The master sends a short message to all the slaves. Each slave scans its part of the specified image for the maximum value, and then the slaves daisy-chain communicate the maximum value to the master. The master then sends a short message to all the slaves, and each slave multiplies its part of the image by a constant. Thus, there is some master-slave and inter-slave communication involved in this scaling operation. This time should be approximately inversely proportional to the number of slave nodes.

READIMAGE, read an image

1.50 ± 0.10	1.10 ± 0.10	1.00 ± 0.10
	comms=1.36	comms=1.5

WRITEIMAGE, write an image

2.40 ± 0.10	1.85 ± 0.05	1.25 ± 0.05
	comms=1.30	comms=1.92

These times are for the host system disk. Accessing the ATR1 SCSI disk takes a little longer. These times should be essentially independent of the number of slave nodes. They depend on external factors such as the disk speed, the bus speed, and perhaps the host operating system or other data transfer software.

QUADUV, fit every local region with a quadratic polynomial, for a 21-pixel kernel

108.0 ± 1.0	147.0 ± 1.0	41.0 ± 1.0
	calcs=2.45	calcs=8.78

This requires a substantial amount of calculation, including a 6-parameter least squares fit, for every pixel. This time should be inversely proportional to the number of slave nodes.

BRANCH, in a minimal loop

0.0218 ± 0.0002	0.0086 ± 0.0001	0.0012 ± 0.0001
-----------------	-----------------	-----------------

JUMP, in a minimal loop

0.0222 ± 0.0002	0.0088 ± 0.0001	0.0013 ± 0.0001
-----------------	-----------------	-----------------

The times for BRANCH and JUMP commands vary greatly, depending mainly on the length of the feature command file, particularly that part of the file before the command. The times will also depend on disk file access times or disk caching capabilities. These times are for unrealistically small feature command files. These times depend strongly on the speed of the host computer for command files of significant size.

In systems of this type, two different speeds are of interest: the speed of calculations within a node, and the speed of communication between nodes. Which is more important depends almost entirely on the particular application. Our experience suggests that calculation speed is generally more important in automatic target recognition. In the above timing measurements, some times are dominated by calculation time, and some by communication time.

For those timing measurements that are almost totally indicative of calculation time, a value is given for "calcs" for ATR2 and ATR3. This is the relative calculation speed per node, relative to ATR1. It is calculated by

$$\text{calcs} = \frac{(\text{ATR1 time}) * (\text{number of ATR1 nodes})}{(\text{ATR2 time}) * (\text{number of ATR2 nodes})}$$

for ATR2, with the obvious analog for ATR3. The values for this speed ratio vary significantly for different types of operations, because of the internal differences in the processors. There is a tendency toward a greater speed advantage for ATR2 and ATR3 for the more complicated calculations. We use as the representative calculation-intensive operation the two-dimensional median filter, MEDIAN. For this operation, ATR2 has a relative speed per node of 2.18, and ATR3 has a relative speed per node of 21.67. The important relative calculation speed per cost, which is simply the relative speed per node divided by the relative cost per node, is about 1.17 for ATR2 and 2.32 for ATR3.

This software package contains no operations that are purely communication. Even such operations as reading an image from a disk file involve a significant amount of calculation, in calculating array indexes and converting from 8-bit integers to 32-bit floating point values. Perhaps the best indication we have of relative communication speed is the OVERLAP operation, in which 512 floating point values (2048 bytes) per data transfer are exchanged between neighboring processors without type conversion and the only arithmetic is array index calculation. For this, like most inter-node communications, it is not reasonable to speak of speed per node, because the time of the overall operation usually does not depend significantly on the number of nodes. In the typical inter-node communication, there is in effect a parallelism with many pairs

of nodes communicating simultaneously, so that the overall time is essentially the time required for any one pair of nodes to communicate. Thus, we represent the relative communication speed by the ratio of the times:

$$\text{comms} = \frac{(\text{ATR1 time})}{(\text{ATR2 or ATR3 time})}$$

This relative communication speed, as measured for the OVERLAP operation for 10 overlap rows, is 1.99 for ATR2 and 0.755 for ATR3. The communication slowness of ATR3 is surprising, in light of the raw A-link speed of 250 Mbit/second compared with the ATR1 T-link speed of 20 Mbit/second. The ATR3 system has a substantial per-message system software overhead for inter-node communication. This is apparent in the very long time required for ATR3 to do the SMTHY operation, which involves many short messages exchanged between neighboring nodes. The ATR3 communication speed is much better for longer messages.

The final version of the parallel processor system software was not yet available when these timing measurements were done. We know that the final system software will allow streamlining certain parts of the ATR software, and we speculate that this will significantly increase the inter-node communication speed. No measurable change is expected in calculation speed.

CONCLUSIONS

The ATR3 hardware is complete except for the expected addition of A-links to the host. This addition will not adversely affect the system operation in any way; it may enhance the communication speed, but probably not significantly for the present ATR software. The existing hardware is fully operational, with no known defects.

We expect that the parallel processor system software will be enhanced by the addition of certain inter-node communication functions, which might significantly increase the communication speed of this ATR3 system.

The existing ATR3 system is fully operational. It is a computationally powerful system for target recognition and other image manipulation applications. The software is easily expandable; new functions can be incorporated into the existing framework with minimal difficulty. The hardware is also expandable, in that additional parallel processor nodes can be added to increase the speed and total memory of the system.

REFERENCE

1. J. K. Partin, G. D. Lassahn, and J. R. Davidson, *Automatic TLI Recognition System Hardware Implementations*, INEL-95/0501, October 1995.

APPENDIX A

E14, F14, and G14 COMMANDS

E14, F14, and G14 COMMANDS

CONTROL OF PROGRAM

REM, ECHO_ON, ECHO_OFF, ECHO, ECHOTIME, READY
LABEL, JUMP, BRANCH, IF, PAUSE, STOP, END
GOSUB, SUBDEF, RETURN

DEFINING IMAGES AND KERNELS (OPERATORS)

DEFIMG, DEFKERN, COPDEF, CLEAR, SET_AB
also READIMAGE, READSCENE, RESAMPLE, UNDERSAMPLE, NEWIMG

READING IMAGES AND KERNELS FROM FILES

READIMAGE, READSCENE, READKERNEL, BANDR, PHEAD; also INCFIL
INM, INS

BASIC IMAGE OPERATIONS

ZEROIMAGE, SETPIX, NTRP00, NTRP01, COPY, COPYEDGE, OVERLAP, RESAMPLE,
UNDERSAMPLE, INSERT, EXTRACT, REMAP, REGISTER

ARITHMETIC OPERATIONS ON IMAGES

MAX, MIN, MAXCON, MINCON, REPLO, REPHI, ADD, SUB, MUL, DIV, ADDCON,
SUBCON, MULCON, DIVCON, SQRT, ABS, TAN, ATAN, ATAN2, LOG, EXP: All the
images in these operations must be already defined, all the same size, and all distributed the same
way among the daisies. The images need not be different; dst can be the same as src or src2,
etc. const is a single floating point value. These operations do not use or set the values of
overlap rows.

CONVOLUTION and related operations

CONVOLVE, SSQ

GRADIENTS

GRADT, XGRAD, YGRAD, GRADCON; also XY2RT

FILTERING IMAGES

SMTHX, SMTHY, MEDIAN, MED1X, MED1Y, SMTHXS, SMTHYS

MISCELLANEOUS IMAGE OPERATIONS

LIN01, LIN02, XLIN01, NLIN01, EDJ02

MODMSK

QUADXY, QUADUV

SEGLAB

RIJCON, GRADCON

MOMUV

PEAK1, PLNK1, PMRG1, PACC1, PMOMXY1, PMOMUV1, PMOMXY, PMOMUV

XIMG, YIMG

GEOMETRIC CORRECTIONS

SBEND

DISPLAYING IMAGES

VGA, DISP, DISPRES; also **SCALE, CONTOUR**

IMAGE INFORMATION

STATS, SUMPIX, HIST2, PDFXYZ, PDFXY1; SET_AB, DEFIMG

FEATURE IMAGES

WRITEFEAT, FEATFIL, FEAT*; also **SCALE**

WRITING IMAGES TO FILES

WRITEIMAGE, WRITEFEAT, WRITERESULT; also **INCFIL, SCALE OUTM, OUTS**

SCALAR VARIABLES

PRINTS, SABS, SADD, SDEFF32, SDEFI32, SDIV, SEQ, SMAX, SMIN, SMUL, SSQRT, SSUB (formerly called **PRINTU, UABS, UADD, UDEFF32, UDEFI32, UDIV, UEQ, UMAX, UMIN, UMUL, USQRT, USUB**), **STAN, SATAN, SATAN2, SLOG, SEXP**

The user can define variables, either 32-bit integers or 32-bit floating, set their values, print their values, and use them as parameters in commands. Some scalar variables are pre-defined and their values are automatically set by certain operations. The pre-defined scalar variables are named **\$N, \$NCOL, \$NROW, \$SCENE, \$MINI, \$MAXI, \$MINJ, \$MAXJ** (integers), and **\$AVG, \$SIG, \$MAX, \$MIN, \$A, \$B, \$AVGX, \$AVGY, \$SIGX, \$SIGY, and \$COXY** (floating). The program DOES distinguish between upper and lower case characters in variable names. The arithmetic operations for scalar variables allow free mixing of integer and floating types.

STRING (FILE NAME) MANIPULATION

SEQ, SADD, INCFIL, PRINTS

The user can manipulate certain file names that are stored in the program. These are **\$FSIA[n]**, an array of scene image file names; **\$FFIA[n]**, an array of feature image file names; and **\$FRI**, the result image file name. The user cannot define his own file name or string variables.

The command names themselves are NOT case sensitive; the command names can be typed in upper case, lower case, or any mixture of cases. The user-accessible and user-defined variable names ARE case-sensitive. Command parameters may be separated by commas or spaces or both.

ABS dst, src
Set image **dst** = absolute value of image **src**.

ADD dst, src1, src2
Set image **dst** = image **src1** + image **src2**.

ADDCON dst, src, const
Set image **dst** = image **src** + **const**.

ATAN dst, src
Set each image **dst** pixel equal to the inverse tangent of the value of the corresponding image **src** pixel. Angles will be in radians, in the interval $(-\pi/2, \pi/2)$.

