MIMA, A POWERFUL SYSTEM FOR SATELLITE MAP PRODUCTION

Håkan Malmström and Eva Cronström
Swedish Space Corporation
P.O. Box 4207, S-171 04 Solna
Sweden
Commission II

MIMA — the Mighty IMage Analyser — is a software system for satellite image processing, developed by Swedish Space Corporation (SSC). The software is installed on a TERAGON 4000 system consisting of hardware and basic software, from TERAGON SYSTEMS (TS).

1 BACKGROUND

SSC has more than ten years of experience in daily work with image processing systems. Through this work, much knowledge about the needs of efficient tools for image processing for beginner and expert operators has been compiled. SSC has been running the receiving station at Esrange in Kiruna since 1978. Here remotely sensed data from a number of satellites is received.

The construction of the small scale image processing system EBBA has added to the experience in and knowledge about system hardware and software design. By the early 80's, SSC had also gained a solid experience of existing image processing systems. By now it was known what type of image processing system that would be ideal for remote sensing application work. No system on the market at that time, held all of the desired features.

However, in 1982 a group of engineers from the Technical University in Linkoping, Sweden, founded a company, now known as TERAGON SYSTEMS. The concept presented by TS met with SSC's basic demands. Fruitful discussions and developments have since then resulted in an excellent system for remote sensing applications. As the contact between the hardware producer and the future software developer and user was established very early in the development process, SSC has been able to take part in and influence much of the work carried out by TS. This has also resulted in a system with a good balance between hardware and software.

2 TERAGON 4000 HARDWARE AND BASIC SOFTWARE

The enormous amounts of data that are handled in satellite image processing, force us to regard most other image processing systems as non-operational, at least for productional satellite image processing purposes. Three main characteristics of the TERAGON 4000 system are of vital importance for processing of satellite images in a production environment:

- fast dedicated processors
- fast data transfer
- virtual image memory
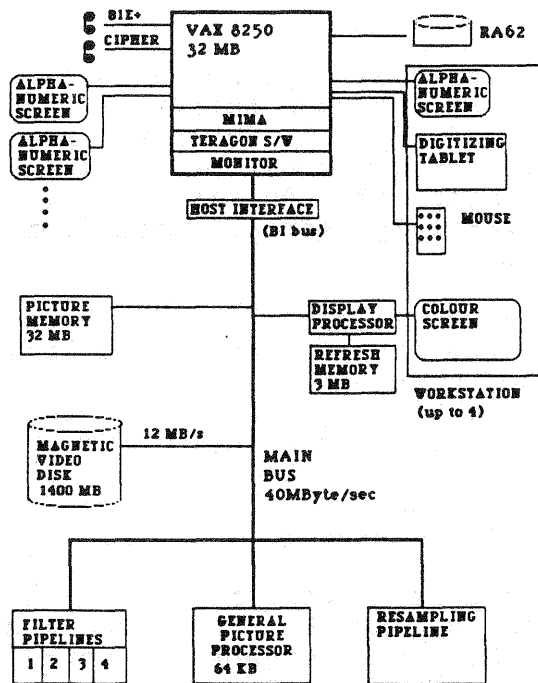
The hardware design is presented in Figure 1.

Figure 1: Hardware of the TERAGON 4000 system

Each TERAGON 4000 system can support up to four workstations. The host computer is a VAX — a microVAX or one of the 700- or 8000-series machines.

The processing capacity is very important for interactive work at the terminal. In the TERAGON 4000 system, dedicated processors filter a 1000 x 1000 8 bit image, with a 33 x 33 pixel filtermask, in 60 seconds. Resampling is another common operation with high demands in processing capacity. A resampling of a 28Mb 8 bit image with a 16 point resampling kernel, is in MIMA carried out in about 8 minutes.

The processing capacity is a nice feature, but it is not enough. To be of substantial help, it must be supported by a data transfer speed of the same magnitude. In MIMA this is the case, both as far as the transfer rate of the main bus - 40Mb/s - and the speed of accessing the disk memory - 12Mb/s, are concerned.

