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# VIDEO PROCESSING DEVICE FOR AUTOMATED TRACKING OF THE OBJECT IDENTIFIED IN IMAGE BY THE OPERATOR

*Results of Developing a Video Processing Device for Automated Tracking of the Object Identified in Image by the Operator research project (code VC 200.18.14) have been presented. The required functions of the device have been analyzed. Algorithms, software and hardware for automated tracking of the object identified in image by the operator have been designed.*

*Keywords: image, filtration, object comparison, object tracking, and real-time systems.*

The present-day military equipment cannot exist without efficient automated systems of target tracking and surveillance. One of the tools that would substantially increase combat efficiency of contemporary special equipment is the high quality video cameras for daytime and night time surveillance and devices enabling automatic visual tracking of a selected target, thus significantly facilitating the operator's actions and enhancing the efficiency of tracking.

The purpose of the research undertaken at the Glushkov Institute of Cybernetics of the NAS of Ukraine was to increase the efficiency of specialised video systems, particularly for armoured equipment, through development of algorithms and a device for process video data for automatic tracking of an object selected within the image by an operator.

Lately, plenty of methods for image processing have been developed — particularly digital filters allowing to substantially reduce the impact of noise, blurring, and increase the detecting properties of the TV and thermal vision channels of observation as well as methods of identification and tracking video sequence targets. There arise, however, plenty of questions in the course of implementation of these methods, in the course of construction of algorithms for their implementation and devices which foresee usage of these algorithms.

This work is a continuation of a previous project accomplished in 2013 (ВК-200.16.13 «Development of algorithms and software patterns to analyse television and thermal vision images» [1] and pertains to applied aspects of development and instrumentation of specialised equipment (particularly armoured equipment) by devices for processing of video data for automatic tracking of object specified in the image by the operator.

Work has examined and developed methods and algorithms that became the basis for the development of a set of software facilities of a device for automatic tracking of a target out of which an operator can select one that is most applicable to solve basic tasks in a specific situation.

Image can be enhanced by filtering, and increasing the sharpness and the contrast. Algorithms to highlight outlines and to compare using the outlines or the separate sections enable to discern targets according to form, regardless of affinnic transformations such as dislocation, shifting, scale and in the conditions of obstacles of different varieties. Algorithms for tracking allow to automatically track targets specified by the operator on the image, and to display coordinates of targets onto executive devices.

Analysis of modern signal processors and processors based upon an ARM core allowed us to undertake a selection of components required to construct a device to process video data with a minimal amount of components. The structure and functional scheme of the device for processing video data and the software for verifying the suggested algorithms have been developed (particularly, an updated item of software to compare the outlines of the objects of video images under the conditions of affinite transformations and interferences of various nature, and a complex item of software used to track separate points of video sequence targets that also includes software for primary processing of video data).

In the course of development and processing of algorithms, another thing that was taken into account was their implementation in a device for processing of video data that was developed on a selected processor using internal quick memory only. Below you can also find suggestions as to the directions in which performance can be boosted of the devices used to process video information to implement labour-intensive algorithms in real time.

## ALGORITHMIC SUPPORT OF A DEVICE TO PROCESS IMAGES

For a vast majority of tasks faced by systems of tracking, the analysis of images is a process whereby processing of images is taking place with highlighting or specification of certain points of targets and are calculated according to their characteristics, and these characteristics are used to search for these targets or points in the subsequent frames of video sequence. The solution for the problem is, as a rule, split into several stages:

- filtering, enhancing the quality, and possibly also a pyramide provision of images with a stage by stage processing of separate images of the pyramid;
- extraction of signs of targets or their specific sections (outlines, image regions of specified targets);
- transformation into other representations of these properties and calculation of their characteristics;
- advanced search using calculated characteristics of the most similar objects or points within the subsequent frames of the video sequence and calculation of their coordinates;
- issuing of signals corresponding to the shiftings of coordinates onto the executive devices.