ATAN2 dst, srcy, srcx
The common inverse tangent function with two arguments, corresponding to the opposite and adjacent sides of a right triangle. Set each image **dst** pixel equal to the inverse tangent value (the angle), with the opposite side value from image **srcy** and the adjacent side value from image **srcx**. Angles will be in radians, in the interval $(-\pi, \pi]$.

BANDR nbands
BANDR band, img [, byt0 [, ncol [, bpp]]]
BANDR (no parameters)

This **BANDR** command is used to prepare for reading row-interleaved images from a file with the **READIMAGE -1** command.

In its first form, with only one parameter, the **BANDR** command sets the number of bands to **nbands**.

In its second form, with more than one parameter, **BANDR** sets parameters for band (or sub-image) number **band** (**band** = 1, 2, ... **nbands**), as follows. **img** is the number of the memory image to receive band **band**, or if the **img** value is zero, band **band** is not used. **byt0** is the number of bytes from the beginning of the image file composite row to the beginning of band **band**. **ncol** is the number of columns (pixels, not necessarily bytes) to be read for band **band**. **bpp** is the number of bytes per pixel (see the **READIMAGE** command) for band **band**. It is acceptable to skip bands of the file; however, all bands that are specified by this **BANDR** command should be in order of increasing **byt0**, the order in which they occur in the file. If the value -1 is given for **byt0** or **ncol**, or if the value 0 is given for **bpp**, for any band, the **READIMAGE -1** command will attempt to determine the correct values for these parameters from the file header. If values are not specified for the last 1, 2, or 3 parameters in this **BANDR** command, their values stored in the program are not changed. Initial values for all these parameters are 0.

With no parameters, the **BANDR** command prints the current values for all bands for which non-zero parameters have been specified.

BRANCH n
Jump to the .fc file line which is **n** lines removed from the line containing this **BRANCH** statement. **n** may be positive or negative. **n=0** is an error condition, since this would establish an infinite loop of repeatedly branching to the current line. Although **n=1** is not an error, a **BRANCH** command with **n=1** is superfluous. It causes a jump to the following line, which

would be the normal sequence even if the **BRANCH** statement were absent. (**BRANCH** does not exist in program G.)

CLEAR (no parameters)

Clear the tables that hold information about images, operators, and user-defined scalar variables, and free the memory allocated for these things.

CONTOUR *dst, src, sval, dval*

This operation draws one contour curve in destination image *dst*, representing a curve of constant intensity in source image *src*. If a pixel in *src* has intensity at least as great as the floating point value *sval*, and at least one of its four nearest neighbors has intensity less than *sval*, then the corresponding pixel in *dst* is set equal to the floating point value *dval*. Otherwise, *dst* pixel values are left unchanged. *src* should have at least 1 overlap row. *dst* does not need to be the same size as *src*.

CONVOLVE *dst, src, opr*

Set image *dst* equal to the convolution of image *src* with operator (kernel) *opr*. That is, set each *dst* pixel equal to the sum of $\{src * opr\}$, summed over the domain of the operator *opr* with the operator's "center" pixel positioned on the *src* pixel that corresponds to the *dst* pixel. The pixels of image *dst* in the excluded edge region, which is defined by the domain of the operator *opr*, are set to zero. *src* should have enough overlap rows to accommodate operator *opr*; the overlap rows must be present and have valid values. Correct values can be put into the overlap rows with the **OVERLAP** command. The number of overlap rows should be at least as large as the larger of the absolute value of *jmax* or the absolute value of *jmin* for operator *opr*. *opr* must be greater than 0. *dst* and *src* should be different images. The image *dst* does not need to be the same size as the image *src*, but the two images do need to be distributed among the daisies in a manner compatible with the **RESAMPLE** algorithms. If there is question about compatibility, it may be helpful to have extra overlap rows for image *src*.

Note that this is not strictly a proper convolution calculation, which would require reversing the signs of the two indexes in the operator.

COPDEF *dst, src [, novl]*

Define space for previously undefined image *dst* so that it is compatible with the previously defined image *src*. That is, the total sizes are the same for the two images, and their primary rows are distributed the same way among the several daisies, so that the two images are compatible for 2- or 3-image operations. The new image *dst* will have *novl* overlap rows regardless of how many overlap rows the old image *src* had. If a value is not given for *novl*, image *dst* will be created with the same number of overlap rows as image *src*. **COPDEF** does not set any pixel values. **COPDEF** sets *\$A* and *\$B* to 0.0 and 1.0 for *dst*.

COPY *dst, src*

Copy image *src* to image *dst*. Both images must be already defined and of the same size.

COPYEDGES *dst, src, opr*

Copy the values of the pixels at the edges of image *src* to the corresponding pixels of image *dst*. The edge pixels are specified by the domain of the operator *opr*. That is, if a

certain pixel of image **src** can be used as the center pixel of the operator **opr** without the domain of the operator **opr** extending off the image **src**, then that certain pixel is NOT an edge pixel and it will not be copied. This same definition of edge regions in terms of an operator is used in many of the operations described later in this report. **opr** should be greater than 0 for this operation, since it would not make sense to copy an edge region which contains no pixels. Images **dst** and **src** should be the same size.

DEFIMG img, ncol, nrow [, novl]

DEFIMG img

DEFIMG (no parameters)

The first form of **DEFIMG**, with 4 parameters, reserves memory in each daisy to hold part of image **img**. **novl** is the number of overlap rows. If no value is given for **novl**, the value 0 is used. The full image comprises **ncol** columns by **nrow** rows. If either **ncol** or **nrow** is 0, the image **img** is un-defined; its memory space is deallocated and any image data is lost.

You do not have control over which part of the image is held by which daisy. Two images of the same size may be distributed differently among the several daisies, if the two images do not have the same number of overlap rows or if they were created by different processes; such image pairs are not compatible for most multiple-image operations. If two (or more) images are defined by this **DEFIMG** command with the same values of all 3 parameters **ncol**, **nrow**, and **novl**, they will be compatible for two-image operations. See the **COPDEF** command.

DEFIMG does not set pixel values. **DEFIMG** sets the scale factors A and B for image **img** to 0.0 and 1.0.

The second form of **DEFIMG**, with only one parameter, sets the user-accessible variables **\$NCOL**, **\$NROW**, and **\$N** to the number of columns, number of rows, and number of overlap rows in image **img**. If the echo is on, these values are printed on the screen.

The third form of **DEFIMG**, with no parameters, lists on the screen the image number, number of rows, number of columns, and number of overlap rows for all defined images.

DEFKERN opr, imin, imax, jmin, jmax

DEFKERN opr

DEFKERN (no parameters)

The first form of **DEFKERN**, with 5 parameters, reserves memory in each daisy to hold all of the convolution operator (or kernel) **opr**. The parameters **imin**, **imax**, **jmin**, **jmax** define the domain of this operator, in the horizontal (positive to the right) and the vertical (positive downward) directions respectively, relative to the "center" pixel. The "center" pixel does not need to be in the center, or even in the two-dimensional domain specified by **imin**, **imax**, **jmin**, **jmax**. The "center" pixel is merely the pixel with operator domain coordinates **i=0** and **j=0**, which is often, but not necessarily, in the center of the domain. **opr** must be greater than 0. Operator 0 is always automatically defined with **imin**, **imax**, **jmin**, **jmax** all equal to zero; this is useful as a dummy operator with a one-pixel domain. Using operator 0 to specify an excluded edge region implies that none of the image is excluded.

The second form of **DEFKERN**, with only one parameter, sets the user-accessible variables **\$MINI**, **\$MAXI**, **\$MINJ**, and **\$MAXJ** equal to the corresponding values for operator **opr**. If the echo is on, these values are printed on the screen.

The third form of **DEFKERN**, with no parameters, lists on the screen all the defined kernels and their domain limits.

DISP caption, img [, row0 [, col0 [, Q]]]

Display image **img** on the high-resolution RGB monitor. The top left corner of the image will appear at **row0,col0** in the screen display. Red will be used for pixels with value less than **Q**, green for pixels with value greater than **Q**. If a value is not given for **Q**, the value 0.0 is used. If values are not given for **row0** and **col0**, values 0 and 0 are used. Pixel values should be between 0.0 and 255.0 (see **SCALE**). The character string **caption** will be printed below the image on the screen. **caption** should not contain any embedded spaces. If a "." is the first character of the string given as the caption, then the last-used file name will be used as the caption. If the echo is on, the image will remain on the screen, and the program will stop execution, until the operator hits a key on the keyboard. The ATR2 system uses the environment variable **QT9**. ATR3 uses the environment variable **DISPLAY**, and assumes that the window manager program **mwm** is running in the background.

DISPRES caption, img, row0, col0, Q, res

This is like **DISP**, except that the pixels are colored red or green according to whether the corresponding pixel in the image **res** (normally, but not necessarily, a result image) has a value less than **Q**. This allows an input image to be displayed with color coding based on a result image.

DIV dst, src1, src2

Set image **dst** = image **src1** / image **src2**.

DIVCON dst, src, const

Set image **dst** = image **src** / **const**.

ECHO (no parameters except a remark)

Echo this input line back to the screen if the echo is on.

ECHO_ON (no parameters)

Turn on the echo, so that commands are printed on the operator's screen as they are executed, along with certain related information including warnings of possible errors. The default condition is echo on.

ECHO_OFF (no parameters)

Turn off the echo.

ECHOTIME (no parameters except a remark)

Echo the time and this input line to the screen, regardless of the setting of the echo parameter. This is useful for timing studies and diagnostics.

EDJ02 bright, tangle, src, skr, opr, length, width, avg, g

Find edges. This **EDJ02** uses **XGRAD** followed by **LIN02** and **YGRAD** followed by **LIN02** to find sharp gradients in the image **src**. Image **bright** is set to the magnitude of the gradient, and image **tangle** is set to the tangent of the angle between the gradient direction and the x-axis. The **opr**, **length**, **width**, and **avg** parameters are used in **LIN02**. **g** is a gradient threshold; gradient amplitudes less than **g** are set to zero and ignored. **skr** is the number of an image than can be used for scratch space. It does not matter whether image **skr** is previously

defined; this operation will define, use, and destroy image **skr**. This EDJ02 operation requires one overlap row for image **src**. All four images should be different, all of the same size. bright pixels in the excluded edge region defined by the domain of **opr** are set to zero.