The virtual memory technique is of great importance for operators and application programmers working with MIMA. See Figure 2.
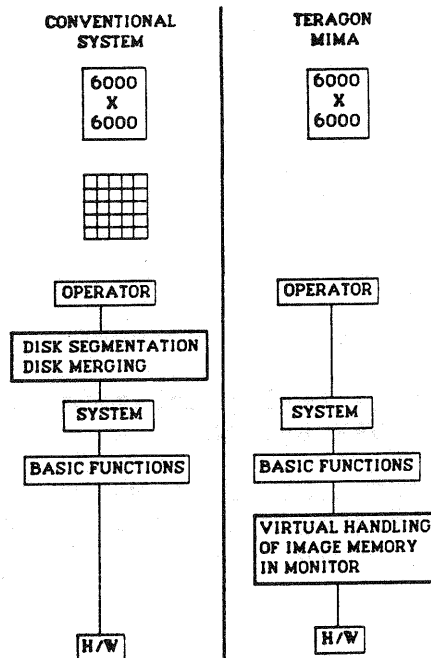

Figure 2: Segmentation of large images in a conventional system and in a TERAGON 4000 system

The possibility to work with complete images, for example a SPOT scene of 6000 x 6000 pixels, saves a lot of tedious segmentation work, and eliminates many erroneous segmentation calculations. The virtual image memory handling also means that the operator does not have to administrate the physical image memory himself. The only thing he needs to remember or care about is a reference to each image. In MIMA a user defined name is used as the reference to each image. The number and sizes of images handled by the system at any time are unlimited, restricted only by the amount of available disk memory.

The position of each of the images handled in MIMA is defined by a usermodel containing a virtual electronic table. Every image is positioned on the electronic table. In order to display the images on the screen, the operator positions a viewport over the table, and the viewport is then displayed on the screen. See Figure 3.

Table with images. Virtually unlimited in size.

Two viewports have been defined on the table.

The viewports.
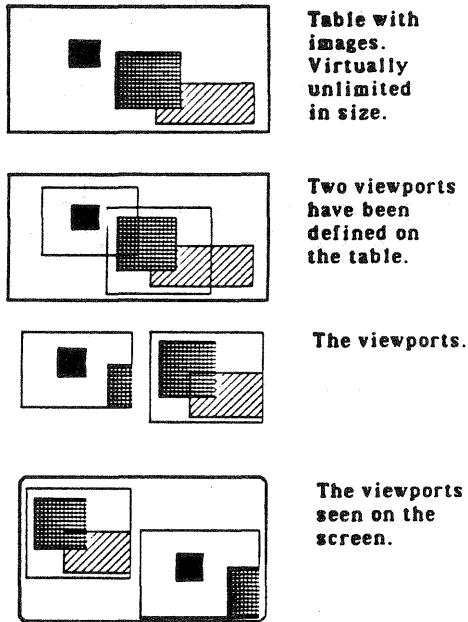
The viewports seen on the screen.

Figure 3: Display model for TERAGON 4000

The electronic table is virtually unlimited in size, limited only by "maxint" in the VAX system.

Finally, the TERAGON 4000 contains a well documented BASIC SOFTWARE, with good dialogue supporting and menu handling tools for the application programmer.

3 MIMA SOFTWARE

There are several demands on a software for remote sensing applications:

- good support for bookeeping of non-image information
- support for bookkeeping of geographic locations of each pixel in the system
- operator's interface designed for both beginners and experts
- safety system, ensuring no execution stops after hours of work
- tools for reading different magnetic tape formats
- well defined and efficient tools for carrying out desired operations

MIMA has been designed to meet with these demands.

3.1 Bookkeeping

The non-image information in general image processing systems are normally rather limited - lines, points, bits, etc. For remote sensing applications however, a number of additional attributes need to be linked to the image. This information may exist already on the magnetic tape, and may also be created during the image processing session. The goal has been to eliminate all notes scribbled down and spread around the work station, or lost in the mess on the desk.

