Interactive Image Processing in Cosmic Remote Exploration with GDR Image Processing Systems

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1. Introduction

The development of space technology has rapidly advanced aerospace exploration of the Earth and other heavenly bodies with the help of digital image processing techniques over the past ten years.

Nowadays, scanners on board a multitude of satellites are continuously generating masses of digital data (10^{15} bits/year). High-resolution satellite photographs, as those shot with the MKF 6 camera of VEB Carl Zeiss Jena, have to be digitized and processed. Multispectral techniques are an invaluable tool of aerospace terrestrial exploration. A particularly remarkable example of the type of equipment used for this technique comes from the GDR with the multispectral camera MKF-6. It has six channels covering the medium wavelengths of 0.48; 0.54; 0.60; 0.66; 0.72 and 0.84 µm. At a useful format of 56 x 80 mm the resolution is 160 lines/mm. An area of 120 x 170 km can be covered from an altitude of 250 km (resulting in a resolution of 6 m).

The fields and conditions of application vary just as much as the demands expected of the hardware and software for digital image processing systems.

- Processing:
  Individual pictures, experimental processing
  Masses of pictures, routine processing
- Resolution of digitized film imagery:
  1 mm to 10 µm
- Pixels per image: 10^3 to 10^9
- Data format of the shades of grey of the pixels:
  1 to 16 bits, floating point, complex
- Presentations of an object: 1 to 32
- Processing speed:
  Universal computer is sufficient/a special processor is required

The GDR image processing system described was developed for experimental processing of digital image data of remote sensing of the Earth. This places high demands on the resolution (number of pixels), on data formats, and on the number of images of an object. Characteristic features of remote sensing are:

- Masses of data:
  A single set of pictures shot with the MKF 6 camera results in about 100 M-bytes at a resolution of 10 µm
- Multiple image concept:
  Multispectral and multitemporal images and stereo pairs
- Resolution:
  Between 10 and 2000 m on the surface of the Earth
- Updating:
  Between 0.3 and 1000 days (from meteorology to cartography).

2. Interactive Image Processing System robotron A 6470

2.1. Application aspects

The industry and the research of the German Democratic Republic have a great tradition in image processing. Internationally acknowledged results have been achieved by a close cooperation with Soviet research facilities of cosmic remote exploration that initiated the era of computer-aided digital image processing with the processing of first photos of the moon side turned away from the earth in the year 1959.

The large experience of the German Democratic Republic in the field of air photo obtainment, processing and evaluation are utilized by many countries in the fields of photogrammetry, cartography, geology and geodesy.

Based upon the experiences and careful analyses of the requirements of various users as well as upon the international trends, the robotron A 6470 image processing system has been developed by the 'Zentralinstitut für Kybernetik und Informationsprozesse der Akademie der Wissenschaften der Deutschen Demokratischen Republik' and by the VEB Kombinat Robotron.

This A 6470 system is a modular high-performance interactive hardware and software system, which may be configurated in different models according to the application conditions.

The following application possibilities illustrates the efficiency of the robotron image processing system:

1. Visualisation of images as they are provided, for instance, by the multispectral scanner, by the radar and over TV-input.

2. Encoding and compressing of image information for a succeeding storage, transfer or evaluation respectively, e.g. by points lines and areas.

3. Improving the quality of images for the viewer, but also for the technical further-processing by image improvement and reconstruction.

   It includes:

   - Pseudo-coloration i.e. by means of look-up table one of the 256 values from a color area of 2^{18} values will be assigned to each pixel
   - Interesting features and objects are shown off by their edges, i.e. by means of special filters the edges and corners are strengthened.
   - Geometric correction of distortion and projection, e.g. as prerequisite for mapping.

4. Evaluation of images

   It includes:

   - Localization, recognition and identification of objects
   - Individual statements. The evaluation of images also enables the derivation of statements such as ice edge, forest fires, harvest results etc.
   - Feature determination and classification. At this place the multispectral classification is of a particular importance.