END (no parameters)

Indicate the end of the feature calculation script in the .fc file, and also stop the feature calculation process for the current scene. The **END** differs from the **STOP** command in that a **BRANCH** or **JUMP** or **GOSUB** command can cause the program to skip over a **STOP** command and execute later commands, but the program will never skip over an **END** command and will never read any of the .fc file after the first **END** command. Each script in a .fc file should contain at least one **STOP** or **END** command, and it might contain more than one **STOP** command. **END** should not be used as part of an **IF** command.

EXP dst, src

Set each image **dst** pixel equal to the exponential (inverse natural logarithm) of the corresponding image **src** pixel.

EXTRACT dst, src, row, col

Copy all of image **dst** from the region of image **src** with top left corner at row **row**, column **col**. If the requested region does not lie entirely within image **src**, part of the destination image **dst** is left unchanged. **dst** and **src** should be different images. This operation does set the overlap rows in **dst**.

FEATFIL [-1]

FOR PROGRAM F ONLY. Read a file name from the scene list file and enter that file name into the internal list of feature image file names, without actually reading or writing any image file. The "+" and "." file name constructs, used in the **READSCENE** command, also apply here. This command is useful in the **F** program when the feature images are the same size as the scene images, in which case the program can use the same file for both feature and scene masks and does not need to write a separate file for the feature mask. Note that the feature mask file name should always be the first name in the list of feature image names.

If the -1 parameter is given, the file name used by **FEATFIL** is not stored as the last-used scene file name. Thus, the next call to **READSCENE** or **FEATFIL** with a reference to the previous scene image file name ("+" or ".") does not use the file name referenced in this call to **FEATFIL** but uses the previously stored scene image file name.

FEAT* src1, src2

FOR PROGRAM F ONLY. The program **F** maintains an internal list of feature images that have been defined, and this list is used during the calculation of the sums in **F**. Feature images are defined by a **WRITEFEAT**, a **FEATFIL**, or a **FEAT*** command. They are automatically assigned sequence numbers as they are defined. The first feature image, number 0, must always be the mask. The first "real" feature image is number 1. This operation **FEAT*** puts a special code into the list of defined feature images. The code directs the sums calculation subroutine to use an additional feature image that is not actually stored in a file; this additional feature image is the product (pixel-by-pixel multiplication) of the two previously defined feature images numbered **src1** and **src2**. (**src1** and **src2** may be the same.) This allows the use of a feature image that is the product of two other feature images, without taking the time to write

and read a file for this image. This FEAT* command should not be used until both of the feature images `src1` and `src2` are defined.

GOSUB `subname` [, ...]

Execute the "subroutine" named `subname` that is in the `.fc` file. See the SUBDEF command. The GOSUB command must have as its first parameter the name of the subroutine to be executed. It should usually have additional parameters to match the parameters specified in the subroutine definition, in the SUBDEF command. This software does not check for matching parameter number or type. If the GOSUB command specifies more parameters than the SUBDEF command, the extra parameters are ignored. Depending on the nature of the subroutine, it may be acceptable for the GOSUB command to have fewer parameters than the SUBDEF command specifies.

If a subroutine parameter is a scalar (not an array), the value of the scalar in the GOSUB command is copied to the corresponding variable in the SUBDEF command. If the subroutine changes the value of its variable, that change is NOT made in the corresponding GOSUB parameter value (unless the GOSUB parameter and the SUBDEF parameter are the same variable). If a subroutine parameter is a whole array (not just one element of an array), the address of the GOSUB parameter array is copied to the corresponding SUBDEF parameter, so that both array variables are references to the same array of values in memory. Thus, if the subroutine changes the value of an element of an array parameter, that change is actually made in the GOSUB array element. To specify a whole array as a GOSUB parameter, give the name of the array with no index in brackets. That is, the parameter `XXX[3]` specifies one element (element number 3, the fourth element) of the array `XXX`, but the parameter `XXX` specifies the whole array `XXX`.

GRADCON `dstb`, `dsta`, `srcb`, `srca`

Concentrate (or sharpen) the peaks in a vector field, in the direction of the vector. This is intended to concentrate a gradient vector field, such as is obtained from operation GRADT or from the combination of XGRAD, YGRAD, and XY2RT. Image `srcb` contains the source vector magnitude, image `srca` contains the tangent of the angle between the vector and the x axis, and images `dstb` and `dsta` will contain the corresponding quantities for the concentrated vector field. GRADCON assumes that the single rows and columns of pixels at the edges of the source images are all zero, and it sets these edge pixels to zero in `dstb`. This operation uses one overlap row for each of the source images. All the images should be of the same size. The destination images need not be distinct from the source images or from each other. (It does not make sense for the two source images to be the same.) If the two destination images `dstb` and `dsta` are the same, the destination image will contain the concentrated vector magnitudes. This operation can be repeated to obtain more sharpening, but the OVERLAP operation should be done before each GRADCON operation. This operation is not perfect, but is quite good. There is sometimes some concentration in the wrong direction, which gets worse with repeated application of GRADCON.

GRADT `dstr`, `dstt`, `src`

Set image `dstr` equal to the magnitude of the gradient, and image `dstt` equal to the tangent of the angle between the gradient angle and the x (horizontal) axis, for the gradient of the intensity in image `src`. This operation uses one overlap row for `src`. The destination images need not be different. If the two destination images `dstr` and `dstt` are the same, the destination

image will contain the gradient magnitudes and the gradient direction values will not be written to any image. The top and bottom rows, and the left and right columns, of **dst** are set to zero. Both **dst** and **dstt** should be different from **src**, and all three images should be of the same size.

HIST2 src, xcl, nbin, vmin, vmax

Calculate the histogram of intensity values for image **src**. Operator **xcl** defines an excluded edge region; **xcl** may be 0. The histogram will have **nbin** bins representing the pixel values from **vmin** to **vmax**, plus two more bins, for value less than **vmin** (in bin 0) and for values greater than or equal to **vmax** (in bin **nbin**+1). This operation sets the user-accessible variables **\$N** = number of pixels in the histogram range, **\$AVG** = average value of those pixels, and **\$SIG** = standard deviation of those pixel values. These statistics are calculated from the histogram, not directly from the image.

IF v1, op, v2, command

Evaluate the logical statement **v1 op v2** and, if the statement is true, execute **command**. **v1** and **v2** are scalars, either constants or user-defined scalar variables. **op** is any of the 6 relational operators "**==**" (equals), "**!=**" (does not equal), "**<**" (is less than), "**>**" (is greater than), "**<=**" (is less than or equal to), and "**>=**" (is greater than or equal to). **command** may be any of the valid commands listed in this appendix, except **END**. The entire **IF** command, including **command**, must be on a single line in the **.fc** file.

INCFIL filename [, nleft [, nright]]

This command increments the file name **filename**. Only those characters in the base part (not the path or the extension) are incremented. Only the characters from the **nleft**'th through the **nright**'th before the extension (or before the end of the file name) are incremented. If **nleft** or **nright** is not supplied, the default values allow all the characters in the file name base to be incremented.

"Incrementing a file name" means that we treat the base file name, exclusive of the path and extension, as if it were a kind of string of digits representing a number, and we increase it by one. For example, if we do not give values for **nleft** or **nright**, **C:FILE15.IMG** increments to **C:FILE16.IMG**; **NAME29** to **NAME30**; **FILE9** to **FILE10**; **TESTA** to **TESTB**; **F7Z** to **F8A**; **XZZ** to **YAA**; **TT99** to **TU00**; etc. The path and extension are never changed. Alphabetic characters always increment to other alphabetic characters, and numerals to other numerals. For **nleft=2** and **nright=2**, **TT99** increments to **TT09**; for **nleft=3** and **nright=2**, **TT99** increments to **TU09**.

INM filename [, header [, ncols [, nrow [, row0 [, col0 [, bpp]]]]]]

FOR PROGRAM G ONLY. This command first invokes the **READIMAGE** operation for image 2, which is the mask image in the mask-generating process. If image 1 is not a compatible scene image, this command defines image 1 to be compatible with image 2 and sets all of its pixels to 0. Finally, this command invokes the **MARK** command.

INS filename [, header [, ncols [, nrow [, row0 [, col0 [, bpp]]]]]]

FOR PROGRAM G ONLY. This command first invokes the **READIMAGE** operation for image 1, which is the scene image in the mask-generating process. If image 2 is not a compatible mask image, this command defines image 2 to be compatible with image 1 and sets all of its pixels to 0. Finally, this command invokes the **MARK** command.

INSERT dst, row, col, src

This command copies image **src** into image **dst**, with the top left pixel of image **src** going into **dst** pixel (**row**, **col**). This operation copies only that part of **src** that will fit into the specified area of **dst**. **src** and **dst** should be different images. This operation does set the overlap rows in **dst**.

JUMP label

Jump to the line numbered **label** in the .fc file. **label** is normally the parameter in a LABEL statement somewhere in the .fc file, in which case this JUMP command causes a jump to the line containing that LABEL command. **label** can also be any constant or user-defined variable whose value is a line number. (JUMP does not exist in program G.)

LABEL label

Set the value of the user-defined variable **label** equal to the line number of the line containing this LABEL command. If **label** is not already defined, this LABEL command will define it as a type I32 variable. The intent is that the variable **label** will be used with the JUMP command and for no other purpose, but **label** is actually simply another user-defined type I32 variable and it can be manipulated just as any other user-defined variable. Of course, if the value of **label** is changed after it is set by the LABEL command, later JUMP **label** commands may produce undesired results. (LABEL does not exist in program G.)