Some of the types of information that are stored along with the image data in MIMA are:

- IMAGE HISTORY - information mainly added by the system as the different functions are run
- IMAGE DESCRIPTION - operator defined text information
- COORDINATE INFORMATION - transform between image and map coordinates
- LOOK UP TABLES - each image has several look up tables that can be loaded into the hardware at any time

When working with MIMA, the operator can concentrate on the actual analysis and processing work, and leave the bookkeeping to the system.

3.2 User Coordinates

After geometric correction of a raw image to a desired map projection, each pixel location in the image can easily be transformed to a map or ground coordinate system. This is done by defining a user coordinate system with five parameters. See figure 4.
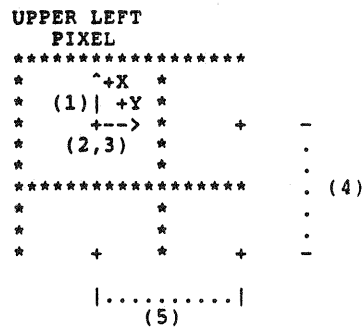
```
UPPER LEFT
   PIXEL
*******************
*      ^+X   *
*   (1)| +Y  *
*      +-->  *        +     -
*   (2,3)    *        .
*            *        .
*******************   . (4)
*            *        .
*            *        .
*      +     *    +   -

    |..........|
        (5)
```

Figure 4: Definition of user coordinate system by
          five parameters -
          1)Axis direction
          2,3)X0 and Y0 for centre of upper left pixel
          4,5)Scale factors in X and Y directions

307

The transformation is used when the operator is working in user coordinates. One of the advantages with user coordinates is that the operator does not have to care about lines and columns in the image coordinate system. He only has to deal with the coordinates he is used to, X and Y in UTM-coordinates for instance. Working directly in the desired coordinate system significantly brings down the rate of errors unintentionally introduced by the operator. See Figure 5.
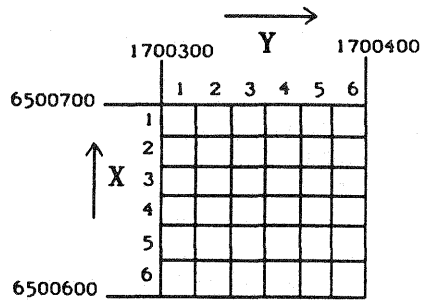
Figure 5: Coordinates in image data given in line/column and X/Y.

3.2.1 Subtables –

The user coordinates discussed above concern images. For handling map related data in MIMA, certain areas of the electronic table have been allocated to contain map information. These areas are named subtables. See Figure 6.
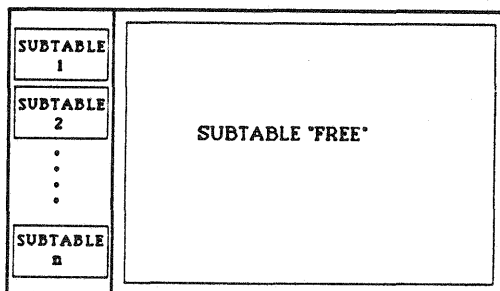
Figure 6: Electronic table with subtables to the left.

Each subtable is defined as a quadratic area on the electronic table. As it is defined in relation to ground coordinates, each position on the subtable can now be transformed to a position on the ground. The system swiftly handles all transformations, and allows the operator to work with ground or image coordinates, whichever is prefered at any given time.

The definition of the subtable ground coordinates is in accordance with the definition of the user coordinate system of an image, as described above.

Each subtable has a set scale and size. In house at SSC for instance, we have defined subtables covering Sweden in resolutions of 10, 20 and 50 metres. In line with what has been said before about the lack of limits in the system, the number and sizes of subtables are no more limited than the electronic table itself - virtually unlimited.

There are two main purposes for the subtable concept. When an image has been geocoded - resampled to a certain map projection - once, the MIMA operator no longer has to worry about the geographical location of the image. Once the correct user coordinate system for the image has been set, the system in the future automatically positions the image in the right position in relation to the ground coordinate system of the subtable. No more boring coordinate calculations and transformations!