Considering the abovementioned analysis of tasks that the device is to perform and the requirements for it, it is suggested that on the first stage the algorithm and software support is to include the following methods and algorithms:

- methods and algorithms for preliminary processing of images (filtering off interferences, enhancing contrast and sharpness of images, underlining contours of an object, and nonlinear reception of brightness);
- algorithms used to trace an object;
- tools used to specify initial coordinates for a specified object and output of object coordinates onto executive devices of the system.

## TRACING THE IMAGE OBJECTS

The task to track objects of an image can be stipulated in several options:

- if the tracked object is mobile, the spectator with a video camera is static;
- if the tracked object is static, and the spectator with a video camera is mobile;
- if the tracked object is mobile, and the spectator with a video camera is also mobile;

There exists a necessity to acquire coordinates of an object There exists a necessity to acquire the coordinates of object's relative location and orientation of the observer or the direction towards the object relative location of the observer and, accordingly, to define in which direction and at which speed the specified objects are moving. Generally, the task is comprehensively solved by identifying the observed object on the acquired


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video images sequence by examining 'visual properties' most widespread in the craft of objects tracking such as motion, form, colour, and intenseness of radiation.

In order to conduct an analysis, the following algorithms have been selected that are most often used to capture and track objects:

- algorithm of Motion Templates — based on the search for boundaries of objects in each frame of a video stream [2]. Shift of a boundary on a frame subsequent to the preliminary frame defines the vector of object movement. The present algorithm is most efficient in the course of motion of large objects and is often used to discern dynamic gestures in human-device interfaces;
- algorithm of mean shift (Mean-Shift) — based upon a mathematical model whereby local extremum of a set of distinguished points is being examined — that is, the algorithm tracks the shift of the points mass centre that define the object being tracked acquiring the vector of object movement at the output [3]. High efficiency is achieved due to difference of brightnesses of the object and its background;
- algorithm of incessantly adapting shift (CamShift) — based upon the mean shift algorithm but differs from it by automatically adjusting the boundaries and dimensions of a window within which characteristic points are located [4]. Thus, a more precise tracking of an object is taking place whereby the object modifies its dimensions;
- the Lucas—Kanade algorithm - based on the differential calculation of an optical stream using an analysis of pixels (it is foreseen that the optical stream is the same for the pixels within the centre of the tracking window), whereby the dislocation of the pixels between the neighbouring frames is to be non-significant [5]. The present algorithm has been applied in software vision apps for over twenty years so far and has proven its high efficiency for a wide circle of applications;
- the Viola—Jones algorithm, based upon the detection of sets of pixels in a frame that are concurrent with the templates selected in advance, that are comprised of white and black rectangles [6, 7]. In order to discern various objects, one needs to have a unique set of templates that is being created by way of training the algorithm using a certain separate object. An algorithm that has been trained correctly is operating with high efficiency but the process of training itself is pretty much labour intensive and requires the developer/researcher to acquire and be in the possession of special knowledge about the present algorithm and also calls for an initial selection to be undertaken properly and with decent level of organisation.

To start the tracking algorithm, one needs to initialise the primary tracking region in a primary array of characteristic points. There are algorithms that automatically identify the searched object if it appears, while for the rest, the object is specified manually. In addition to this, certain algorithms have to be studied prior to their application.

In order to undertake the implementation, the Lucas-Kanade method has been selected whereby consideration has been taken with regard to the fact that as per the assignments of the work, the point on the tracked object shall be specified by the operator.

The Lucas-Kanade algorithm has been widely used to solve problems related to object's motion. It pertains to the local methods of calculation of an optical stream since it is processing pixels around a certain point.

The subject algorithm suggests that:

*a*) shifting of points at the current and the preceding images is not significant;

*b)* that the shifting of points around a certain point is the same;

*c)* that values of intenseness of pixels do not change over time:

$$I(x, y, t) - I(x + \delta x, y + \delta y, t + \delta t) = 0, \qquad (1)$$

where $I(x, y, t)$ stand for function of pixel intensity with coordinates $(x, y)$ in the frame $t$ and $(\delta x, \delta y)$ — shifting of a pixel between consequent frames $t$ and $t+\delta t$.