LIN01 bright, tangle, src, opr, length, width

Find lines in image **src**. Set each pixel in image **bright** equal to the brightness of the line (if any) passing through the corresponding pixel in image **src**, and set the corresponding pixel in image **tangle** equal to the tangent of the angle between the line and the x (horizontal) axis. LIN01 will not find lines with negative brightness. **bright**, **tangle**, and **src** should all be the same size, and **bright** and **tangle** should be different from **src**. If **bright** and **tangle** are the same image, the image will be set equal to the brightness values and the angle information will not be stored in any image. Operator **opr** contains weights for the local region which is analyzed for the presence of a line. **length** is the minimum acceptable line length parameter, and **width** is the maximum acceptable line width parameter. **length** and **width** are measured in pixels, but they are floating point values and fractional parts are meaningful. This operation uses overlap rows for image **src**; it does NOT set any overlap row values in either of the destination images **bright** or **tangle**. **bright** pixels in the excluded edge region defined by the domain of **opr** are set to zero.

The LIN01 algorithm is designed to find bright lines on a zero-intensity background, with no negative pixel values. One procedure that is usually reasonable is to subtract a smoothed version of the source image from the raw source image, and then use the MAXCON operation to remove negative pixel values, before using LIN01. Dark lines can, of course, be found by negating an image before starting so that the dark lines appear bright. This algorithm treats the **src*opr** intensity versus position data as a bivariate probability density function, finds the principal axes, and compares the standard deviations in the principal directions with **length/sqrt(12)** and **width/sqrt(12)** to determine whether the distribution is "long" and "narrow" enough to be construed as a line. (For a line of uniform intensity, the standard deviations of the distribution are equal to **length/sqrt(12)** and **width/sqrt(12)**.) In other words, this algorithm looks at the peak in the **src*opr** values, regarded as a function of the two position coordinates **x** and

y, and checks to see whether this peak is long and narrow enough to be considered a line. Lines that do not pass through the "central" pixel of the local region defined by **opr** are rejected.

Note that positive x is to the right, positive y is downward, and positive angles are clockwise from the positive x axis.

LIN02 bright, tangle, src, opr, length, width, avg

This is a line-finding operation like **LIN01**, except that **LIN02** rejects lines if the absolute value of the average intensity in the local region is less than **avg**. **LIN02** can find lines with negative brightness.

LOG dst, src

Set each image **dst** pixel equal to the natural logarithm of the corresponding image **src** pixel.

MARK (no parameters)

FOR PROGRAM G ONLY. Create or modify the 3-level mask to accompany the scene in image 1. The mask with its accompanying scene image (or images) is used in the training program F. This mask creation process is described in the user's manual.

MAX dst, src1, src2

Set each image **dst** pixel equal to the maximum of the corresponding image **src1** pixel or the corresponding image **src2** pixel.

MAXCON dst, src, const

Set each image **dst** pixel equal to the maximum of the corresponding image **src** pixel or the floating point value **const**.

MEDIAN dst, src, opr [, Nlo [, Nhi]]

Do an order sort filter, in which the output (filtered) value is neither the largest nor the smallest of the values in the local region of the source image. This is a non-linear filter that removes local minima with domains of **Nlo** or fewer pixels, and local maxima with domains of **Nhi** or fewer pixels. For each pixel in image **dst**, **MEDIAN** finds the corresponding pixel in image **src** and aligns thereon the center pixel of operator **opr**. For each non-zero element of **opr**, the corresponding **src** pixel is put into a list of pixel values. The list is sorted according to value. The **dst** pixel value is set equal to the corresponding **src** pixel value, unless this value is smaller than the (**Nlo**+1)th smallest value or larger than the (**Nhi**+1)th largest value in the list, in which case the limiting list value is used for the **dst** pixel value. Thus, if **Nlo** is 1 and **Nhi** is 2, for example, the **dst** pixel value cannot be the smallest or the largest or the second largest value in the operator domain of **src** pixels. The operator values are not used except to specify which source pixels are in the local neighborhood, which is that part of the operator domain for which the operator values are not zero. **src** should have enough overlap rows to accommodate **opr**. **Nlo** and **Nhi** should normally be greater than 0, and less than half of the number of non-zero operator elements. If either **Nlo** or **Nhi** is -1, that -1 value is replaced by half (integer division by 2) of the number of non-zero elements in the operator. If **Nlo** is missing from the command, -1 is used for the missing value. If **Nhi** is missing from the command line, the value of **Nlo** is used for the missing value. If the operator has an odd number of non-zero elements, and **N** is half of that number (integer division by 2), this

MEDIAN operation is a standard median filter. Pixels in the excluded edge region of **dst** are set to zero. **dst** and **src** should be different images, and they may be different sizes.

Note that if **Nlo** is 0 and **Nhi** is one less than the number of non-zero elements in the operator, this MEDIAN operation gives the maximum of the pixel values in the local region; this and the similar **Nhi**=0, **Nlo**=N-1 are convenient ways to get a local maximum or local minimum. The code implements these special cases much more efficiently than the general case of MEDIAN.

MED1X dst, src, N [, xcl]

Set image **dst** equal to image **src** median filtered with a window of **N** pixels in the **x** (horizontal) direction by 1 pixel in the **y** (vertical) direction. The domain of the operator **xcl** defines an excluded edge region, in which **dst** pixel values are left unchanged and **src** pixels are not used. If **xcl** is not given, 0 is used for its value. **dst** and **src** should be different images of the same size. **N** should be an odd integer.

MED1Y dst, src, N [, xcl]

Same as **MED1X**, except this filter is in the **y** direction. This **y**-direction filter uses (N-1)/2 overlap rows in **src**.

MIN dst, src1, src2

Set each image **dst** pixel equal to the minimum of the corresponding image **src1** pixel or the corresponding image **src2** pixel.

MINCON dst, src, const

Set each image **dst** pixel equal to the minimum of the corresponding image **src** pixel or the floating point value **const**.

MODMSK new, old, res, xcl, region, Q

Set image **new** equal to a mask obtained by modifying the mask in image **old**. Image **res** is a result image from a previous program E calculation. If **region** is 2, then any pixel with value 2 in **old** is changed to 0 in **new** if the **res** pixel value is less than **Q**. If **region** is 1, then any pixel with value 1 in **old** is changed to 0 in **new** if the **res** pixel value is greater than **Q**. If **region** is 3, both operations are done. Other pixels are simply copied from **old** to **new**. Thus, the designated target (2) and background (1) regions in the mask are shrunk so that they do not extend beyond the target and background regions indicated in the result image **res**. This hopefully makes the mask more efficient without damaging its intended target and background designations. Operator **xcl** defines an excluded edge region in which **new** pixels are left unchanged. All three images should be the same size, and **new** may be the same image as either **old** or **res**.

MOMUV src, opr, dst1 [, dstu [, dstv [, dstuu [, dstvv [, dsta]]]]]

MOMUV treats the intensity values in the local region as if they were an un-normalized probability density function (PDF), and calculates the second and lower moments of the PDF. **MOMUV** does a coordinate rotation to maximize the second moment about zero (not about the mean) in the **U** direction. If the PDF indicates no preferred direction, the **U** axis is along the **x** axis (horizontal, positive to the right). Image **src** is the source image, and kernel **opr** defines the local region and the weights for the pixels in the local region. Images **dst1**, **dstu**, **dstv**,

dstuu, **dstvv** and **dsta** are destination images for the weighted average intensity, the moments U, V, UU, and VV (the UV moment is always 0), and the tangent of the angle from the x axis to the U axis. If the value 0 is used for any of the destination image numbers, the corresponding quantity is not written to any image. If an image number is not supplied for **dstu** ..., the value 0 is used for the missing image numbers. The x coordinate is positive to the right, and the y coordinate is positive downward, and the origin is at the center pixel of the local region. **src** must have enough overlap rows to accommodate **opr**. The images must all be the same size. **src** should normally be different from all the destination images. The excluded edge pixels in each **dst** are set to zero.

MUL dst, src1, src2

Set image **dst** = image **src1** * image **src2**.

MULCON dst, src, const

Set image **dst** = image **src** * **const**.

NEWIMG [(I32 scalar variable)]

Set \$N equal to the number of a not-yet-defined image. If all images are already defined, set \$N equal to -1. If the name of an integer scalar variable is given as a parameter for this **NEWIMG** command, the variable's value is set equal to the \$N value.

NLIN01 dst, bright, tangle, opr

Count how many line extensions pass through each pixel. This operation is similar to **XLIN01**. But, whereas **XLIN01** yeilds the sum of the intensities of all the line segments whose extensions would pass through the central pixel, **NLIN01** is an attempt to count the number of line segments whose extensions would pass through the central pixel, independent of the line segment intensities. **NLIN01** does not work very well. The weights in the operator **opr** should sum to 1.0 along any one ray from the center pixel.

NTRP00 dst, src, opr

NTRP00 does an interpolation, replacing pixels that have value 0.0 in the source image **src** with new values in the destination image **dst**. The new value is the weighted average of all the non-zero-value pixels in the local region, with the weights contained in the kernel **opr**. **src** should include enough overlap rows to accommodate **opr**. **dst** and **src** should be the same size. **dst** should usually be different from **src**.

NTRP01 dst, src, opr

NTRP01 does an interpolation, replacing pixels that have value 0.0 in the source image **src** with new values in the destination image **dst**. The new value is determined by a weighted least squares fit with a linear function of position to all the non-zero-value pixels in the local region, with the weights contained in the kernel **opr**. **src** should include enough overlap rows to accommodate **opr**. **dst** and **src** should be the same size. **dst** should usually be different from **src**.

OUTM filename [, header]

FOR PROGRAM G ONLY. Write the mask (image number 2) to file **filename**, optionally specifying the image file format with the parameter **header** which defaults to format 1. This is the same as the WRITEIMAGE command for image 2.

OUTS filename [, header]

FOR PROGRAM G ONLY. Write the scene image (image number 1) to file **filename**, optionally specifying the image file format with the parameter **header** which defaults to format 1. This is the same as the WRITEIMAGE command for image 1.

OVERLAP img

Set currently correct values in the overlap rows of image **img**. That is, each daisy obtains (from other daisies) the correct, current values of the pixels in its own overlap rows. This should be done before operations like CONVOLVE (convolution calculation) or MED1Y (median filter in the y direction) which use the overlap rows. The overlap rows are automatically assigned the correct values when an image is read from a file (commands READIMAGE and READSCENE). The overlap rows are NOT assigned the correct values for most other operations.