The second reason for the subtable concept is connected to the effect of the human factor. Coordinate transformations done manually are time consuming, and often give erroneous results.

Image mosaicing is a process that heavily accentuates the advantages of the MIMA subtable concept. Each image to be mosaiced has been geocoded, and can therefore be positioned on the electronic table in the correct position without operator assistance. The operator can concentrate on the actual mosaicing work problems; where to cut the images and how how to equalize the radiometries, for instance.

3.3 Operator Interface

The characteristics of MIMA, described in detail above, provide the operator with a well tailored environment:

- images copied into MIMA, with their attributes like associated name, coordinates, layes and so on, are known to the system. All image names can be listed at any time, when requested by the operator.
- the operator can request a list of image attributes at any time.

- the complete history of any image in the system can be listed at any time. This information contains details on the origin of the image, the different processes the image has gone through, the parameters of these processes, and so on.
- the operator can enter a descriptive text for each image and each image layer. This descriptor is included in the attribute file.
- if desired, the operator can work solely in image or ground oriented X and Y coordinates, and must not deal with lines and columns.
- the number of images in the system is limited only by the available disk memory.

3.4 Operator Dialogue

The operator dialogue is of vital importance for system acceptance. A dialogue designed for beginners is often very informative but "talkative", and the expert operator get bored from answering all the questions all the time. On the other hand, a dialogue designed for experts is often very condensed. The beginner finds it vey hard and time consuming to get acquainted with the system. The ideal solution would be to give both types of operators – as well as the ones in between (probably in majority) who know some commands very well and some not at all – the possibility to choose which type of dialogue to use. This solution has been implemented in MIMA.

The executing commands in the system can be reached in two ways; either by stepping through a command tree, where the commands are sorted by type of process they perform, or by direct access.

The input of an executing command and its parameters can be done either by answering a row of questions, one for each parameter, or by entering the command and all the parameters on one single line. In the later case the questions are omitted, and will not appear on the screen.

The TERAGON 4000 basic software library for operator dialogue contains several tools for making the operator dialogue more efficient. The most distinguished of these tools are:

- BACKING. While inputing parameters sequentially, any already answered question can be recalled, and the answer changed. Input of a '<' steps the dialogue one question backwards, and the operator is again prompted for an answer. Input of '<<' reverses two questions in one step, and so on. After backing more than one question, the default answers of the intermediate, unchanged, questions have been updated, and a RETURN

will be sufficient to step forward and keep the correct answers.

- End Of Command. At any time, at any prompt, the operator can quit the ongoing function. This is done by entering '^EOC'. The answers entered into the quit function have no significance after the '^EOC'.
- Higher priority commands. At any time, at any prompt, the operator can choose to execute a higher priority command. The operator enters a '^', followed by the desired command. The ongoing command is "put on hold", the higher priority command is executed, and the execution of the first command is then resumed. All "bread and butter" commands in the system have high priority, and may therefore be carried out while executing other commands.
- Default value. All questions have a default answer. When answering a single question, the default value is used by hitting the RETURN key. When entering several answers on a single line – the experts way – a default answer is chosen by entering a '.'.

All the above described basic utilities are used in MIMA when applicable.

The alphanumeric screen layout has been designed to give the operator structured information on what's happening in the system. MIMA has separate windows for INFORMATION, LISTS, COMMANDS, HEADERS and ERRORS, which helps the operator to get a good overview of the information on the screen. See Figure 7.
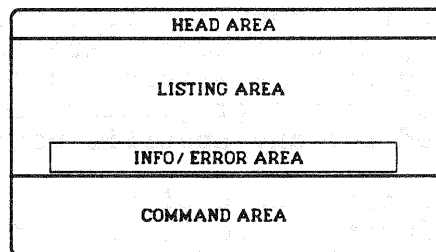


```
┌─────────────────────────────────┐
│           HEAD AREA             │
├─────────────────────────────────┤
│                                 │
│          LISTING AREA           │
│                                 │
│  ┌───────────────────────────┐  │
│  │     INFO/ ERROR AREA      │  │
│  └───────────────────────────┘  │
│                                 │
│          COMMAND AREA           │
│                                 │
└─────────────────────────────────┘
```

Figure 7: Layout of alphanumeric screen in MIMA

3.5 Error Handling

All systems contain errors of various types:

- errors caused by impossible answers input by the operator
- errors caused by bugs in the code
- errors caused by hardware incompleteness or breakdown

It is a well known fact that systems contain errors. The quality of a system can be evaluated by counting the frequence of error occurrence, and by studying how each error situation is handled by the system.