Let us assume that $D = \{q_1, q_2, ..., q_n\}$ stands for a set of points around the point $P$.

Considering the insignificant shift during a linear expansion of the function for each of the points into the Taylor's series, we acquire a system of equations that is being resolved by resorting to the least weighted square method [5]. In order to determine the weight coefficients for pixels on the image, the following function is applied: $W(x, y)$. According to this method, in order to find a solution, one needs to reduce the following error to a minimum:

$$\varepsilon(\upsilon) = \sum_{x,y\in D} W(x, y) \cdot [I(x, y, t) - I(x+\delta x, y+ +\delta y, t+\delta t)]^2 = \sum_{x,y\in D} W(x, y) \cdot \left(\frac{\partial I}{\partial x}\upsilon_x + \frac{\partial I}{\partial y}\upsilon_y + \frac{\partial I}{\partial t}\right)^2, \quad (2)$$

where $\upsilon = (\upsilon_x, \upsilon_y)$ stands for the speed of shift according to the corresponding coordinates.

In order to find the minimum error it is necessary to set $\frac{\partial \varepsilon(\upsilon)}{\partial \upsilon_x}, \frac{\partial \varepsilon(\upsilon)}{\partial \upsilon_x}$ to zero.

The following equations are obtained:

$$\begin{cases} \sum_{x,y\in D} W(x, y) \cdot \left[\left(\frac{\partial I}{\partial x}\right)^2 \cdot \upsilon_x + \frac{\partial I}{\partial x} \cdot \frac{\partial I}{\partial y} \cdot \upsilon_y + \frac{\partial I}{\partial x} \cdot \frac{\partial I}{\partial t}\right] = 0 \\ \sum_{x,y\in D} W(x, y) \cdot \left[\frac{\partial I}{\partial x} \cdot \frac{\partial I}{\partial y} \cdot \upsilon_x \left(\frac{\partial I}{\partial y}\right)^2 \cdot \upsilon_y + \frac{\partial I}{\partial y} \cdot \frac{\partial I}{\partial t}\right] = 0. \end{cases} \quad (3)$$

These equations can be represented in the matrix form $A \cdot \nu + B = 0$, where

$$A = \begin{bmatrix} \sum_{x,y\in D} W(x, y) \cdot \left(\frac{\partial I}{\partial x}\right)^2 & \sum_{x,y\in D} W(x, y) \cdot \left(\frac{\partial I}{\partial y}\frac{\partial I}{\partial x}\right) \\ \sum_{x,y\in D} W(x, y) \cdot \left(\frac{\partial I}{\partial x}\frac{\partial I}{\partial y}\right) & \sum_{x,y\in D} W(x, y) \cdot \left(\frac{\partial I}{\partial y}\right)^2 \end{bmatrix},$$

$$\nu = \begin{bmatrix} \upsilon_x \\ \upsilon_y \end{bmatrix}, \quad B = \begin{bmatrix} \sum_{x,y\in D} W(x, y) \cdot \left(\frac{\partial I}{\partial x}\frac{\partial I}{\partial t}\right) \\ \sum_{x,y\in D} W(x, y) \cdot \left(\frac{\partial I}{\partial y}\frac{\partial I}{\partial t}\right) \end{bmatrix}. \quad (4)$$

Hence, $\nu = -A^{-1} \cdot B$.

The present algorithm is simple and a prompt one, thus , in many cases, it is pretty efficient. Defects of the present algorithm include the fact that it can be used only in cases of insignificant shifts of an object between the frames. In order to eliminate this defect, the pyramidal method of Lucas-Kanade is used on practice.

We accepted the tracking algorithm examined above as the basic algorithm. Let us define this procedure by simply using the term of «*tracking*»», whereas the algorithm of tracking with a pyramidal visualization of images shall be designated by a term of «*pyramidal tracking*».