2.2. Hardware Configuration

The result of research and development work on digital image processing is a series of specific image-processing components according to the modular concept of the 16-bit microcomputer system robotron K 1600. The creation of image processing systems of varying capacity on the basis of this K 1600 microcomputer, given compatibility to DEC PDP-series or soviet computer CM 4 with 256 k-byte working memory; an additional arithmetic processor can be supplemented as well as other computer typical peripherals (magnetic tapes, printer, imag. processing periphery: floppy disk storages).

Display unit:

Image refresh memory can be organised along two lines:

- 768 x 512 pixels x 1 to 8 bits (image layers)
  or
- 1536 x 1024 pixels
  (at a diminished number of image layers)

Individual layers of image storage can also be separately assignet to graphics. In all cases only 640 x 512 pixels are simultaneously visible.

The display unit offers the following functions:

- Point operations (write, read, complementation)
- Windowing (PAN), i.e. write, read, erase
- Simultaneous magnification of both coordinates (ZOOM) in increments of 1 to 16
- Overlaying different cursor forms (fade out, fade in, small cross, cross-lines, blink, fixed)
- Look-up tables to assign one of 256 values of a colour range of 2^{18} to any pixel, independent of memory occupancy
- Displaying any image storage fragment
- Write mask (separate write protection for every bit plane)

A colour monitor is used to display the images.

Trackball:

The trackball is used to enter two independent increments or decrements for varied application, e.g. to control different functions such as video addresses and cursor position. It is also possible to trace the cursor path.

Film I/O Unit:

This input/output device is used for precision scanning or recording of original film imagery mounted on a drum. It uses a laser beam for this purpose, and the minimal dot size is 10 µm.

Image Store:

The image stores are of modular design in blocks of 512 x 512 x 8 bits each. Four of these modules belong to the standard equipment. These can be supplemented by another four modules for the storage of up to eight images in the format 512 x 512 bytes for processing by the display processor of the system.

Although image store and display processor are primarily conceived for the 8-bit word width, storage organization still permits other additional word interpretations. Interesting points in this connection are, for example:

- Higher accuracy by uniting two image storage modules each into an image store for 512 x 512 x 16 bits
  or
- Preparation of image data for binary or bit-serial processing of images by contracting the eight neighbouring points of each image point into a single byte.

The commands of the control computer will initialize the following modes of operation in the individual image storage modules:

- Read/write at video speed

The corresponding image in this mode is read out or defined under the time conditions of the video norm, i.e. the unit operates as an image refresh memory. Programmable functions in this context are the enlargement by integer-number factors up to 16-fold enlargements as well as the co-ordinates of the image point which represent the left-hand upper corner point of the image that is to be read out. This means that an indefinite number of interactive image manipulations are possible without changing the content of the image store, e.g. searching an image for interesting details.

- Privileged DMA Mode

This image storage function serves the purpose of fast data exchange between connected control computer and image memory. For this purpose, the microcomputer specifies the coordinates of the corner point, the format of the image fragment that is to be read out or described, and the number of one of eight possible access sequences. The image storage modules will operate at a maximum data rate of 1.5 M-bytes/s under this mode. This speed can be possibly diminished by the refresh operations for the 16 k-bit semi-coductor store that are required between two transfer cycles and from which the image store is set up.

- DMA Mode in Background

The background mode was introduced as an extra data exhange function because privileged DMA data transfer between image store and control computer causes interrupts of a video mode for the same image storage module. Storage access to return times of lines and image is thus assured without limiting the time flow of the video mode. Results show that the time for data exchange between microcomputer and image store module under this mode are perfectly sufficient for fast data exchange. For instance, a complete image can be read out or described within a few seconds.

Display Processor

Figure 1 shows the structure of the display processor. The switching network is designed as an input channel multiplexer which switches the eight images to the individual processing inputs of the display processor. The input channel multiplexer contains additionally several retaring registers. The combination of switching and retarding function makes it possible to feed the display processor with multi-images for context-dependent algorithms as well as single-channel images for the execution of local operations at video speed.

