UNIVERSAL DIGITAL IMAGE PROCESSING SYSTEMS IN EUROPE - A COMPARATIVE SURVEY

by

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Abstract

In the paper, a selected group of eleven universal (computer based) image processing systems is surveyed and compared. They constitute a seemingly representative sample of the vast variety of such systems built in the last decade in European countries. The survey covers systems built for research purposes, either in image processing as such or for some other specific problem area, as well as more practically-oriented ones, including a commercially available routine picture analyzer. An overall classification of their general aims as well as basic parameters and features of their hardware structure, software support and application area is given.

1. Introduction

The purpose of this paper is to cast an overall glance at the vast European scene of universal image processing systems designs. In many different research institutions all over Europe there were designed or are being constructed various such systems, aimed either as tools facilitating basic research in digital picture processing or as practical devices for some more or less specific application. They are often constructed independently of the other analogical constructions existing or planned elsewhere. Their structure and parameters are frequently selected on ad hoc basis or result from specific limitations of chance elements (or building blocks) "just at hand" at the time of the system construction. As it is therefore understandable, they represent a great variety of structures, technical parameters as well as usage modes. Nevertheless, some general features can be found in this variety. The goal of this paper is to put some order in it, providing thus some guidelines for future designers, to help them in their own system development.

Because of rather great number of groups interested in picture processing and building their own systems, it was of course impossible to make this survey fully exhaustive. The main criterion of selection has been simply the familiarity of the author with the system, either personal or through generally accessible scientific literature and a sort of a questionnaire sent to the designers (see Acknowledgments section), or both. Several systems, less known to the author (lacking enough technical data to fill in the tables below) have had to be therefore excluded. For example, it resulted in omitting several seemingly interesting systems developed in FRG (see [6]) about which I have got too fragmentaric informations and too late to be able to collect them for this survey.

Furthermore, only universal systems have been considered, i.e. that easily programmable for different tasks of sufficiently wide problem area. In effect, all of them include such or another programmable digital processor used to process pictures: a general-purpose (mini-)computer or a special hardwired image processor. Finally, all ERTS (Earth Resources Technology Satellite) image processing systems have been deliberately excluded from this survey, as they are a class by itself, having rather specific single source of images and their own specific analysis techniques, emphasizing classification of single pixels described by multispectral data, rather than contextual processing of two-dimensional shapes in the picture.

In spite of this non-exhaustiveness, the small set of only 11 systems surveyed here seems to be in several respects quite representative for the diversity of European image processing systems. I apologize for all omissions of the systems whose features substantiate them to be included in any such survey pretending to be representative. Any system designer confident that his system should have been included here is encouraged to send the system characteristics to the author - it will eventually help in preparation of the next version of the survey. The first version of this paper was presented at the EUSIPCO-80 conference in Lausanne [34], and was also included in the materials of the associated course on Parallel Picture Processing [35]. The materials of this course contain also descriptions of several other image processing systems (mostly of the d-type, see below), not surveyed here.

2. Image processing systems

All systems surveyed here are listed in Table 1. In the text they will be referred to by names given in the first column. Those having no name will be "called" by the first three letters of the name of the laboratory head (see [6, 7]).

The systems can be classified according to their general goals. The following classes are distinguishable:

Table 1. Some European image analysis systems.

Name	Country	Institution	References
CELLO	Sweden	Department of Clinical Cytology, University Hospital, Uppsala	[1 - 4]
(Nag)	FRG*)	Fachbereich Informatik, Universität Hamburg	[5, 6]
(Leb)	USSR	Institute of Information Transmission Problems, Moscow	[7 - 9]
BIHES**)	Hungary	Computer and Automation Institute, Budapest	[10 - 12]
MODSYS***)	FRG	Fraunhofer-Institut für Informations- und Daten--verarbeitung, Karlsruhe	[13 - 16]
CPO-2	Poland	Institute of Biocybernetics and Biomedical Engineering, Warsaw	[17 - 20]
VIP	Italy	Istituto di Cibernetica del CNR, Arco Felice (Napoli)	[21, 22]
PICAP	Sweden	Department of Electrical Engineering, Linköping University, Linköping	[23 - 26]
CLIP 4	England	Department of Physics and Astronomy, University College, London	[27, 28]
GOP	Sweden	Department of Electrical Engineering, Linköping University, Linköping	[32, 33]
Leitz T.A.S.	France & FRG	I.R.S.I.D. et École des Mines de Paris (license); Ernst Leitz Wetzlar GMBH, Wetzlar, and R. Bosch Fernseh-Anlagen GMBH, Darmstadt (production)	[29 - 31]