In MIMA the error situations are handled in two ways. Bad or impossible answers input by the operator are handled by status signals between the functions. Other errors like Ctrl/C entered by the operator or errors in MIMA are taken care of by the MIMA error handler. The standard VMS error handler is disconnected, and all errors are taken care of by the MIMA error handler. This concept ensures the operator uninterrupted work, with no risk of being "thrown" out of the system after hours of work. In the worst case, when an interruption occurrs during an ongoing function, the error handler ensures resumed execution at MIMA main level.

3.6 Magnetic Tape

Anyone familiar with remote sensing data from different sensor systems and different receiving stations, knows that there are an immense number of magnetic tape formats in use. In MIMA some frequently used standard tape formats can be read and stored on disk by using a simple command. It is easy for the MIMA application programmer, to make a tape reading programme tailored for any specific need.

Any "unknown" tape format can also easily be read using MIMA functions. The SCAN function tells the operator all he needs to know about the tape format structure, and the READ function lets him read the information on the tape and store it on disk.

3.7 MIMA Functions

MIMA contains some 95 executing functions. Many of these are of "bread and butter" type, and can be found in any system. In MIMA however, all functions can be executed on any size of image, no segmentation has to be carried out by the operator when processing large images.

The characteristic processing functions can be divided into 8 groups; BASIC, CLASSIFY, FILTER, GEOMETRY, GRAPHIC, INTERLAYER, MONOLAYER, AND MOSAIC.

BASIC
Combine selected – geometrically and radiometrically – portions of images
Convert between different bit depths
Invert images
Calculate, display, list and match histograms
Scale, threshold and update images radiometrically

CLASSIFY
Classify an image with up to twelve input layers

FILTER
Design, compile and run filters

GEOMETRY
Adjust an image location with subpixel offset
Geocode an image using control points from reference image or map
Roam on virtual table by pointing on map oriented on the digitizer
Rotate and scale images, with subpixel or full pixel precision

GRAPHIC
Draw and write in images
Read vectors from tape, convert them to raster, and display in overlay on colour screen

INTERLAYER
Add/subtract images with selected weights and offsets
Logical operations between images
Quotients of images

MONOLAYER
Run filters already designed and implemented
GAUSS
LAPLACE
MAJORANT
MEDIAN
MEXHAT
PREWITT
SOBEL
SWELLCONN
THINNINGCONN
VARIANS
ZEROTRANS

MOSAIC
Join two or more geometrically matching images by interactive drawing of joining line and semi-automatic radiometrical smoothing of transition zone

The basic philosophy when designing the MIMA functions has been the conviction that the operator is superior to any automatic system. The functions have been designed to be powerful interactive tools, in order to make the operator cost efficient when working with the system.

Two functions will be described in more detail; GEOCODE and FILTER.

3.7.1 GEOCODE -

Geocoding is the procedure where an image is resampled to a reference coordinate system. The reference coordinate system can be given in three different ways; via an earlier geocoded image, a map, or a list of geodetically measured points. The geocoding procedure contains three steps:

- marking of Control Points (CP's)
- calculating the coefficients for the geometric resampling formulas
- resampling of the image

This procedure is normally very time consuming, and the efficiency can be greatly increased by supplying the operator with powerful tools for this kind of work. The GEOCODE function in MIMA provides such tools.

The CP-marking process is done in three steps in MIMA.