PACC1 src, sum1, sumx, sumy, sumxx, sumyy, sumxy

This command calculates sums for each **src** image peak previously defined by PEAK1 and PLNK1, which sums can be used to calculate the moments of each peak as if the peak were an un-normalized distribution function. On input, **sum1** should be the same as **peak** output by PLNK1 or PMRG1, **sumx** should be **accx**, and **sumy** should be **accy**. This command treats each peak in **src** as a probability density function (unnormalized), calculates sums for each peak, and assigns the sum values to the destination image pixels corresponding to the accumulator pixel in **peak** (hence the term "accumulator"). **sum1** is set equal to the sum of the **src** pixel values in the peak. **sumx** and **sumy** are set equal to the sums of the distances (in pixels) from the accumulator pixel to the other pixels in the peak, multiplied by the **src** pixel value. **sumxx**, **sumyy**, and **sumxy** are set equal to the sums of the products of the distances, multiplied by **src**. The sums appear in the accumulator pixels only; the donor pixels are set to zero (except for **src**, which is unchanged). These images should all be the same size, and they should all be distinct. No overlap rows are needed for this operation (although some of the images need an overlap row for the preceding operations).

PAUSE (no parameters)

The PAUSE command causes the program to wait until any key on the keyboard is struck.

PDFXYZ img [, xcl [, vmin, vmax]]

Treat the entire image **img** as a probability density function in two dimensions, and calculate certain moments. **xcl** is the number of a kernel that defines an excluded edge region. If only one parameter (**img**) is given for this PDFXYZ command, **xcl** is assumed to be 0, which implies that no edge region is excluded. Only the pixels with values between **vmin** and **vmax** are included in this calculation. If fewer than 4 parameters are given with this PDFXYZ command, all pixels (except those in the excluded edge region) are included regardless of their values. This command sets \$AVGX = average *i* value, \$SIGX = standard deviation in the *i*

direction, \$MINI = minimum i value, and \$MAXI = maximum i value, and it sets the analogous user-accessible variables for the j or y direction. i or x increases from left to right, j or y increases from top to bottom, and i=0, j=0 is the top left pixel. This command also sets \$COXY = covariance of i and j, and \$N = number of pixels included in the sums.

PDFXY1 *img, xcl, vmin, vmax*

This PDFXY1 command is similar to the PDFXYZ command, except that this PDFXY1 command uses 1.0 instead of the pixel value for the weight (the probability density function value) when calculating the weighted sums. This PDFXY1 command requires all 4 parameters.

PEAK1 *src, peak [, accx, accy]*

This command finds peaks in image *src*. It compares each pixel in *src* with its 8 nearest neighbors. If the *src* pixel value is less than any of its neighbors, or if it is equal to a neighbor with a lower address (lower row number or same row and lower column number), the *src* pixel is declared not a peak and the corresponding pixel in *peak* is set to zero. Otherwise, the *src* pixel is considered a peak, and its value is assigned to the corresponding pixel in *peak*. This is intended to work with *src* images that have only non-negative pixel values. If values are given for parameters *accx* and *accy*, images *accx* and *accy* are set to zero for non-peak pixels, and they are set to 0.5+i and 0.5+j for peak pixels, where i and j are the peak pixel coordinates. The images *accx* and *accy* are set as an aid in the use of the PLNK1 command following this PEAK1 command. All the images should be distinct, and all should be the same size. *src* should have at least 1 overlap row. (The other images need overlap rows for later operations such as PLNK1.)

PHEAD *filename [, header [, length]]*

Read and print the header from the image file *filename*. *header* is an integer code specifying the type of header (see READIMAGE). If the value -1 is given for *header*, or if no value is given for *header*, the program will attempt to determine the header type by itself. If the value 0 is given for *header*, the program simply prints the first *length* bytes of the file in hexadecimal and ASCII. The parameter *length* is not used, and need not be supplied, unless *header* is 0.

PLNK1 *src, peak, accx, accy*

This command associates each non-zero pixel in image *src* with a nearby intensity peak. The PEAK1 command should be used to set the values in *peak*, *accx*, and *accy*, before this PLNK1 command is used. All four images should be the same size, all four should be distinct, and each of the four should have at least one overlap row.

For a peak in image *src*, we will speak of an accumulator pixel and (usually) several donor pixels. The accumulator for a peak is the pixel with the greatest intensity in *src* in that peak; a donor is any pixel in that peak other than the accumulator (and with a *src* value greater than 0). The result of this PLNK1 operation is that each donor pixel in a peak is associated with the accumulator for that peak, by being assigned the accumulator pixel's values in images *peak*, *accx*, and *accy*. That is, for each donor pixel, the values of *accx* - 1/2 and *accy* - 1/2 are the coordinates of that donor's accumulator pixel, and the value of *peak* is the value of that donor's accumulator pixel in *src*. Each donor pixel is associated with the same peak as its nearest (of 8) neighbor pixel with the largest value in *src*. (This neighbor pixel value is larger than the donor's own value, or the "donor" is actually an accumulator.) If there is a tie for highest value

nearest neighbor, the lower address neighbor is favored. This PLNK1 is intended for src images with non-negative pixel values. src pixels with value zero are not assigned to any peak. Unlike most operations, PLNK1 automatically sets the values in the overlap rows of flag, accx, and accy before those images are used, so you don't have to. You do have to set the (at least one) overlap rows in src, although usually the src overlap rows will be set before PEAK1 is used and they will still be set when PLNK1 is used.

PMOMUV src, mom0, avgu, avgv, varuu, varvv, tang, maxsag

PMOMUV is like PMOMXY with rotated coordinates, just as PMOMUV1 is like PMOMXY1 with rotated coordinates.

PMOMUV1 mom0, avgu, avgv, varuu, varvv, tang

This command is like PMOMXY1, in that it converts the sums from PACC1 into moments. However, this function works in a u-v coordinate system which is rotated relative to the x-y coordinate system, so that the largest second moment of the peak is along the u axis. In this coordinate system, the second cross moment varuv is always zero. Instead of this moment, PMOMUV outputs the tangent of the angle from the x axis to the u axis, in the array tang. If the peak has no preferred direction, the u axis is chosen along the x axis. On input, mom0 should be the same as sum1 output by PACC1, avgu should be sumx, avgv should be sumy, varuu should be sumxx, varvv should be sumyy, and tang should be sumxy. These images should all be the same size, and they should all be distinct. No overlap rows are needed for this operation (although some of the images need an overlap row for the preceding operations).

PMOMXY src, mom0, avgx, avgy, varxx, varyy, varxy, maxsag

This PMOMXY function is simply a single command incorporating PEAK1, PLNK1, PMRG1, and PMOMXY1. This command treats each peak in image src as an un-normalized distribution function (probability density function), and calculates the moments of each peak. Two or more peaks connected by a path not lower than maxsag lower than the higher peak are treated as one peak. PMOMXY assigns the moment values to the destination image pixels corresponding to the maximum-value pixel in src, for each peak. mom0 is set equal to the sum of the src pixel values in the peak. avgx and avgy are set equal to the distance in pixels from the maximum-value pixel to the centroid of the peak. varxx, varyy, and varxy are set equal to the second moments (the variances and the covariance) about the centroid. These several moment values are put into the destination image pixels corresponding to the peak maximum pixel in src; the other destination pixels are set to zero. These images should all be the same size, and they should all be distinct, and they should all have at least one overlap row. Use the OVERLAP src command or some equivalent command before PMOMXY; OVERLAP is not necessary for the other images (PMOMXY does the other required overlap operations automatically).

PMOMXY1 mom0, avgx, avgy, varxx, varyy, varxy

This command converts the sums from PACC1 into moments. On input, mom0 should be the same as sum1 output by PACC1, avgx should be sumx, avgy should be sumy, varxx should be sumxx, varyy should be sumyy, and varxy should be sumxy. This command treats each peak in PACC1's src as a probability density function (unnormalized), calculates the moments for each peak, and assigns the moment values to the destination image pixels

corresponding to the peak pixel in **flag**. **mom0** is left unchanged, equal to **sum1**, the sum of the **src** pixel values in the peak. **avgx** and **avgy** are set equal to the distance in pixels from the accumulator (peak) pixel to the centroid of the peak. **varxx**, **varyy**, and **varxy** are set equal to the second moments (the variances and the covariance) about the centroid. These images should all be the same size, and they should all be distinct. No overlap rows are needed for this operation (although some of the images need an overlap row for the preceding operations).

PMRG1 src, peak, accx, accy, sumxx, sumyy, sumxy, maxsag

This command merges peaks that are connected by a path in **src** such that the lowest pixel value along that path is not lower than the higher peak value minus the (floating point) value **maxsag** and the lowest pixel is also greater than 0. That is, all the pixels in two or more merged peaks are assigned to the same accumulator. The images **src**, **peak**, **accx**, and **accy** should be set by a prior call to the command **PLNK1**, and these four images will have the same meanings (although perhaps different values) after **PMRG1** as after **PLNK1**. The images **sumxx**, **sumyy**, and **sumxy** are used for scratch by **PMRG1**. All seven images should have at least one overlap row, all should be the same size, and all should be distinct. It is not necessary for you to set the values of these overlap rows except for image **src** which is probably already set from the prior operations **PLNK1** and **PEAK1**.

PRINTS [src ...]

Print the values of any scalar variables or file name variables listed as parameters. If no parameters are listed, all scalar variables are printed.

QUADUV src, opr, dst1 [, dstu [, dstv [, dstuu [, dstvv [, dsta]]]]]

Like **QUADXY**, **QUADUV** fits the local region with a quadratic function. **QUADUV** then does a coordinate rotation from the x-y to the u-v coordinates, with the u-axis chosen in the direction that maximizes the second derivative with respect to u. Image **src** is the source image, and kernel **opr** contains the weights for the pixels in the local region. Images **dst1**, **dstu**, **dstv**, **dstuu**, and **dstvv** are destination images for the coefficients of the 1, u, v, uu, and vv terms in the fitted polynomial. (The uv term is always zero.) Image **dsta** is the destination for the tangent of the angle between the x axis and the u axis. If the value 0 is used for any of the destination image numbers, the corresponding quantity is not written to any image.