*) Federal Republic of Germany; **) Budapest Intelligent Hand-Eye System;

***) Final version has been recently renamed S.A.M. (Sensorsystem for Automation and Measurement).

a) Systems created as tools to investigate some specific scientific problem with computational means: not intended to be multiplied in several copies; the principal goal is to solve the problem rather than to build a system (CELLO, (Nag), (Leb)).

b) Systems created as general purpose (although simple) image processing devices: intended for a wide range of processing tasks; rather research- than application-oriented; eventually with some perspective of building several copies for different users; the principal goal is to build a universal system for research in image processing itself rather than to solve some specific application problem (VIP, CPO-2).

c) Systems intermediate between the two above types: with some specific application in mind (e.g. "robot-eye") but universal enough and serving as a "research prototype" rather than a unique laboratory assembly or a finished production model; the principal goal is to build a fairly universal system, although good for some specific application (BIHES, MODSYS).

d) Systems experimenting with new computer architectures for two--dimensional data processing inherent for image processing: used to gain experience in effectiveness of the proposed set of hardware operations and memory organization; the principal goal is to build an effective and universal new processor rather than a simple and cheap "working" assembly of existing devices (PICAP, CLIP 4, GOP).

e) Commercially available systems for routine picture analysis: universal enough to be usable in sufficiently wide range of different practical tasks but simple enough to be feasible for production and marketing; the principal goal is to cover a wide range of rather simple routine applications, yet worth of automatization, due e.g. to massive amounts of analyses required (Leitz T.A.S.).

How these general systems goals influence specific construction features will be shown in the next three sections, discussing hardware, software and application aspects of the systems.

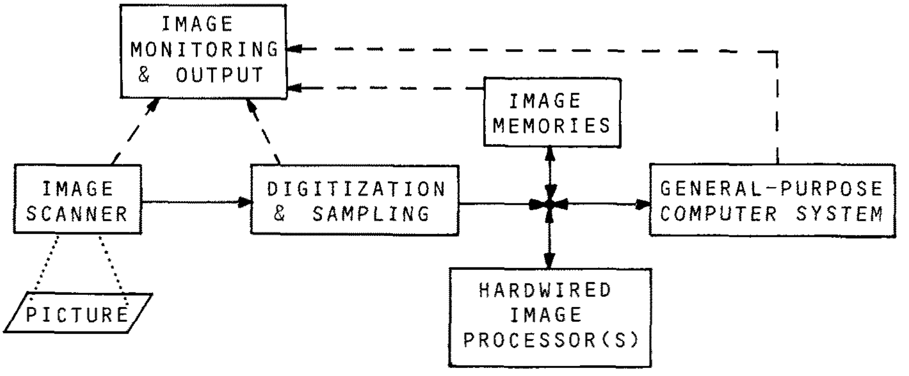

Fig. 1. General scheme of a universal image processing system

3. Hardware structures

The general configuration of a universal image processing system can be schematically drawn as in Fig. 1. Depending on the type of the system as given in the previous section, different parts of this scheme become more important. For the type (a), the central part is the computer in which all processing is done, and the image scanner and output are simply computer peripherals making it possible to input/output the necessary data. They are built (or bought) to fit best the needs of the particular problem. Hardwired processors and image memories are usually absent - the latter are eventually used to extend the computer memory or as flexible display buffers. In the systems of the type (b) and (c), the role of picture input/output and the computer is equalized, image memories are used as input image buffers, hardwired processors are usually absent due to cost considerations and not yet too advanced state of the art. The type (d) systems are built around the proposed hardwired processor. The image memories are partially contained in the processor and partially used as picture input/output buffers. The computer serves as a supervisor facilitating programming and non--pictorial communication with an operator. In the systems of the type (e), all parts are highly integrated, the hardwired processor is an important part, although mainly capable of performing simple counting of picture features on binary images (areas, components, etc.) rather than full-scale of multivalued picture processing.

Table 2. Image input/output devices.

