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IMAGE PROCESSING IN INTELLIGENT MEDICAL ROBOTIC SYSTEMS

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Abstract. The paper deals with the use of high-performance computing systems with the parallel-operation architecture in intelligent medical systems, such as medical robotic systems, based on a computer vision system, is an automatic control system with the strict requirements, such as high reliability, accuracy and speed of performance. It shows the basic block-diagram of an automatic control system based on a computer vision system. The author considers the possibility of using a reconfigurable computing environment in such systems. The design principles of the reconfigurable computing environment allows to improve a reliability, accuracy and performance of whole system many times. The article contains the brief overview and the theory of the research, demonstrates the use of reconfigurable computing environments for the image pre-processing, namely morphological image processing operations. Present results of the successful simulation of the reconfigurable computing environment and implementation of the morphological image processing operations on the test image in the MATLAB Simulink.

1 Introduction

Nowadays the trend of the development of modern intelligent medical systems (IMS), such as medical robotic systems, assumes the use of a modern equipment (a fully or partially automatic control system). Strict requirements are imposed on those medical systems in terms of quality, reliability, accuracy and speed of performance.

Computer vision systems (CVS) represent a fast-developing field and are widely used in the structure of IMS [1, 2]. In their simplest version they comprise a hardware component in the form of a computing system and a software component in the form of a digital image processing algorithm. The use of high-performance computing systems as part of CVS allows improving qualitative characteristics of its operation, which in turn allows reaching new improved characteristics of the automated process control system as a whole.

The present paper examines the synthesis of reconfigurable digital image processing systems and their use as CVS in IMS. These systems are reconfigurable computing environments for digital image processing tasks.

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2 Structure of control system

In the general case the structure of automated control system with CVS looks as follows (Figure 1).

Figure 1 presents a scheme consisting of the following units:
– *Current image*, produced using any photo or video camera;
– *Object parameters* – parameters, based on the assessment of which the whole system needs to carry out the automation task;
– *Control device* – device that executes the parameter assessment algorithm;
– *Actuating mechanism* – mechanism that on the basis of control device data performs manipulations over the plant;
– *Plant*.

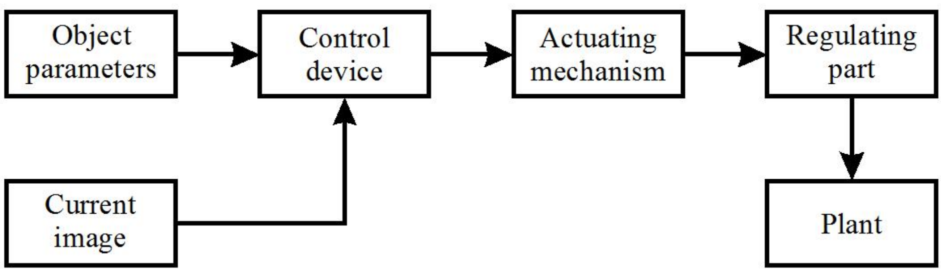


Figure 1. General structure of control system.

Depending on the type of control, in the general case the system control law looks as follows:

$$U(t) = \left\{ A,\ if\ \ B - \Lambda \cdot B \le X \le B + \Lambda \cdot B \right\} \qquad (1)$$

Here $A = [a_1, a_2, ..., a_i, ..., a_n]$ is the range of control signal values; $B = [b_1, b_2, ..., b_i, ..., b_n]$ is the range of plant parameter values; $\Lambda = [\lambda_1, \lambda_2, ..., \lambda_i, ..., \lambda_n]$ is the range of plant parameter identification errors; $X = [x_1, x_2, ..., x_i, ..., x_n]$ is the range of identified plant parameters.

Therefore, proceeding from the control law described above, qualitative characteristics of control system performance to a large extent depend on the part of its structure that is in charge of identifying plant parameters, i.e. control device that in our case is a CVS as hardware-software complex in charge of executing the preset digital image processing algorithm.

As it was earlier said, the present paper suggests using the reconfigurable digital image processing system.

3 Reconfigurable computing environments

As it was earlier said, reconfigurable digital image processing system is one of the key aspects in performance of the control system demonstrated in Figure 1.

The special feature of the digital image processing system, whose general structure is presented in Figure 2, is the use of *reconfigurable computing environment* (RCE) as computing system.

RCE is a discrete mathematical model of a high-performance computing system consisting of identical and identically interconnected basic elements (*processing elements* / *PE*), softset for performing any function out of a complete range of logical functions, memory and any connections with neighbors [3–5]. PE in the RCE used operate on the basis of logical functions of AND, OR, NOT.