QUADXY src, opr, dst1 [, dstx [, dsty [, dstxx [, dstyy [, dstxy]]]]]

QUADXY does a weighted least squares fit of a quadratic function of position to the pixels in a local region of the source image, and writes the 6 polynomial coefficients to the 6 destination images **dst1**, **dstx**, **dsty**, **dstxx**, **dstyy**, and **dstxy**. If the image number supplied for any destination image is 0, the corresponding quantity is not written to any image. If an image number is not supplied for **dstx** ..., the value 0 is used for the missing image numbers. The x coordinate is positive to the right, and the y coordinate is positive downward, and the origin is at the center pixel of the local region. Image **src** is the source image. Kernel **opr** defines the local region and contains the weights. **src** must have enough overlap rows to accommodate **opr**. The images must all be the same size. **src** should normally be different from all the destination images. The excluded edge pixels in each **dst** are set to zero.

READIMAGE filename, img [, header [, ncols [, nrow [, row0 [, col0 [, bpp]]]]]]

(see also the following **READIMAGE filename, -1 ... command**)

Read all or part of an image from file **filename** into memory image **img**. The values of **header** indicate the type of header on the image file, as follows:

header	meaning
0	no header
1	Data Translation 512-byte header
2	Perceptron 11-byte header
3	Microsoft OS2 bit map file header
4	Microsoft Windows bit map file header
5	Daedalus 2048-byte header
6	Casi 1024-byte header
7	AMPS synthetic aperture radar

ncols is the number of columns in the file image. **nrow** is the number of rows of pixels to be read. The memory image **img** may be smaller than the file image in **filename**; the memory image is taken from that region of the file image with top left corner at row **row0** and column **col0**. Thus, for the common case in which the file image is the same size as the memory image, **row0** and **col0** should be set to 0. **bpp** is the number of bytes per pixel. Acceptable values are 1; 2, implying the less significant byte of each pair is first in the file; and -2, implying two bytes per pixel with the more significant byte first. **img** must be greater than 0.

Unlike most operations, **READIMAGE** does set the values of the pixels in the overlap rows of image **img**. If the file image does not have enough rows to fill the memory image, the unfilled memory image rows are left with the same values they had before.

The **filename** and **img** parameters must always be supplied with this command. If either of **row0** or **col0** is not supplied, it is assumed to be 0. If any of **header**, **ncols**, **nrow**, or **bpp** is not specified, the value -1 is assumed. If any of these 4 parameters has the value -1, the program attempts to determine a correct or reasonable value for the parameter from the file header, from the sizes of already-defined destination images, and from the **BANDR** parameters. This attempt may require the assumption of equal sizes for a file image and the corresponding memory image.

The image may be already defined, using **DEFIMG**, **COPDEF**, **RESAMPLE**, or a previous **READIMAGE** or **READSCENE**. If image **img** is not already defined, the program will attempt to define image **img** with **ncols** columns and **nrow** rows, with 0 overlap rows. If the header is type 1, the program will attempt to read the values of the scale factors A and B from the header in the image file, and set the image table A and B values and the pre-defined scalar \$A and \$B values accordingly. Otherwise, these will be set to 0.0 and 1.0.

READIMAGE filename, -1 [, header [, bpr [, nrow [, row0]]]]

(see also the previous **READIMAGE filename, img ... command**)

This form of the **READIMAGE** command, with "-1" given instead of an image number, assumes that the file contains several images with interleaved rows. That is, the file contains the first row of the first image, the first row of the second image, ..., the first row of the Nth image, the second row of the first image, the second row of the second image, ..., perhaps with additional bytes interspersed and perhaps with a file header. This command reads the several images from the file in one operation. Other than the following comments, this **READIMAGE -1** command has the same features as the standard **READIMAGE** command.

The information about each image or band is assumed to be already specified with the BANDR command. If any of the images specified in the BANDR command are not already defined when this READIMAGE -1 command is issued, this command will attempt to define those images. If nrow is given as -1 and the several images do not have the same number of rows, this READIMAGE -1 command will read only enough rows to fill the smallest destination image. bpr is the number of bytes in each composite row of the image file, including any row headers and any bands that are not of interest in this particular read operation. If bpr is given as -1, the program will attempt to determine the correct value from the file header.

READKERNEL filename, opr

Read a local convolution operator (or kernel) from file filename into operator buffer number opr. The program assumes that the operator buffer has already been defined (operation DEFKERN) and that the buffer and the file are compatible. opr must be greater than 0. The file is assumed to contain ASCII characters, with the several values separated by spaces, commas, or end-of-line characters.

READSCENE img [, header [, ncols [, nrow [, row0 [, col0 [, bpp]]]]]]

READSCENE -1 [, header [, bpr [, nrow [, row0]]]]

READSCENE (no parameters)

Read an image from the file whose name is in the scene image list file (.sl). This READSCENE is like READIMAGE, except that for READSCENE the file name is not given in the feature command file (.fc) but is given instead in the scene list file (.sl).

The program remembers previously specified names of scene files. If, instead of a file name, the entry in the scene list file (.sl) is a "+" followed by an integer value n, then the previously used file name for the n-th scene image is incremented and used as the present file name. (See the INCFIL command for an explanation of incrementing a file name.) If a "+" is given without an integer value, the value of n is assumed to be the same as the number of the present scene image. For example, assume that this is the feature command file's third call to READSCENE (we are getting scene image 3), and that we are processing the fifth scene (this is the fifth use of the feature command file in this execution of the program). This call will use the third scene image file name in the fifth block of file names in the scene list file (.sl). If the file name is "+", the file name used for the image 3 (the current scene image number) in scene 4 (the previous scene number) will be incremented and then used here. If the file name is "+2", the file name to be incremented and used here will be the one for image 2 of scene 5, which is the last image 2 file name specified. If the file name is "+4", the file name to be incremented and used here will be the one for image 4 of scene 4, since the file for image 4 of scene 5 has not yet been specified.

A "." has an effect similar to a "+", except that the old file name is not incremented before being used.

Each time the READSCENE command is used after the scene list file (.sl) is ended, the effect is the same as if "+" were read from the scene list file.

The scene list file (.sl) contains a block of image file names for each scene. For program E, the first file name in each block is the name of the result file to be written, and the following file names in the block are real scene image file names numbered 1, 2, ... For program F, there is no result image written, and the block of file names in the scene list file does not start with a result image file name. Instead, for program F, the file names in a block are all treated as scene image file names, and they are numbered 0, 1, 2, ... It is often convenient to use the

mask image file name for the first scene image file name, so that the mask will be "scene image" number 0 and the "real" scene images will be numbered 1, 2, ... Note that the first feature file written for each scene by program F must be the mask feature file, so it is handy if the first scene image file read is the scene mask image file.

The READSCENE command with no parameters reads and stores the next scene image file name from the scene list file (.sl) without reading any image. The specified file is not accessed at all; it does not even need to exist. This command is a way to get a file name into the program's memory without actually reading the file.

(READSCENE does not exist in program G.)

READY (no parameters)

Query all slaves, including the SCSI and video interfaces, and wait for each to respond. This READY command causes the system to wait until all nodes have finished their tasks, which is useful for timing measurements and for debugging.

Usually, the fact that a slave responds to this or any other input indicates that the slave has finished previous tasks. However, if the slave is doing an operation that requires communication with other nodes, this READY query may cause an error condition in the slave program. Correctly written master node subroutines will prevent this query or any other communication from being sent to a slave while the slave is in such a vulnerable situation; the master node subroutine should not allow the input of any user command until all the slave nodes are no longer vulnerable.

REGISTER hhh, ggg, fff, fs1, gs1, gs2, gs3, gs4, bux, buy, bu1, bxv, byv, bv1 [, dux [, duy [, du1 [, dvx [, dvy [, dv1]]]]]

Register two images. That is, remap image ggg into image hhh so that the features in image hhh are optimally aligned with the corresponding features in image fff. Images ggg and fff are not changed by this REGISTER operation. Images fff and hhh must be the same size and must be compatible for arithmetic operations (they must be distributed the same way among the nodes); image ggg may be different in size. fs1, gs1, gs2, gs3, and gs4 are images that can be used as scratch space by this REGISTER operation. If 0 is given as the number for any of these scratch images, the program will find its own scratch space in place of that image (if sufficient memory is available). If a valid image number is given for any of these scratch images, then that image must be already defined. fs1 must be compatible with fff, and gs1, gs2, gs3, and gs4 must be compatible with ggg. All of the images must be distinct; none of the images needs any overlap rows. bux, buy, bu1, bxv, byv, and bv1 are first guesses at the optimal mapping coefficients, as described for the REMAP operation using hhh for dst and using ggg for src. dux, duy, du1, dvx, dvy, and dv1 are the allowable ranges of variation of the mapping coefficients; that is, the final value of bux, for example, will not be allowed outside the range from bux-dux to bux+dux. If any of the range limits is not given, the value -1 will be used in its place. If a negative value is given (or assumed by default) for any of the range limits, the program will choose its own limit value. The final optimized values of bux, buy, bu1, bxv, byv, and bv1 are returned in the user-accessible variables \$AVGX, \$AVGY, \$AVG, \$SIGX, \$SIGY, and \$SIG. The value of [1-corr] is returned in \$COXY, where corr is the cross-correlation of the two images hhh and fff, with only the remapped ggg part of hhh and fff used if hhh is not completely covered by the remapped ggg. Possible corr values range from -1 to 1, so \$COXY=[1-corr] values range from 0 (perfect correlation) to 2.

REM (no parameters except a remark)
no action.

REMAP *dst, src, bux, buy, bu1, bvx, bvy, bv1*

Copy pixel values from image *src* to different pixels in image *dst*. The pixel location transformation is

$$\begin{aligned}(\text{src col}) &= \text{bux} * (\text{dst col}) + \text{buy} * (\text{dst row}) + \text{bu1} \\(\text{src row}) &= \text{bvx} * (\text{dst col}) + \text{bvy} * (\text{dst row}) + \text{bv1}\end{aligned}$$

where the coefficients are given as floating point values. If the corresponding *src* pixel does not exist, the *dst* pixel is left with the value it had before this operation. The overlap rows in *dst* are undefined after this operation.

REPHI *dst, src, const, rep*

Set image *dst* pixel equal to the corresponding image *src* if that *src* pixel value is no greater than *const*; otherwise, set the *dst* pixel value to the floating point value *rep*. (Values equal to *const* are not changed.)