System	Input scanner		Sampling:	Digitization		Output devices
	Type	Scan time	in pixels	Gray levels	Thresholds	
CELLO	OSIRIS: linear diode array mechan. scanned	30-60s	256 × 256	64 (256)	fixed, with software normalization	TV b/w & colour, Versatec
(Nag)	TV	~1s	574 × 512	256	?	COMTAL diplay, Facsimile writer
(Leb)	OPTRONICS P-1700 drum scanner	(large)	max: 1024 × 1024	256	fixed	TV b/w & colour, OPTRONICS P-1700 microfilm plotter
BIHES	TV (vidicon)	20ms	144 × 192	16	off-line control	Tektronix 613 (storage tube)
MODSYS	TV or diode array	20ms	380 × 256	2	fixed	(TV)
CPO-2	TV (vidicon)	40ms	512 × 512	16	hand & computer controlled	TV b/w & colour
VIP	TV (plumbicon)	20-320ms	256 × 256	2 - 16	single threshold computer contr.	Versatec
PICAP	TV	40ms	64 × 64	16	computer contr.	TV b/w & colour
CLIP 4	TV	(20 or 40ms ?)	96 × 96	64	?	TV b/w, Versatec, Tektronix 611, Microfilm plotter
GOP	TV, laser drum scanner	40ms, ?	512 × 512, 4096 × 4096	256	?	TV colour, laser drum plotter
Leitz T.A.S.	TV (plumbicon)	40ms	256 × 256 hexagonal	2: normal or "sliced"	settable to 100 levels	TV colour

The computer (frequently a microprocessor) is used mainly for further elaboration (e.g. statistical) of obtained counts.

In the Table 2 some technical parameters of the image input/output part of the surveyed systems are given. The differences between various types of the systems can be seen quite markedly. The (a)-type systems (CELLO, (Nag), (Leb)) are characterized by usually large number of gray levels (256) and usually special input scanners. For the (Leb) system, its application for image enhancement enforces an accurate and high-resolution image acquisition and hardcopy output. In CELLO, to achieve densitometric accuracy in medical specimens scanning, a special OSIRIS vibrating-prism scanner was adopted (see references in [1, 3]) and the sophisticated light-sensitivity, shading and positioning correction software system run on a dedicated PDP 8/f computer was built [3], see Table 3. In the (Nag) system, however, a standard TV input was applied - it is justified by its use for off-line research in image sequences analysis (e.g. road traffic monitoring), so that less accuracy suffices. The scanning time is also not critical, due to an off-line research-oriented mode of system's usage. It required anyway the storage of sufficiently long image sequences. A large--capacity image memory was needed for this purpose. Here, an analog TV-disk capable of recording 600 TV-frames (Table 3) was employed. All the above systems are therefore characterized by rather slow but usually accurate scanners (except partially (Nag)), great number of pixels scanned (except partially CELLO) and large number of grey levels (usually 256).

All other systems use standard TV camera as an input scanner - it is easily accessible, low-cost, easy in use and accurate enough for general-purpose applications. It is interesting that none of the systems surveyed use flying-spot scanners - they are expensive and limit the form of input pictures, and are used rather in some special-purpose systems (of the (a)-type, e.g. for particle tracks images analysis in nuclear physics). The TV-camera input scanners discussed here (other than (Nag)) sample and digitize the input in real time, i.e. during a single TV-frame, or even half-frame in the case of smaller resolution. The number of pixels is usually small in the (d)-type systems (PICAP: 64 × 64, CLIP 4: 96 × 96). The small number of pixels results from the dimensions of a special parallel or semi-parallel processors array included in these systems -

larger dimensions would result in too big costs and less reliability of the hardware. This small picture "window" can be usually moved over an entire TV-frame and used with different pixel spacing (PICAP). In the CLIP 4, the window is unmovable - the aim of this system is basic research in parallel image processing however, so that an input flexibility has been of secondary importance and made rather simple. The exceptionally high resolution of the GOP system is due to different organization of the processor: the large (up to 512 × 512 pixels) image matrices held in the processor memories are processed by four parallel "computation pipelines", reading the memory in a "rolling" fashion. There is, in fact, no parallel array of processors: the parallelism exists in fetching pixels of the neighbourhood (up to 64 × 64 pixels), but the image scan is performed serially (similar principle was actually applied also in PICAP system).

Practically all systems employ sampling with a square raster. The very interesting exception is the hexagonal raster of the Leitz T.A.S. system. The hexagonal raster has advantages of uniform structure of the local point neighbourhood (no connectivity paradoxes), and smaller number of points in this neighbourhood (25% gain in local operations specification). Its disadvantage, among others, is nonuniform representation of the natural horizontal/vertical coordinate lines [23].