Thus, at the input of the «tracking» procedure, we have the current and the preceding frames of a video sequence as well as coordinates of the point on the preceding frame which we are following. At the output, we acquire the coordinates of this point within the current frame (or, we acquire none, if tracking is interrupted).

Let us visualize the algorithm of «pyramidal» tracking in large blocks:

1) We organize a cycle for consequent acquisition of frames of a video sequence;

2) we acquire the next frame of a video sequence;

3) we use the acquired frame to build up the next pyramid of an image with a specified number of levels $k$ by way of Gaussian filtering and thinning of the image horizontally and vertically for each of the pyramid levels;

4) we verify the presence of coordinates of a point $(x, y)$, which is to be tracked (if no point is present, — we proceed to step 7; if any point is present, — we continue with the actions);

5) we calculate the coordinates of the point for $k$-th level of the pyramid$(x = x/2^k, y = y/2^k)$;

6) cycle according to the levels of a pyramid ($n = k$, while $n \geq 0, n = n-1$);

7) procedure of «tracking» ( input: image of the $n$-th level of the current and the preceding pyramid, coordinates $(x, y)$; output: coordinates $(x, y)$; $x = x*2, y = y*2$;};

8) the preceding pyramid = the current pyramid;

9) proceeding to step 2.

The pyramidal algorithm allows us to track the points with a substantially higher degree of frame to frame shifting - that is, to track the point of an object that is moving at a substantially higher speed.


***Fig. 1.*** Tracking program shell

On the present stage of works, a complex program of tracking has been developed that is used to process separate blocks and the algorithm as a whole according to separate points of the objects of video sequence determined by the operator. The shell of the complex tracking software is depicted at Figure 1.

According to the Technical Assignment, the following items have been elaborated and implemented: user interface; the shell of the complex software in general and the input blocks for video images input from out of the video sequence (video file) and output onto the screen (color or modified grey color image can be set by the option defined as «Output»); blocks for pre-processing of video images (various filters, to be set in the Filtering setting); software unit enabling the operator to specify a point on the image that is to be tracked; the basic procedure of tracking according to the point specified by the operator.

At Figure 1, one can also see one of the frames of a video sequence as the Tracking software is on, as indicated by the operator (see the plus sign on the tank image). The operator shall specify the point by placing the mouse arrow in the appropriate place (press left mouse key).

## METHOD OF GEOMETRIC COMPARISON OF OUTLINES OF IMAGE OBJECTS USING TORQUES OF OUTLINE SECTIONS

Within the framework of the present work, in order to find the object during a disruption in tracking, the authors suggest to apply the method and algorithm [8] that allow to compare current disrupted sections of outlines of objects that are under surveillance with the specimens of the object that have been acquired in the course of stable tracking. In order to reduce the number of direct geometrical comparisons of the outlines, torques of sections of outlines are preliminarily calculated as a sum of torques of lines that are linking neighboring pixels horizontally, vertically, and diagonally and then, their torque invariants are compared. Thereby, also, possible scale deviation is also taken into consideration.

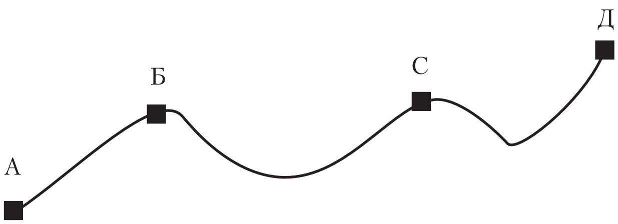


***Fig. 2.*** Outline divided into fragments

The formula of calculation of outlines until the $k$-th order:

$$M_{j,k-j} = \sum_{i=1}^{N-1} B_S \cdot x^j_i y_i^{k-j}, j = (0, k), \quad (5)$$

where $M_{j,k-j}$ — stand for torques of outlines; $B_i$ — stand for values that equate 1 for inter-pixel lines horizontally and vertically and $\sqrt{2}$ for inter-pixel lines, diagonally; $x_i$, $y_i$ — stand for coordinates of the medium of interpixel lines; $N$ — stands for number of pixels in an outline (number of inter-pixel lines is one unit less).