REPLO *dst, src, const, rep*

Set image *dst* pixel equal to the corresponding image *src* if that *src* pixel value is greater than *const*; otherwise, set the *dst* pixel value to the floating point value *rep*. (Values equal to *const* are changed to *rep*.)

RESAMPLE *dst, src, xcl, ncol, nrow, novl*

Resample image *src* and put the result into image *dst*. The operator *xcl* defines an excluded edge region of image *src*; *xcl* may be 0. There is no excluded edge in *dst*. If image *dst* is not yet defined, it will be defined with *ncol* columns, *nrow* rows, and *novl* overlap rows, and its scale factors *A* and *B* will be set to 0.0 and 1.0. Note that images defined by this **RESAMPLE** operation may be distributed among the daisies differently than images of the same size defined by other processes. If image *dst* was previously defined, it is assumed to have been defined with the correct size and with the correct parts allocated to each daisy, and the values supplied for *ncol*, *nrow*, and *novl* are ignored. The values of the overlap row pixels in *dst* are NOT set by this **RESAMPLE** operation. The resampling is done by the simplest nearest-pixel method, with no interpolation or smoothing. If image *src* has fewer rows than image *dst* and image *src* has overlap rows, the overlap rows will probably be used in the **RESAMPLE** procedure, so their values (if not already current) should be updated with the **OVERLAP** command before this **RESAMPLE** command is used. *src* overlap rows may also be used if the *src* and *dst* images are not distributed exactly correctly among the slave nodes, as might happen if one of the images is defined by a process other than a **RESAMPLE** of the other image.

RETURN (no parameters)

This command is the logical end of a subroutine. It causes the software to leave the subroutine and go to the command immediately following the **GOSUB** command that invoked the subroutine.

RIJCON *dst, src, opr*

This is an imperfect operation that tries to concentrate ridges. A weighted least squares fit is used to fit a quadratic polynomial to the local region in the source image *src*, with kernel

opr containing the weights and specifying the local region. If the fitted polynomial describes a ridge, the ridge is smoothed along its length and concentrated in the direction perpendicular to its length, in the destination image **dst**. **dst** should be different from **src**, and they should be the same size. **src** should include enough overlap rows to accommodate **opr**. The excluded edge pixels in **dst** are set to zero.

SABS dst, src

Set scalar variable **dst** = absolute value of **src**.

SADD dst, src1, src2

Set scalar variable **dst** = **src1** + **src2**. Or, concatenate two strings, which may be either file name variables or literal strings, and put the concatenated string in the file name variable **dst**.

SATAN dst, src

Set scalar variable **dst** = arctangent of **src**, in radians from $-\pi/2$ to $\pi/2$.

SATAN2 dst, src1, src2

Set scalar variable **dst** = arctangent of **src1** / **src2**, in radians from $-\pi$ to π .

SBEND dst [, src [, col0 [, addcol [, maxang]]]]

This SBEND operation does the s-bend geometric correction. For image **src**, the pixels within each row (or the columns in the image) are assumed to represent samples that are uniformly spaced in terms of the angle to the side of the camera center line. Image **dst** will have pixels that represent samples that are uniformly spaced in terms of the distance from the camera center line on a flat scene plane or a flat film plane. **src** and **dst** must be the same size, and they may be the same image. If a value is not given for **src**, it is assumed to be the same as **dst**. **col0** is the (floating point) number of the image column corresponding to the camera center line, where angle = 0. **col0** is the same for **src** and **dst**, and the **src col0** pixels are mapped directly to **dst col0**. **maxang** is usually the maximum angle included in the camera's field of view, corresponding to pixels at the edge (largest column number) of the images, and column **col0** + **addcol** is the pixel column number corresponding to this maximum angle. However, you are not required to use **maxang** and **addcol** values with this simple physical interpretation. Formally, the **src** pixels in columns **col0** + **addcol** and **col0** - **addcol** are mapped directly to the same columns in **dst**. Pixels in columns other than these three special columns are shifted laterally (to different columns) in the SBEND operation. The columns numbered **col0**, **col0** + **addcol**, and **col0** - **addcol** do not have to actually exist in the images **src** and **dst**.

If a value is not given for **col0**, it is assumed to be the center column in the images. If values are not given for **addcol** and **maxang**, they are assumed to be 357.0 columns and 0.75049 radian (43.0 degrees), which are the values for a normal Daedalus image.

SCALE dst [, src [, xcl]]

Image **dst** is set equal to image **src** multiplied by a scale factor chosen to make the largest value in image **dst** equal to 254. The edge pixels, defined by operator **xcl**, are excluded; their values in **src** are not considered in determining the scale factor, and their values in **dst** are left unchanged. The image **dst** coefficient A is set to 0.0 and B is set to the scale factor used in this scaling operation, without regard to the coefficient values for image **src**, and the user-accessible variables \$A and \$B are set equal to A and B. **dst** and **src** should be of the same size, and they

may be the same image. If a value is not given for **src**, it is assumed to be the same as **dst**. Usually, **SCALE** should be used immediately before **WRITEFEAT** and other 8-bit image writing operations to be sure that the limited dynamic range of 8 bits per pixel is best utilized. **SCALE** is also useful before screen display operations.

SDEFF32 src1 [src2 ...]

Define 32-bit floating point variables with names **src1**, **src2**, ..., similar to **SDEFI32**.

SDEFI32 src1 [src2 ...]

Define 32-bit integer variables with names **src1**, **src2**, ... Variable names are limited to 30 characters. The first character of a variable name must be an alphabetic character, not a numeral or a special character. You must not try to re-define an already defined variable. This operation does not assign values to the newly-defined variables. If a variable name is immediately followed by brackets enclosing an integer constant or an already-defined integer variable (with no intervening spaces), the variable is defined as an array instead of a scalar. For example, the command

SDEFI32 AAA[7] B

defines **B** as a single type **I32** (32-bit integer) variable and **AAA** as an array of 7 type **I32** variables which can be referred to individually as **AAA[0]**, **AAA[1]**, ... **AAA[6]**.

SDIV dst, src1, src2

Set scalar variable **dst** = **src1** / **src2**.

SEGLAB dst, src

SEGLAB assigns unique labels to image segments. **SEGLAB** assumes that image **src** has patches of marked pixels, with values greater than 0, separated by regions of background pixels, with values less than or equal to 0. For each marked **src** pixel, **SEGLAB** sets the corresponding destination image **dst** pixel to some value that comprises a label for the segment. Each contiguous segment gets a unique label, equal to $1+r+c/nc$ where **nc** is the number of columns in the images and **r** and **c** are the row and column number for the lowest-numbered pixel in the segment. **dst** pixel values are not changed if the corresponding **src** pixels are not marked as segments. Normally, all **dst** pixels should be set to 0 before starting a segmentation procedure that uses this subroutine. **dst** pixel values that are not 0 on entering this subroutine are construed as indicating a pixel that is already labeled. A non-zero value for a **dst** pixel and a greater-than-zero value for the corresponding **src** pixel is an inconsistency, indicating overlapping patches (segments). When this occurs, the old labels will not be changed, and the non-overlapping parts of the new overlapping patches will get a new label. Successive uses of the same destination image with different source image will result in unique labels for all the patches (segments) in the several source images as long as those patches do not overlap. **src** and **dst** must be different images, they must be of the same size, and both **dst** and **src** must have at least one overlap row.

SEQ dst, src

Set (numerical, integer or floating) scalar variable **dst** = **src**, where **src** may be either a scalar variable or a numerical constant. Or, set file name variable **dst** equal to **src**, where **src** may be either a file name variable or a literal string with no embedded spaces.

SET_AB img, A, B

SET_AB img

The first form sets the A and B coefficients for image **img** to floating point values A and B. ([This image] = A + B*[original image].) These coefficients were initially set to A=0.0, B=1.0 when the image was defined. This operation does NOT rescale the image; it merely sets the values of the stored coefficients. The second form does not change the A and B coefficients for image **img**. Both forms then set the user-accessible variables \$A and \$B equal to the A and B values for image **img**.

SETPIX img, row, col, val

Set the pixel in image **img**, row **row**, column **col**, to the floating point value **val**. This operation sets pixels in both the primary and the overlap rows. Note that images are stored in memory as floating point data.

SEXP dst, src

Set scalar variable **dst** = exponential (inverse natural logarithm) of **src**.

SLOG dst, src

Set scalar **dst** = natural logarithm of **src**.

SMAX dst, src1, src2

Set scalar variable **dst** = maximum of **src1** or **src2**.

SMIN dst, src1, src2

Set scalar variable **dst** = minimum of **src1** or **src2**.

SMTHX dst, src, sigma, N [, xcl]

Set image **dst** equal to image **src** smoothed in the x (horizontal) direction. The smoothing operation comprises N repetitions of a two-pass (one pass increasing x, one pass decreasing x) exponential smoothing filter, with the exponential filter width chosen to make the half-width (the standard deviation) of the smoothing function of the total operation equal to the floating point value **sigma**. Larger N values make the overall smoothing function look more Gaussian. The domain of the operator **xcl** specifies an excluded edge region, in which the **dst** pixel values are not changed. (The operator **xcl** is not used for anything except specifying this excluded edge region.) **dst** should be the same size as **src**, and they may be the same image.

SMTHXS dst, src, sig [, xcl]

Set image **dst** equal to image **src** smoothed in the x (horizontal) direction. The smoothing operation comprises a two-pass (one pass increasing x, one pass decreasing x) exponential smoothing filter. The filter width is not necessarily constant for the whole image area; the exponential filter width for each pixel is the value of the corresponding pixel in the image **sig**. Such a smoothing operation, with the smoothing width varying from one pixel to the next, might not have some properties normally expected from smoothing operations, such as conservation of the area (or volume) under a peak. The domain of the operator **xcl** specifies an excluded edge region, in which the **dst** pixel values are not changed. (The operator **xcl** is not used for anything except specifying this excluded edge region.) **dst**, **src**, and **sig** should all be

the same size. **dst** and **src** may be the same image, but **sig** should be different from both **dst** and **src**.

SMTHY dst, src, sigma, N [, xcl]

Same as **SMTHX**, but this smoothing is in the y (vertical) direction. (Overlap rows are not needed.)