The number of gray levels is usually 16 for most of the non-(a) -type systems, except MODSYS, GOP, Leitz T.A.S., and partially VIP. The latter operate usually on binary (2-level) images. It is much simpler and faster than processing of many-valued images, and it is quite sufficient in a wide range of applications, especially for good quality, high-contrast pictures. Additionally, in many systems the digitization levels can be shifted by the computer, making it possible to discriminate potentially between great many shades of gray (CPO-2, VIP, PICAP, Leitz T.A.S.). For example, in the VIP system, which main aims were simplicity and low cost, a single, but computer-controlled threshold allows an acquisition of images with many (usually 16) gray levels in the course of several input cycles. Similar solution was adopted in the Leitz T.A.S. system, where, additionally, the threshold can be used in a "sliced" manner (setting to the value 1 all pixels between some narrow grey range required).

All systems process basically black/white (uncoloured) pictures, although some experiments with colour input were done e.g. with (Leb) system and prospective processing of colour (or multispectral) images was assumed for GOP system [33]. The processing of coloured pictures is undertaken anyway by some other groups not reviewed here (see e.g. [6]). Nevertheless, most of the systems use coloured TV output devices to enhance legibility of pictorial results and facilitate interaction with the user with the technique of "artificial colours" (assigning any required colours to pixel values).

Most output devices used are TV monitors (black/white and/or colour), seemingly, like TV-cameras, because of easy availability, easy maintenance and low cost. Eventually TV-like graphic displays are used. For producing hard-copy output, an electrostatic plotters (usually Versatec) or similar facsimile writers are employed. High quality hard-copy output requires microfilm plotters anyway ((Leb), CLIP 4), or laser drum plotters (GOP).

Image processing devices are summarized in Table 3. Picture memories are of various types. Some are simply small buffers facilitating image data input into the computer memory (VIP), other larger TV-refresh memories (CPO-2, CELLO, (Leb)) or "true" image memories controlled by hardwired processors (MODSYS, PICAP, CLIP 4, GOP, Leitz T.A.S.). A somewhat uncommon solution was adopted in (Nag), where analog TV-disk was used - it is justified by the character of this system purpose (see above). TV-refresh memories should of course work with TV-speed, although sometimes, for slower memories (e.g. 1.5μs magnetic cores in CPO-2) it requires a little tricky read/write circuits organization. For small number of gray levels, pictures are usually stored as a stack of bit-planes (single-bit pixels packed into words; different bits of a pixel grey level representation placed in separate bit-planes: CPO-2, CLIP 4, GOP, MODSYS, Leitz T.A.S.). For larger number of gray levels, pixels fit well into bytes, so that the pictures can be stored as arrays of bytes (CELLO, GOP, probably (Leb)). A somewhat uncommon run-coding scheme has been also employed in MODSYS.

Hardwired processors are of course the heart of (d)-type systems (PICAP, CLIP 4, GOP). They implement parallel local (3×3 neighbourhood) logical and arithmetical operations on binary (CLIP 4) or 16-level (PICAP) images, or, in GOP, "general picture

Table 3. Image processing devices.

System	Picture memories: Type	Picture memories: Pixel packing	Picture memories: Capacity	Hardwired proc.: operation types	Computer: Type	Computer: Oper. memory
CELLO	semicon-ductor	array of pixels	512 × 512 × 8b.	planned: image segmentation units	PDP 8/f, PDP 11/55, LSI 11	128kwords 16b.
(Nag)	AMPEX MD 400 TV-disk	-	2 × 600 frames	-	4 × MINCAL 621 (PDP 10)	784kBytes total
(Leb)	semicon-ductor	?	?	-	ALPHA 16 (US mini)	32kwords 16b.
BIHES	?	?	16kBytes	-	VIDEOTON R-10	20kwords 16b. (2μs)
MODSYS	?	pixel array or run-length contour coding	256 × 512b. + 4k × 16b.	propagation; counting	Z-80	potentially more than 8Mbytes (?)
CPO-2	magnetic cores	stack of 4 bit-planes	4 × 16kwords 16b.	-	K-202 (Polish)	44kwords 16b. (1.5μs)
VIP	shift register	16 one-bit pixels/word	4 × 16b.	-	HP 21MX (2108)	32kwords 16b. (0.8μs)
PICAP	shift register	-	3 × 64 × 64 × 4b. + 9 × 64 × 64 × 4b.	semi-parallel, local, logical & arithmetic	Datasaab D5/30 (Swedish)	128kBytes
CLIP 4	shift register	bit-plane stack	2 × 96 × 96 × 6b. + 96 × 96 × 35b.	parallel, local single-bit & propagation	PDP 11/10	?
GOP	?	array of pixels or bit-plane stack	16kwords 16b., 16kwords 20b., 8kwords 16b.	local semiparallel arithmetical convolution: "General Operator"	Eclipse	128kwords
Leitz T.A.S.	?	bit-planes	8 × 256 × 256b.	hexagonal, local & propag.; counting	LSI 11/2	64kBytes