The calculation of torques of the sections of outlines shall be a simple and more expedited process, if while crawling and vectorizing the outlines, for each of them, the vector of torques shall be calculated with a size of $N - 1$ (number of interpixel lines). Each component of the vector equates to a torque of the section from its beginning to the corresponding point of a contour line.

Thus, the torque *M(Б-C)* from point Б to point C shall be equal to (see Figure 2):

$$M(Б - C) = M(A - C) - M(A - Б), \quad (6)$$

where $A$ — stands for the commencement of the outline; *M(A — C)* — stands for the torque of the section between A and C; *M(A — Б)* — torque of the section between A and Б.

For a detailed description of the method and the algorithm, please see [8].

## TECHNICAL IMPLEMENTATION OF THE DEVICE

According to the requirements pertaining to the application and the functions foreseen, the device is to include the following blocks:

- a CPU with cache memory;
- a RAM device;
- an HDD;
- a bus switchboard;
- analogue video input devices, video decoder and controller of direct access to the memory for input of video data simultaneously with the calculations;
- two-channel digital-analogue converter to emit analogue signals to operate executive devices;
- the digital signals input-output unit allowing to receive signals of management and output of signals of the device condition;
- a unit allowing to connect with the personal computer via USB or UART, allowing to input device settings;
- power unit enabling the conversion of lateral voltage 27 B into the required stable voltages providing power to all device units.

Today, there are a lot of companies producing digital signal processors (DSPs) targeted at specific areas of application. Modern DSPs can be subdivided into three categories: *1)* cheap ones with a set point; *2)* highly productive ones with a set point; and *3)* floating point processors. This is a very rough classification since plenty of processors can be allocated to two categories at the same time. For application in video, it is largely proposed to use highly productive processors with a set point. According to the assessment made by experts from Berkeley Design Technology, Inc (BDTI), the main producers of such families of DSP processors in the market are Analog Devices (ADI), Freescale, and Texas Instruments (TI). There also exist plenty nascent companies offering highly productive DSP processors with a set point. These are multi-core devices possessing architecture with mass parallelism.

Selection of a processor platform in the course of video devices design is a pretty complicated assignment. In order for it to be correct, one needs to analyze a set of questions:

- assessment of the processor's productivity;
- assessment of bandwidth required by the system;
- analysis of input/output devices of the processor;
- selection of the CPU arithmetic;


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- considering technical characteristics;
- analysis of means of software development.

According to the specified criteria, the construction of a device capable of processing of video data require a hybrid crystal made by Freescale company. This crystal possesses almost all main components for processing of video data, such as:

- two processors with ARM-Cortex™-A5 (500 MHz) and Cortex™-M4 (167 MHz) cores;
- RAM/DDR of a pretty large size: — 1.5 Mb;
- means for analogue and digital input of video images off video cameras;
- digital-to-analogue converters used to output the directing signals in the analogue form;
- high speed memory access channels.

At Figure 3, one can see the layout of a device for processing of video data.

The device is comprised of the following units:

- Vybrid MVF61NS151CMK50 CPU with Cortex — A5 (500 MHz) and Cortex — A4 (167 MHz) cores and a wide range of peripherals (may be replaced with MVF61NNS151CMK50, MVF60NS151CMK50, MVF60NN151CMK50 crystals);
- HDD connected to QSPI interface;
- impact power unit to convert power from 5V to 3.3V and other voltages required by the CPU and HDD;
- impact power unit to transform voltage from 27V to 5V.

Device operation shall be taking place in two modes:

1. Recording the program to HDD after production of a device. In this mode, the device is connected to a PC via USB and software is recorded onto HDD by means of a special installation software. Input of power unit is switched to 5V USB-fed mode.