The elements of the three identical processor lines of the display processor are:

- Fast read/write stores which are loaded by the microcomputer and which function as look-up table (input function former). These transform the data according to given transformation rules; the output data are represented by 10-bit word width.
- The real-time arithmetic and logic unit (ALU) which links the transformed data into data of 12-bit word width by 32 logical and arithmetic functions.
- The maximum/minimum detector which establishes the extreme values in each image run for read out by the control computer.
- The norming unit which converts the 12-bit data of ALU into results with 10-bit word width according to a linear function defined by the control computer.
- The fast read/write store as look-up table which, similar to the afore-mentioned input function former, reverts the output data of the norming unit into the byte format (output function former) according to a transformation rule loaded by the control computer.
- Histogram generator and accumulator which calculates the image total and the distribution of intensity in the form of a histogram of the results image in each image run.
- Further function formers are switched between the outputs of the display processor and the digital/analog converter to generate the analog video signal to match the processed images to the colour dynamics of the monitor without influencing the processing function.

The following simple examples illustrate the manner of operation.

Linear Combination of a 4-channel Multispectral Image

This function, required for main axis transformation, for maximum likelihood classification and multispectral colour mixing, involves dot-by-dot execution of the following operations:

$$OUT\ 1 = a_1 \cdot IM1 + a_2 \cdot IM2 + a_3 \cdot IM3 + a_4 \cdot IM4$$

$$OUT\ 2 = b_1 \cdot IM1 + b_2 \cdot IM2 + b_3 \cdot IM3 + b_4 \cdot IM4$$

$$OUT\ 3 = c_1 \cdot IM1 + c_2 \cdot IM2 + c_3 \cdot IM3 + c_4 \cdot IM4$$

with the four images IM1, IM2, IM3 and IM4

Multiplication with the coefficients $K_m = (a_m, b_m, c_m)$ is conducted via the input function former, while the products are added with the arithmetic logic unit.
The 9 adding and 12 multiplying operations required for each of the image co-ordinates i and j are thus completed in 80 ns, i.e. the function is calculated with an image run of 40 ms.

Linear 3 x 3 Filtering of a Grey Density Image

This local operation requires the calculation of

$$Y_{i,j} = \sum_{m=-1}^{1} \sum_{n=-1}^{1} a_{m,m} \cdot X_{i-m,\ j-n}$$

for all image co-ordinates, i.j. This can be implemented by the following steps:

Step 1:

$$\text{OUT 1} = a_{-1,-1} \cdot IM1(j-1) + a_{-1,0} \cdot IM1 + a_{-1,1} \cdot IM1(j+1) \rightarrow IM2$$

$$\text{OUT 2} = a_{0,-1} \cdot IM1(j-1) + a_{0,0} \cdot IM1 + a_{0,1} \cdot IM1(j+1) \rightarrow IM3$$

$$\text{OUT 3} = a_{1,-1} \cdot IM1(j-1) + a_{1,0} \cdot IM1 + a_{1,1} \cdot IM1(j+1) \rightarrow IM4$$

As in the previous exemple, the multiplications with the coefficients are conducted via the input function former, and the products are added with the arithmetic logic unit. The operation $(j \pm 1)$ is completed in the switching network.

Step 2:

$$\text{OUT 1} = IM2(i-1) + IM3 + IM4(i+1)$$

The reloaded interim results in the image stores, 2, 3 and 4 are summed up in this second image run.

This example takes up a total computing time of 80 ms; 9 multiplication and 8 adding operations are completed for each coordinate (i, j).

2.3.1. System Concept

The objectives of an interactive image processing system are:

- Simple to operate by useres (not programmers) form different fields of application.
- Utmost flexibility to satisfy the reqirements of experimental processing
- Continuously expandable because no boundaries should be imposed upon the scope of user capabilities in experimental systems.

The program system uses the operating system M00S of K 1600, (compatibel RSX 11 M) and it consists of universal, variably applicable function modules which, together with a standardised data base (virtual image), implement elementary functions of image processing, and of a control program. The function modules are activated by the user with commands that have a simple syntax and are immediately processed. Alternatively, they can also form elementary functions of a memory-resident commands program.

2.3.2. Data Base of the Digital Image Processing-System

Masses of data are typical of digital image processing. That is why low-cost data carriers with a high storage capacity (normally magnetic tapes or films) are used for longterm storage. During actual processing, however, fast and random access is decisive for the processing time. The manipulation of a window or fragment of an image is often desirable in large images.