processing operator" [32] local arithmetic convolution (with the neighbourhood size up to 64 × 64). They are realized either in a truly parallel fashion (CLIP 4: an integrated array of 9216 processors [28]) or semi-parallelly (PICAP: single many-instruction local processor shifted around the picture by means of the zigzag shift register [23]; GOP: four parallel pipelined processors scanning serially an image memory with a "rolling" fashion [33]). The propagation operations and also (in PICAP) sequential local operations can be performed. In GOP, the other part of the processor performs (serially) an analysis of the results of local processing and controls the local processing part (e.g., choosing an appropriate convolution mask). Anyway, in other systems, analogical (although simpler) picture processors can be found (MODSYS, Leitz T.A.S.), capable of performing local logical operations on binary images and "counting" operations. Their appearance in the commercial systems like Leitz T.A.S. signifies their coming into "mature age", as they acquire wider practical applicability, not only a laboratory, experimental status.

Computers used in the surveyed systems are usually single micro- or minicomputers of various types. It is interesting to notice two multiprocessor systems (not surprisingly, of the (a)-type: (Nag) and CELLO). Operating memories of these computers are as a rule not small (the minimum seems to be 40kBytes: BIHES), but rather large (up to the order of hundreds of kilobytes: CELLO, (Nag)). It is of course required for any nontrivial picture processing: real pictures carry rather large amounts of information.

4. Software support

The features of the software systems are listed in Table 4. The programming languages used for image processing are divided into three categories:

- basic language: in which all lowest-level picture handling is written,
- intermediate language: more problem-oriented, although not too high-level,
- high-level language: source language for easy application programming.

Usually the assembler of the system computer serves as a basic

Table 4. Image processing software.

System	Basic language	Intermediate language	High-level language	Picture representation
CELLO	FORTRAN IV-PLUS; MACRO-11 assembler	FORTRAN IV-PLUS	CELLO interactive	Array with 1 pixel per byte
(Nag)	Assembler	PASCAL (?)	SAIL	File of lines; line: packed array of bytes
(Leb)	ALPHA 16 assembler	-	FORTRAN	Array with 1 pixel per byte
BIHES	R-10 assembler	PLM macrogenerator	MODBUIL (in PLM) for 3-D objects manipulation	?
MODSYS	Z-80 assembler	PLZ/ASM (assembler-like)	PLZ/SYS (PASCAL-like)	See Table 3
CPO-2	ASSK-3 assembler	PICASSO-SHOW interactive	-	Bit-planes stack or packed (1, 2, 4 or 8 pixels per word)
VIP	HP assembler	-	FORTRAN IV	Packed array: 16 pixels per word or 4 pixels per word
PICAP	PICAP code; DAL 53 assembler	DEFPRO interactive macroassembler	FORTRAN; PPL interactive	Packed array; Run-length coding
CLIP 4	CAP-4 assembler	-	-	Bit-planes
GOP	Assembler	FORTRAN	INTRAC interactive	Array of pixels (?)
Leitz T.A.S.	(LSI 11 assembler ?)	TIP ("push-button" lang.)	TASIC (BASIC-like)	Bit-planes

language. For the (d)-type systems the machine language of the underlying image processor becomes basic: either only it (CLIP 4) or mixed with the computer language (PICAP, GOP). In other systems, sometimes FORTRAN becomes basic, eventually with some help of the assembler (CELLO). As intermediate languages we find various assembler-like languages (BIHES, MODSYS, PICAP), FORTRAN (CELLO, GOP), interactive picture processing language interpreter (CPO-2), "push-button" command language (Leitz T.A.S.), or even PASCAL (Nag). As highest-level languages often FORTRAN is reported (VIP, (Leb), PICAP) or other high-level languages standard for the given computer ((Nag), MODSYS). In other cases, various image processing languages designed specially for the given system or problem area (BIHES, CELLO, PICAP, CPO-2, GOP) or specialized versions of general-purpose languages (Leitz T.A.S.) are used. For several systems, a construction of new high-level image processing languages is planned (ILIAD for CELLO, PAL for CPO-2, PIXAL for VIP).