2. Operation in the normal mode within the system of video surveillance to track the object defined by the operator. The operator shall target the video camera by defining the required focus and shall emit a signal to the device. After this, the defined point is being tracked and the executive devices receive analogue signals corresponding to the change of coordinates of an object, as well as audio or visual signals notifying the operator about the condition of the device (uncertain tracking or disruption in tracking). In addition to this, using digital input interfaces connected to the control devices, the operator may specify the mode of preliminary processing of images as per external conditions.

## DIRECTIONS OF ENHANCEMENT OF PRODUCTIVITY OF DEVICES FOR PROCESSING OF IMAGES

Huge reserves that can be used to accelerate the processes of image processing are processing and usage of means for parallel processing of information. Back since the 1970s, there have been plenty of studies undertaken focusing on these issues (for example, [9, 10]). But it is only today that the technological level of development of the electronic industry has enabled us to implement the element foundation in order to effectively construct parallel calculators and systems. Such devices include processors implementing the SIMD command system (Cortex-A5 NEON MPE expands the functionality of Cortex-A5, enabling the support of the mass of commands of ARM v7 Advanced SIMD v2), programmed logical integral circuits (for example, PLIC produced by Xilinx [11]) or the custom-designed large integral circuits that can be used to implement computers allowing to store and simultaneously process hundreds or even thousands of video images in a single microchip.

In order to explain the principle of parallel processing of the information of the «single stream of commands, several streams of data» type, the Figure 4 displays an option of a structural circuit of a universal multiprocessor built on the base of the PLIC of the FPGA family, produced by Xilinx company.

The multiprocessor that is presented here has been built on a single PLIC chip and includes:

- the controlling RISC processor, «PowerPC 405»;
- digital signal processors «DSP 48 Slices»;
- two port sections of a RAM device.

For the specified structure of a multiprocessor, in the course of KIX-filter algorithm implementa-