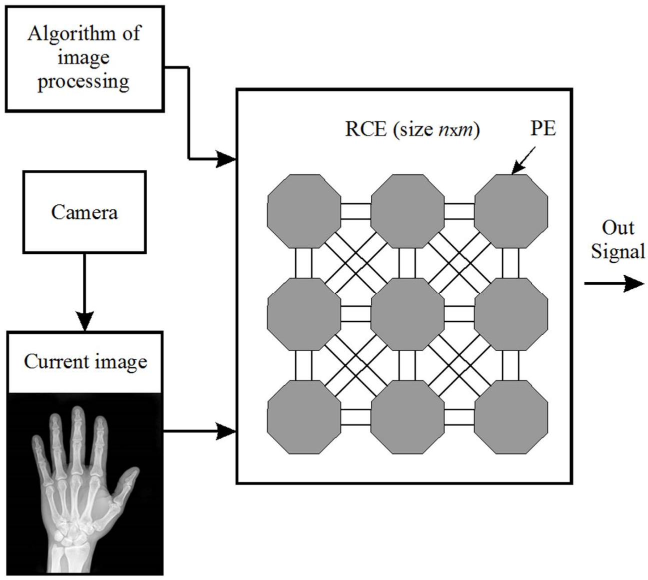


Figure 2. General structure of reconfigurable digital image processing system.

Principles of RCE construction provide it with the following key properties:
– high computing speed;
– reliability, flexibility and structural universality;
– ease of manufacture.

Abstract RCE model is also presented in Figure 2. As one can see, this model reproduces spatial representation of the digital image (matrix with a set of numeric values, where matrix dimensions $n \times m$ are the resolution of the source image and numerical values represent brightness of the corresponding image pixel). Hence RCE size in terms of the number of PE is equal to the resolution of the processed source image.

Therefore, corresponding brightness value of the original image is fed for processing to the input of each PE of RCE used, and then a series of logical operations take place in PE, this series being determined by the image processing algorithm built into RCE operation.

The structure of digital image processing algorithms built into CVS represents a complex set of different operations. The following main stages are usually identified in algorithm operation [6]:
– image pre-processing;
– segmentation;
– highlighting of geometric structure;
– identification of relative structure and semantics.

4 Operations of morphological image processing in RCE

Operations of *morphological image processing* are very often used in the algorithm of digital image processing with CVS at the stages of image pre-processing and segmentation.

The paper suggests a technique for morphological processing of gray scale images adapted to be implemented with RCE.

Mathematical morphology is the instrument of retrieving certain image components that are useful for the understanding and description of object shapes [6, 7]. Morphological methods used for processing of gray scale images are of interest in the context of the present paper.

Using the theory of sets terminology, let us assert that $f(x, y)$ function is called a digital image, if (x, y) represent pairs of whole numbers of Cartesian product Z^2 (Cartesian product of Z multiplied by itself, i.e. multitude of all ordered pairs (z_i, z_j), where z_i, z_j are any whole numbers and f is the transformation that matches brightness value (that belongs to the range of real numbers R) to each pair of coordinates (x, y) [7].

Morphological operations are performed over two images: the one being processed (let us designate it as A) and a special one (let us designate it as B), depending on the operation type and the problem to be resolved. In mathematical morphology such special image is called a structure elements or a primitive. The size of structure element is usually 3×3, 4×4, 5×5 pixels. This is conditioned by the very idea of morphological processing, in the course of which characteristic image details are found. The sought-for detail is described with a primitive, and as a result of morphological processing one can highlight or remove such detail in the whole of the processed image.

There are two fundamental operations in the theory of morphological gray scale image processing: *Dilate* and *Erode*. One can read about the classical mathematical description of such operations in greater detail in [6–10]. Let us determine the primary purpose of these operations in digital image processing:

– for 'dilation' operation, dark details get toned down or disappear completely, processed image becomes brighter than the source one;

– for 'erosion' operation, bright details of the image get toned down.

Coming back to the issue of morphological image processing operations using RCE, there is a need to transform the classical algorithm of such operations into the algorithm that corresponds to RCE requirements described above.

Below the system of functions built into PE operation is presented.

Let us agree that in the following formulas variables a and b are n-bit binary numbers that also represent the values of certain pixels of a gray scale image. In our case 8-bit binary numbers are considered, i.e. 8-bit gray scale images are to be processed.

For the sake of convenience we will designate the value of binary place with a superscript. For instance: a = 10001000 – the input 8-bit binary number; $a^8 = 1$ – the value of the eighth binary place of the input binary number a.

Thus, at $n = 8$ and $i = \overline{1, n}$ the execution of the following system of functions is input into PE:

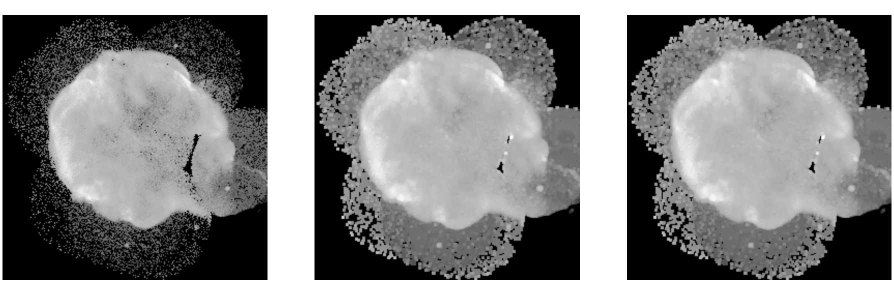
$$
\begin{cases}
R(a,b) = (a^n b^n \vee \overline{a^n \vee b^n}) \cdot (a^{n-1} b^{n-1} \vee \overline{a^{n-1} \vee b^{n-1}}) \cdot \\
\quad \cdot (a^{n-2} b^{n-2} \vee \overline{a^{n-2} \vee b^{n-2}}) \cdot \ldots \cdot (a^1 b^1 \vee \overline{a^1 \vee b^1}), \\
B(a,b) = a^n \overline{b^n} \vee (a^{n-1} \overline{b^{n-1}} \cdot (a^n b^n \vee \overline{a^n \vee b^n})) \vee (a^{n-2} \overline{b^{n-2}} \cdot (a^n b^n \vee \overline{a^n \vee b^n}) \cdot \\
\quad \cdot (a^{n-1} b^{n-1} \vee \overline{a^{n-1} \vee b^{n-1}})) \vee \ldots \vee (a^1 \overline{b^1} \cdot (a^n b^n \vee \overline{a^n \vee b^n}) \cdot \\
\quad \cdot (a^{n-1} b^{n-1} \vee \overline{a^{n-1} \vee b^{n-1}}) \cdot \ldots \cdot (a^2 b^2 \vee \overline{a^2 \vee b^2})), \\
M(a,b) = \overline{a^n} b^n \vee (\overline{a^{n-1}} b^{n-1} \cdot (a^n b^n \vee \overline{a^n \vee b^n})) \vee (\overline{a^{n-2}} b^{n-2} \cdot (a^n b^n \vee \overline{a^n \vee b^n}) \cdot \\
\quad \cdot (a^{n-1} b^{n-1} \vee \overline{a^{n-1} \vee b^{n-1}})) \vee \ldots \vee (\overline{a^1} b^1 \cdot (a^n b^n \vee \overline{a^n \vee b^n}) \cdot \\
\quad \cdot (a^{n-1} b^{n-1} \vee \overline{a^{n-1} \vee b^{n-1}}) \cdot \ldots \cdot (a^2 b^2 \vee \overline{a^2 \vee b^2})), \\
D^i(a,b) = (b^i \cdot (R(a,b)) \vee (a^i \cdot (B(a,b)) \vee (b^i \cdot (M(a,b)), \\
\max(a,b) = [D^n(a,b) \;\; D^{n-1}(a,b) \;\ldots\; D^{n-i}(a,b) \;\ldots\; D^1(a,b)], \\
E^i(a,b) = (b^i \cdot (R(a,b)) \vee (b^i \cdot (B(a,b)) \vee (a^i \cdot (M(a,b)), \\
\min(a,b) = [E^n(a,b) \;\; E^{n-1}(a,b) \;\ldots\; E^{n-i}(a,b) \;\ldots\; E^1(a,b)], \\
f_1 = \max(\max(\max(\max(y_1, y_2), \max(y_3, y_4)), \max(\max(y_5, y_6), \max(y_7, y_8))), x), \\
f_2 = \min(\min(\min(\min(y_1, y_2), \min(y_3, y_4)), \min(\min(y_5, y_6), \min(y_7, y_8))), x).
\end{cases}
\quad (2)
$$

In the above described system f_1 and f_2 designate 'dilation' and 'erosion' operations respectively.

5 Summary

Modeling of RCE for 'dilation' operation of morphological grayscale image processing, as well as validation of this operation were performed using MATLAB Simulink [11]. Validation was performed by comparing results of RCE-based operations with the same operations available in the Image Processing Toolbox extension of MATLAB suite.

The obtained result of processing the source image (Figure 3, *a*) using the developed RCE (Figure 3, *b*) and the one in MATLAB (Figure 3, *c*) are identical, which indicates the correctness of RCE operation. The result of correct RCE operation for 'erosion' operation was also obtained.



a b c

Figure 3. Results of simulation.

The present research is aimed at studying and developing the automated control systems (ACS), using in IMS, with CVS used in their structure. It was demonstrated that correct approach to selection of CVS to be used affects qualitative characteristics of ACS performance as a whole. In today's world there is a need to develop alternative high-performance computing systems that would allow moving to a new qualitative level of the tasks resolved.

The authors examined and demonstrated the possibility of implementing the RCE model for the tasks of morphological gray scale image processing. RCE can be used to achieve the same results of gray scale image processing, as when conventional methods are used, however processing time is significantly reduced in the first case: ‘dilation’ and ‘erosion’ operations are executed over one operating cycle of RCE processing element.

The study and development of RCE for image processing tasks and other classes of problems are the promising lines of research, as far as design concept of such computing environments offers high computational capability compared to computational tools that are currently in use. In turn, there is the possibility of developing a qualitatively new IMS, based on CVS, with a high reliability, accuracy and speed.

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