All systems, especially those having no image processing language, maintain growing libraries of subroutines for basic picture operations or picture processing algorithms. They are usually written in the basic language for run-time efficiency reasons, and sometimes constitute a base for the interactive image processing languages devèloped later on these systems (CELLO, CPO-2, Leitz T.A.S.). This way of development seems to give fairly good effects - it produces quickly something like simple high- (or medium-)level image processing language with widely applicable and effective (in run time) instruction set.

Representation of processed pictures in the computer memory is usually the same as in the image-memories (see Table 3). Sometimes it is adjusted to the features of the language used (Nag) or additional packing schemata are available (CPO-2, VIP, PICAP). The picture representation problem is quite important for efficiency of the processing (if it is done in the ordinary computer), especially for pictures having small number of grey levels (e.g. binary). In this case, appropriate packing of pixels saves memory space as well as allows for appplication of a so-called semi-parallel realization of picture operations on ordinary computers, which results in significant gains of the processing time for some classes of operations [17, 18, 20].

Finally, it should be noted that the task of surveying software

Table 5. Applications.

System	Mode of usage	Basic application areas	Main application example
CELLO	Algorithm development for biomedical applications	Automated cytology	Automated prescreening of pap--stained cervical smears [2].
(Nag)	Research in moving images analysis	Road traffic monitoring	Separating background from moving objects in image sequences [5].
(Leb)	Research and application of image enhancement and filtering	Space probing, Biomedicine, Digital holography	Noise cleaning in pictures from interplanetary MARS and VENUS stations [8].
BIHES	Research in 2-D and 3-D scene analysis	Industrial robot-eye, Workpiece handling	Recognition of bus-body sheets in a paint-spray workshop [12].
MODSYS	Practical visual sensor system for industry: research prototype	Industrial robot-eye, Automatic inspection, Workpiece handling	Recognition of noneverlapping workpieces on a conveyor belt [15].
CPO-2	Research in 2-D image analysis and applications	Biomedicine, Material engineering	Analysis of shape-changes of moving leukemia cells [19].
VIP	Research in 2-D image processing	Biomedicine	?
PICAP	Research in parallel image processing and applications	Biomedicine, Fingerprints, Automatic inspection	Malaria parasites detection [25], Fingerprint coding [26].
CLIP 4	Research in parallel image processing	Biomedicine, Automatic inspection	Basic research as yet.
GOP	Research in "general operator" processing and applications	Biomedicine, Material engineering, Fingerprints & other	?
Leitz T.A.S.	Commercial routine image analyzer	Biomedicine, Material engineering	Clustered cells separation (?) [31].

part of the picture processing systems is rather hard and tedious - - available descriptions happen to be rather vague and tangled, the software itself is often built in not very systematic way and is hard to evaluate without going into actual writing of programs for a given system.

5. Applications

General classification of systems according to their construction aims was outlined in Section 2. Here it should be repeated that most of the systems were intended for research purposes, either in image processing field itself (CPO-2, VIP, CLIP 4, PICAP, GOP) or in some specific, more or less "pictorial" application fields (CELLO, (Nag), (Leb), BIHES). Only two of them (MODSYS, Leitz T.A.S.), although not without research aspect, are intended to be more practical instruments, rather than research tools. However, also those of them intended for image-processing research are frequently used to run practical application tasks (Table 5).

Almost all systems are being used for analysis of biomedical pictures - it seems to be the richest source of interesting and challenging as well as practically useful problems of 2-D image processing. Also several systems are applied in the similar area (with respect to the character of images), namely in analysis of structure of materials.

The second numerously represented class of systems is devoted for use as robot-eyes and in closely related problems of workpiece handling and automatic inspection (BIHES, MODSYS, partially PICAP and CLIP 4). Other application areas include space probing, road traffic monitoring, fingerprints and digital holography [9].

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