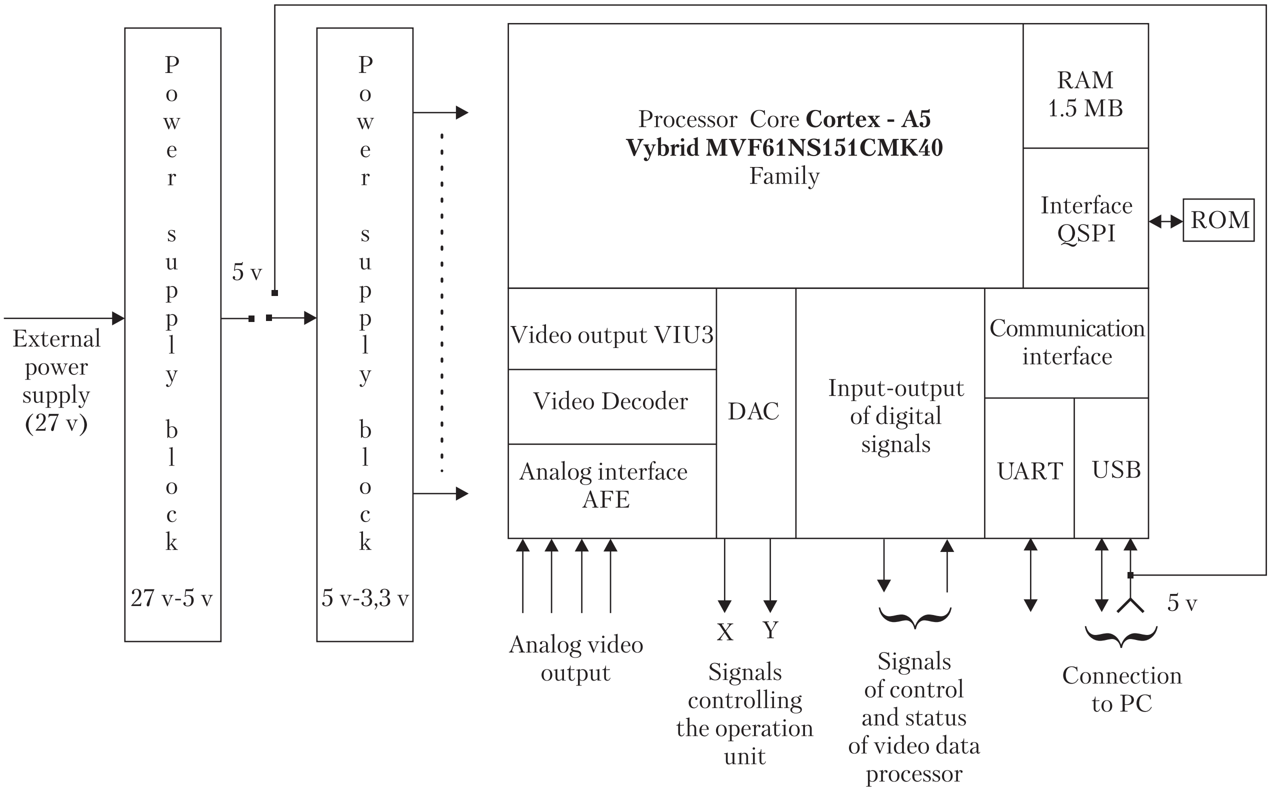


***Fig. 3.*** Function diagram of video data processing device

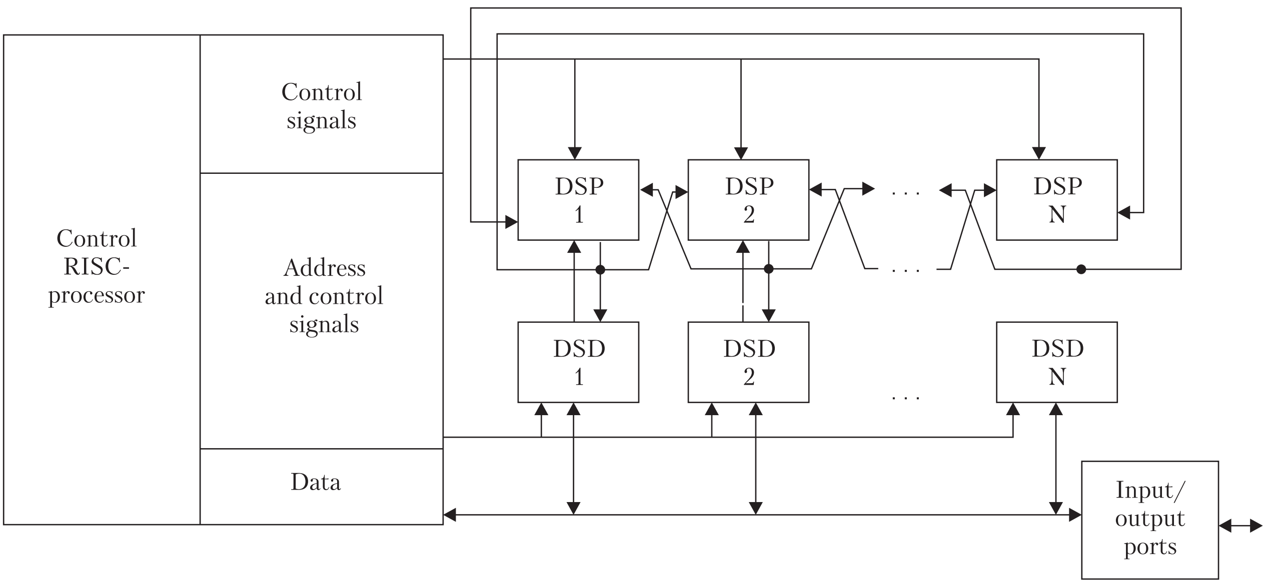


***Fig. 4.*** Structural diagram of general-purpose multiprocessor

tion, for the processing of images with a size of $k \times n$ we shall achieve an increase in the speed of calculations by approximately $k$ , having accepted the time of execution of vector operations over the line of video data (data reading off RAM, multiplication and storage, shiftint) as being 1 tact.