Hence, a temporarily standardised data base - the virtual image - was defined for processing. This digital image is organised as a block-oriented file on external storage. The system offers the capability of selective output of the virtual image for long-term storage or for visualisation. Next to the digital image data, the virtual image contains a virtual image description table (VDT).

The computer print-out shown in figure 4 indicates the contents of VDT, as available to the user. The decisive influence exerted by the virtual image on the flexibility of the system is revealed by the indicated contents of VDT.

Image Type

By overlaying a raster network on a picture (e.g. a photograph), the picture plane is divided by the resulting matrix into an array of small units called picture elements of pixels. A mean value of the shades of grey is attributed to these addressable pixels to produce a raster-format image, otherwise known as the digital image. In addition there exist also compressed imagery of partial aspects of image contents, e.g. runlength code, chain code or vectors. A picture type "array" is declared for the parameter fields to define a maximum 6-dimensional field.

Image Size

This is defined by the number of image rows and columns. Practically any number of rows and columns can be defined.

Data Type

The simplest case requires distinction between image objects and background, i.e. whether an image element is black or white, that is only 1 bit per pixel. In many instances one byte (i.e. 256 grey shades) will be sufficient. Storage space considerations also call for intermediary forms of 2 or 4 bits per pixel. Image processing may also often require the notation of the grey shade in a single word (16 bits), as a floating-point number, or as a complex number by up to 64 bits.

Storage Type

An image processing system generally involves several forms of imagery (multispectral, multitemporal, multilocal) of an image (multiple image). Six forms of storage are available for imaging, such a 3-dimensional image (fig. 5) on the single-plane address space of disk storage. The need to include also imaged processing results (e.g. class assignments) in the multiple image, also with another data type than the initial image, suggests itself.

These two types of image layers are defined by the terms numeric and symbolic bands.

Communication Record

It is possible to store an annotation in the virtual image description table (VDT) - e.g. source, date, recording condition, etc.

Pixel Access Control

Efficient access to the single pixels must be assured with complicated imagery also in adverse cases. This is accomplished by calculating four mapping coefficients for the numeric and symbolic bands for entry in VDT while it is being created. Further-going processing is supported by a set of macros. A pixel coordinate I, J, K is transformed in 32-bit address spaces for numeric and symbolic bands which can be used as virtual block number - offset in block and as mask for symbolic bands - for access to the bit patterns (4, 5).

Image Control Table

The contents of the image control table are evaluated by all function modules fortthe flow of control. The presence of two independent image control tables affords manipulations of the same image, e.g. to compare two bands or fragments. These control tables can be used, among others, to define image windows, to mask bands, and to change scales and index sequences. The latter are useful to rotate and transpose images.

The minimum, median and maximum value of the grey scale of each band, and the covariance matrix, are calculated and entered in VDT to set up the virtual image. This gives the data base the following characteristics:

- It contains image data and control information for processing.
- Access to the points of the virtual image is supported by a set of macros.
- The necessary input/output operations are transparent for the programmer.
- An infinite number of buffers is possible; the use of the buffers is optimised by the access macros.
- The session directory assigns a user's image name to the file name.

2.3.3. Few Image Processing Functions

Commands for data management and information

Commands to manipulate the image description table (VDT)

Commands for pixel by pixel processing

The distribution of the shades of grey of an image, the histogram, can be presented in the form of tables or graphics (HISTOG). The shades of grey can be transformed by any characteristic (CONTRAST. LUTRANS). Pixel by pixel arithmetic operation of digital images is likewise possible (ADD, SUB, MUL, DIV, MOV). The finite-pulse-response-filter, implemented to an operator magnitude of 15 x 15 (FIR-Filter), can be utilized in a diversity of ways through appropriate selection of the coefficients. A median filter (MEDIAN) with freely selectable operator field, is available.

The methods of classification, as associated with terrestial exploration from space, are represented by a supervised method (BAYES, BAYESK, TREC, TREL), and by an unsupervised one (CLUSTER).