SMTHYS dst, src, sig [, xcl]

Same as **SMTHXS**, but this smoothing is in the y (vertical) direction. (Overlap rows are not needed.)

SMUL dst, src1, src2

Set scalar variable **dst** = **src1** * **src2**.

SQRT dst, src

Set image **dst** = square root of image **src**.

SSQ dst, src, opr

Set image **dst** equal to the local sum of squares of image **src**, with weighting coefficients from operator **opr**. That is, set each image **dst** pixel value equal to the sum over the domain of operator **opr** of {**src*****src*****opr**}. The **dst** pixels in the excluded edge region, defined by the domain of the operator **opr**, are set to zero. **src** should have enough overlap rows to accommodate operator **opr**. **opr** must be greater than 0. **dst** and **src** should be different images. The image **dst** does not need to be the same size as the image **src**, but the two images do need to be distributed among the daisies in a manner compatible with the **RESAMPLE** algorithms.

SSQRT dst, src

Set scalar variable **dst** = square root of **src**.

SSUB dst, src1, src2

Set scalar variable **dst** = **src1** - **src2**.

STAN dst, src

Set scalar variable **dst** = tangent root of **src**, with **src** in radians.

STATS img [, xcl]

Calculate pixel value statistics for image **img**, excluding the edge region defined by the domain of operator **xcl**. If **xcl** is not given, the value 0 is assumed and no edge region is excluded. This operation sets the user-accessible variables **\$N** = number of pixels, **\$AVG** = average value of pixels, **\$SIG** = standard deviation of pixel values, **\$MAX** = maximum pixel value, **\$MIN** = minimum pixel value, **\$NROW** = number of rows, **\$NCOL** = number of columns, **\$A** = value of A coefficient in tables, **\$B** = value of B coefficient in tables.

STOP (no parameters)

Stop the feature calculation process for the current scene. For program G, stop execution of the whole program. For program E, go on to the next scene. For program F, accumulate

the sums for this scene and then go on to the next scene, optimizing the coefficients after the last scene.

SUB dst, src1, src2

Set image **dst** = image **src1** - image **src2**.

SUBCON dst, src, const

Set image **dst** = image **src** - **const**.

SUBDEF subname [typcod, varnam] [, ...]

Define a "subroutine" in a .fc file. This is the first line of a subroutine in a .fc file. A subroutine is a block of commands that can be executed from elsewhere in the .fc file via the GOSUB command. The subroutine starts with this SUBDEF command, normally includes several other commands, and normally ends with the RETURN command which transfers control back to the line following the GOSUB command that invoked the subroutine. (Actually, the subroutine does not necessarily need a RETURN as its last physical line in the .fc file, but the logical end of a subroutine must be a RETURN.) The subroutine, and hence the SUBDEF command, should be placed in the .fc file in such a way that the SUBDEF command is never encountered except via the GOSUB command, and the RETURN command is never encountered except after a SUBDEF command.

The subroutine name **subname** is treated as a user-defined variable. Thus, it can be chosen more or less arbitrarily within the limits of normal variable names, and it must be distinct from all other variable names.

Each subroutine variable is specified by two parameters in the SUBDEF command. The first parameter of the pair specifies the type of variable: I32 (32-bit integer), F32 (32-bit floating point), CHR (character), or STR (character string). The second parameter of the pair is the name of the subroutine variable. The name must conform to the rules for user-defined variable names. It must be distinct from all other variable names in the .fc file, and it must not be defined anywhere else in the .fc file. That is, all variables, both within a subroutine and outside of any subroutine, are "global" in the sense that their names are all kept in the same list and they are all accessible from anywhere in the entire .fc file. Subroutine variables are not in any way isolated from other variables.

A subroutine variable can be either a scalar or a one-dimensional array. To specify that a subroutine variable is an array, the name of the variable in the SUBDEF command is immediately followed by an empty bracket pair "[]". Thus, the command line

SUBDEF ABC I32 XXX[] I32 Y STR Z

specifies that **ABC** is the subroutine name; **XXX** represents an array of I32 values within the subroutine; **Y** represents a single I32 value within the subroutine; and **Z** represents a character string within the subroutine. Within the subroutine, we can refer to individual elements of the array **XXX**, with commands like

SADD XXX[J] XXX[2] Y

where **J** is a variable that is defined elsewhere in the .fc file. This command sets element number **J** of array **XXX** equal to the sum of **Y** and element number 2 of **XXX**.

The subroutine variables are accessible from elsewhere in the .fc file. However, you must use caution and not access these variables until after they have been defined, which occurs when the subroutine is defined. This happens the first time the software scans over the SUBDEF

command in the .fc file, even if the software is merely jumping over the SUBDEF command in response to a JUMP command or a GOSUB to a different subroutine.

SUMPIX *img* [, *xcl*]

Calculate the sum of all the pixels in the image *img*, excluding the edge region defined by the domain of operator *xcl*. If *xcl* is not given, the value 0 is assumed and no edge region is excluded. This operation sets the user-accessible variables \$N = number of pixels, \$AVG = average value of pixels.

TAN *dst*, *src*

Set each image *dst* pixel equal to the tangent of the angle specified by the value of the corresponding image *src* pixel. Angles must be in radians.

UNDERSAMPLE *dst*, *src*, *xcl*, *xfact*, *yfact*, *novl*

Undersample image *src* and put the result into image *dst*. This function is the same as RESAMPLE, except that, whereas RESAMPLE specifies the size of the new image *dst* directly, UNDERSAMPLE uses *xfact* and *yfact* to specify the size of the new image *dst* relative to the size of the old image *src*. The size of the new image *dst* will be the size of the old image *src* minus the excluded edge regions defined by the domain of the operator *xcl*, divided by *xfact* in the horizontal direction and *yfact* in the vertical direction. Images defined by this UNDERSAMPLE operation are completely compatible with (are distributed among the slave nodes the same way as) images defined by the RESAMPLE operation.

VGA *caption*, *img* [, *row0* [, *col0* [, *Q*]]]

Display image *img* on the system (console) monitor. The top left corner of the image will appear at *row0*, *col0* in the screen display. Red will be used for pixels with value less than *Q*, green for pixels with value greater than *Q*. The default values for *row0*, *col0*, and *Q* are 0, 0, and 0.0. Pixel values should be between 0.0 and 255.0. The character string *caption* will be printed below the image on the screen. *caption* should not contain any embedded spaces. If a "." is the first character of the string given as the label, then the last-used result file name will be used as the label. This requires that Gordon Lassahn's device handler VGA and compatible video hardware are installed. This display function is rather crude, slow, and buggy, and is not generally recommended.

WRITEFEAT *filename*, *src*

FOR PROGRAM F ONLY. Write image *src* to file *filename*, as in operation WRITEIMAGE, and enter *filename* into an internal list of feature image files. If a string beginning with "+" is given instead of a file name, the previously used feature image file name is incremented and used here. (See the INCFIL command for an explanation of incrementing a file name.) The initial stored feature image file name is \FI\FI000000.FI for ATR1 and ATR2, and /usr/users/fi/fi000000.fi for ATR3. Feature images are always written with a Data Translation header, in which is embedded the value of the last scale factor B used in scaling the image with the SCALE command.

Feature image files are written with each pixel represented as one 8-bit (1-byte) integer. This means that any pixel value outside the range 0.0 to 255.0 will not be correctly represented. It also means that precision is limited. As a worst case example, if the feature image pixel values range from 0.0032 to 0.4158, they will all be written as 0 and all precision will be lost.

You must construct feature images in such a way that there are no negative values. After this is done, you should usually use the SCALE command just before the WRITEFEAT command. This scale command multiplies the image by a constant that allows optimal use of the available precision, and this constant is written to the feature image file and it is used later by the F program to restore the feature image pixels to their original (before scaling) values during the sums calculations.

WRITEIMAGE filename, src [, header]

Write image number **src** to file **filename**. If the value of **header** is 0, no header is written to the file; if the value is 1, a Data Translation header is written. If **header** is not given, a value of 1 is used. Bytes 127 through 152 of the Data Translation header (the first byte of the header is called number 1) will be the scale coefficients A and B in FORTRAN format (1x,e12.6,1x,e12.6). No other values can be used for **header** with WRITEIMAGE.

WRITERESULT src, header, Q

FOR PROGRAM E ONLY. This is the same as command WRITEIMAGE, with two additional features. If **header** is 1, the value **Q** is stored in the file header in place of the value of the scale factor A. The file name for this result image output file is read from the scene list file (.sl), the first of the set of file names given for the scene, the name that takes the place of the name of the mask image in the scene list file used for the training process. If "+" is given instead of a file name in the scene list file (.sl), then the previously used result image file name is incremented and used here. The initial file name is SCSIDISK:\ri\ri000000.ri for ATR1, \ri\ri000000.ri for ATR2, and /usr/users/ri/ri000000.ri for ATR3.

XGRAD dst, src

Set image **dst** equal to the x-gradient (derivative with respect to x, the coordinate that increases from left to right) of the intensity in image **src**. The gradient values are calculated as $\text{gradient} = (\text{intensity}[i+1] - \text{intensity}[i-1]) / 2$. The first and last columns (left and right edges) of **dst** are set to 0. **dst** and **src** should be different images, of the same size.

XIMG dst

Set the value of each pixel in image **dst** equal to the pixel's x (column) coordinate.

XLIN01 dst, bright, tangle, opr

Extend lines found by LIN01. The "central" pixel in the local region of image **dst** is set equal to the weighted sum of the brightnesses of the line segments that are in the local region defined by the operator **opr** and are oriented in the direction so that their extensions would pass through the central pixel. The weights are the values of the pixels in **opr**. **bright** and **tangle** are the images containing the brightness and orientation data from LIN01. **dst**, **bright**, and **tangle** should all be different images, all of the same size. This operation uses overlap rows for both images **bright** and **tangle**. **dst** pixels in the excluded edge region defined by the domain of **opr** are set to zero.

XY2RT dstr, dstt, srcx, srcy [, xcl]

Convert a vector field from x-y representation to r-tangent(angle) representation. Images **srcx** and **srcy** contain the x and y component values. The vector magnitude will be put into image **dstr**, and the tangent of the angle between the vector and the x axis will be put into image

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