Traditionally, the positioning, parameters, and moments of inertia of the tracked object are defined by serial readings of the values of brightness of pixels from the video sensor to computer. It leads to reducing the frequency of frames and the impossibility of tracking the highly dynamic objects. Therefore, in order to increase the operating speed of devices, the processing of video information is linked with the reception by a video sensor by placing the processing device directly onto the sensor [12, 13]. This allows to bifurcate the processing and contributes to a substantial increase of the video recording frequency. Within the framework of this work, the following have been developed: sensor device used to determine whereabouts and parameters of the object [14] and a sensor matrix with image processing capabilities [15].

## CONCLUSIONS

Within the framework of R&D the following results have been obtained:

- Algorithms for operating the device for automated tracking of object identified on image by the operator (including those for linear and nonlinear filtration of image from noises, enhancement of contrast and brightness, selection of outline images and computation of object static parameters, search and identification of partly misshaped objects, and tracking of separate points of moving objects) have been designed;
- Structural and functional diagrams and electric circuits for the device for processing the video data for automated tracking of object identified in image by the operator have been designed;
- The algorithms and circuits of the device are designed to be used in the operating control system of the real object for defense purposes, which enables to extend the functionality and to raise the efficiency of the control system;
- Directions for raising effectiveness of devices for processing of video data, which enable to perform more sophisticated real-time image processing have been defined.

The research results, in particular the method and algorithms for search and identification of partly misshaped objects, will be used as framework for further theoretical and applied research in order to widen the scope of application and to raise the effectiveness of real-time operation (for example, for industrial control systems of shape, size, and quality).

The results will be used for designing special-purpose video devices and tracking system to be commercially manufactured at *Photoprylad* RPC for equipping the armored and other military vehicles, for which the respective certificate of R&D result application has been issued.

Upon the results of R&D project 2 articles have been published and 2 patents have been obtained.

*The research was made within the framework of Program for R&D projects (resolution of the Presidium of the NAS of Ukraine of 05.03.2014 no.142), «Development of Device for Processing of Video Data for Automated Tracking of the Object Identified in Image by the Operator» (code BK 200.18.14). The project partner is Photopryld RPC, Cherkasy.*

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## ПРИСТРІЙ ОБРОБКИ ВІДЕОДАНИХ ДЛЯ АВТОМАТИЧНОГО СУПРОВОДЖЕННЯ ОБ'ЄКТА, ВИЗНАЧЕННОГО У ЗОБРАЖЕННІ ОПЕРАТОРОМ

Наведено результати виконання проекту «Розробка пристрою обробки відеоданих для автоматичного супроводження об'єкта, визначеного у зображенні оператором» (шифр ВК 200.18.14). Проаналізовані функції, які повинен виконувати пристрій, та вимоги до нього. Розроблено алгоритмічне, програмне та технічне забезпечення пристрою для автоматичного супроводження об'єкта, визначеного у зображенні оператором.

*Ключові слова*: зображення, фільтрація, порівняння об'єктів, супроводження об'єктів, системи реального часу.

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## УСТРОЙСТВО ОБРАБОТКИ ВИДЕОДАННЫХ ДЛЯ АВТОМАТИЧЕСКОГО СОПРОВОЖДЕНИЯ ОБЪЕКТА, ОПРЕДЕЛЁННОГО НА ИЗОБРАЖЕНИИ ОПЕРАТОРОМ

Представлены результаты выполнения проекта «Разработка устройства обработки видеоданных для автоматического сопровождения объекта, определенного на изображении оператором» (шифр ВК 200.18.14). Проанализированы функции, которые должно выполнять устройство и требования к нему. Разработано алгоритмическое, программное и техническое обеспечение устройства для автоматического сопровождения объекта, определенного на изображении оператором.

*Ключевые слова*: изображение, фильтрация, сравнение объектов, сопровождение объектов, системы реального времени.

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