1. Indicate area of interest in overview image(s). The overview image(s) are created automatically as the GEOCODE function is entered. When two images are used – one as the reference image and one to be geocoded – both of the entire images are shown simultaneously on the screen. See figure 8.
2. The indicated areas in 1 above are now shown in full resolution, and then the operator marks the areas to zoom.
3. The actual markings of CP's are done in zoomed versions of the images. The marked positions are presented with haircrosses, whereafter the operator can accept the marking, or go back to step 1 or 2, and then repeat the process.
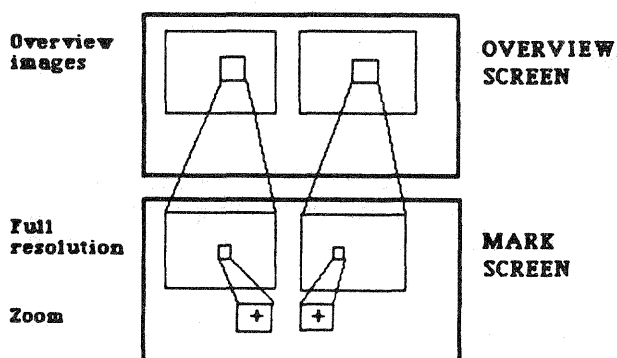
Figure 8: General screen layout of GEOCODE

After CP marking the operator can choose a polynomial of up
to the third degree. The choice is done interactively. Now
the calculation of the coefficients and the resampling can
be carried out. If the coefficient calculation shows a too
large RMS error, the calculation can be repeated with
different parameters before the actual resampling is carried
through. In order to improve the calculation result, the
operator can for instance:

- include more CP's
- exclude CP's from the calculation
- reinclude previously excluded CP's
- choose different factors to be included in the
  polynomial

3.7.2 FILTER -

The filter functions in MIMA, naturally can handle standard
matrix filters with coefficients. Apart from that, the MIMA
operator also can design his own filters interactively in
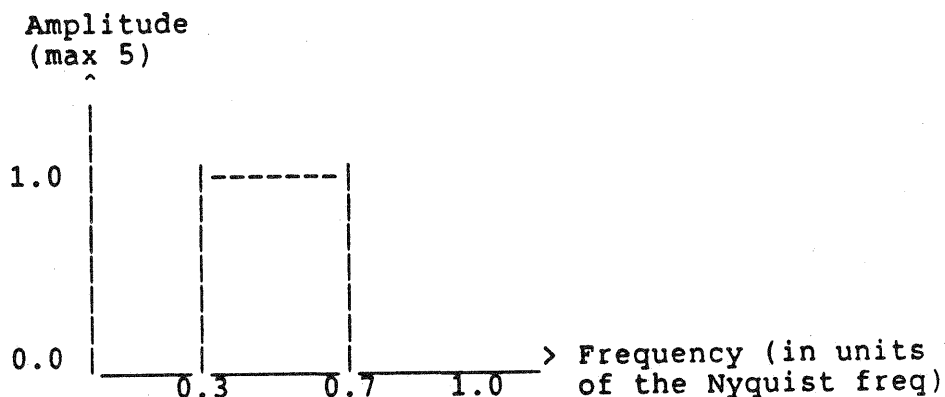the frequency domain. See Figure 9.

```
Amplitude
(max 5)
    ^
    |
1.0 |      |-------|
    |      |       |
    |      |       |
    |      |       |
    |      |       |
    |      |       |
0.0 |_____|_____|_____> Frequency (in units
       0.3     0.7     1.0       of the Nyquist freq)
```

Figure 9: A frequency resonse for a band pass
          filter has been defined by the operator

After defining the breakpoints of a one-dimensional
frequency response curve, and choosing the size of the
filter, the system calculates a two-dimensional rotation
symmetric response, plots the achieved response along with
the requested response on the screen, and then - if the
achieved response is accepted the operator - creates the
matrix filter.

4 SUMMARY

MIMA is a powerful software system for operational processing of large volumes of remote sensing data.

MIMA is based on the powerful image processing system TERAGON 4000, and designed to give optimal support for efficient interactive work for beginners as well as experts.