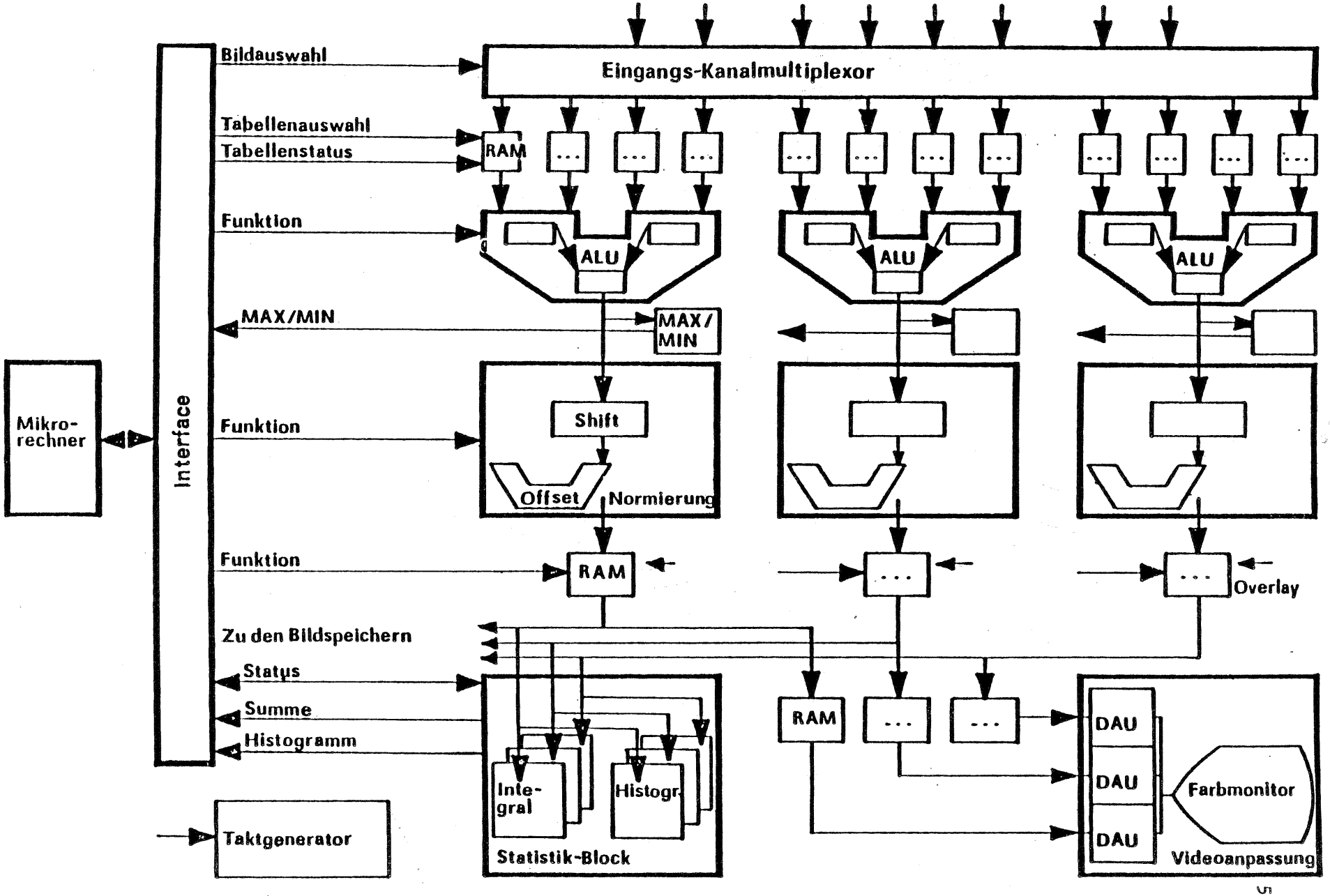
The cursor can be used to mark picture elements and sections on the display screen. The marked picture elements are used to establish the coordinates and the grey shade, to gain the geometric characteristics of the contour, and to fill these with the given shades of grey (POLYGON, CONTOUR).

3. Sale

The image processing systems Robotron A 6470 can be ordered by Robotron-Export-Import, Berlin, GDR.

4. Note

Main parts of description are based on publications of J. Saedler, R.-J. Vilser, W. Schulze, V. Kempe and B. Rebel in "Neue Technik im Büro", No. 3 and No. 4 (1982), VEB Verlag Technik, Berlin, DDR.



Struktur des Displayprozessors