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2015 IOP Conf. Ser.: Mater. Sci. Eng. 81 012101

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Application of reconfigurable computing environments for image processing in X-ray tomography of materials

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Abstract. The article investigates the application of reconfigurable computing environments for image processing purposes, specifically for X-ray images.

1. Introduction

The methods of non-destructive examination of internal structure of objects are directly related to a variety of both scientific and applied domains (robotics, medicine, construction, aircraft and ship industry, etc.). The use of X-ray remains the most convenient and in some cases the only approach to such examinations.

One of the main objectives so far is still the making of X-ray microscopes having higher resolution than the visual range, but unlike electronic microscopes not demanding pre-treatment of samples [1].

Contemporary methods of X-ray tomography are based on the application of high-performance computing data processing methods to tomography data (figure 1).



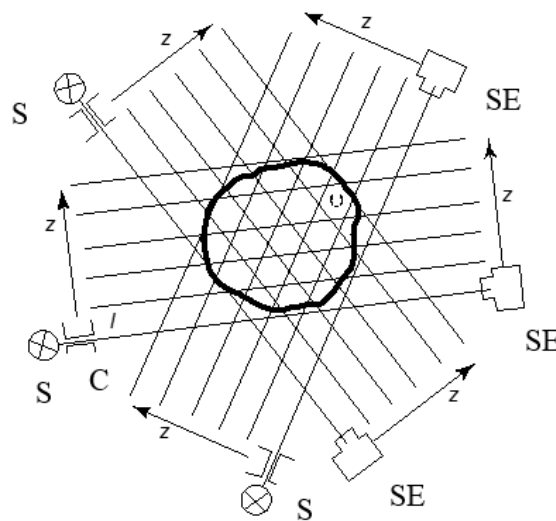


Figure 1. Tomographic scanner schematic.

A narrow beam of X-ray from the source 'S', formed by collimator 'C', passes through the object 'O', after which it is registered by the sensor element 'SE'. Upon simultaneous movement of the source and the detector along the given direction 'z', a sequential scanning of all the areas of the object is performed with the connection between radiation intensity 'I', registered by SE, and linear absorption factor of the object's medium μ has the form of integral equation [2]:

$$I(z) = I_0 \exp \left[- \int_l \mu(z, l) dl \right],$$

where I_0 – incident radiation intensity, dl – absorption path element along beam 'l' which corresponds to the scanning direction. The measurements are repeated for several scanning directions with respect to the object. In order to reconstruct the distribution of μ and accordingly the density and material composition in the volume of the object, special algorithms of computerized data processing are used.

After the scanning itself, at the output of a microtomograph we get a bulk flow of data in the form of X-ray images of the object, which should be treated as quickly and as thoroughly as possible to enable the analysis of the object with respect to various defects. This problem is efficiently solved by the application of *reconfigurable computing environments*.

2. Reconfigurable computing environment for binary image processing

The concept of reconfigurable computing environments (RCE) enables the solution of a vast number of scientific and industrial problems. In a special case this concept may be efficiently used to solve binary image processing problems. It should be noted that nowadays the digital image processing is one of innovative and rapidly developing scientific domains, essential for a vast variety of scientific disciplines such as robotics, medicine, aerospace and geophysical surveys, etc.

A reconfigurable computing environment is a discrete mathematical model of a high-performance system made of an array of identical computers with identical connection to one another, capable of dynamic adjustment to perform any preset logical functions [3–5].

The peculiarity of the reconfigurable computing environment in question is that every computer operates a given basic set of logical functions, specifically AND, OR, NOT.

Figure 2(a, b) shows an abstract 3D-model of an RCE setup for specific operation, while figure 2 (c, d) shows a generic scheme of an RCE built of these computers.

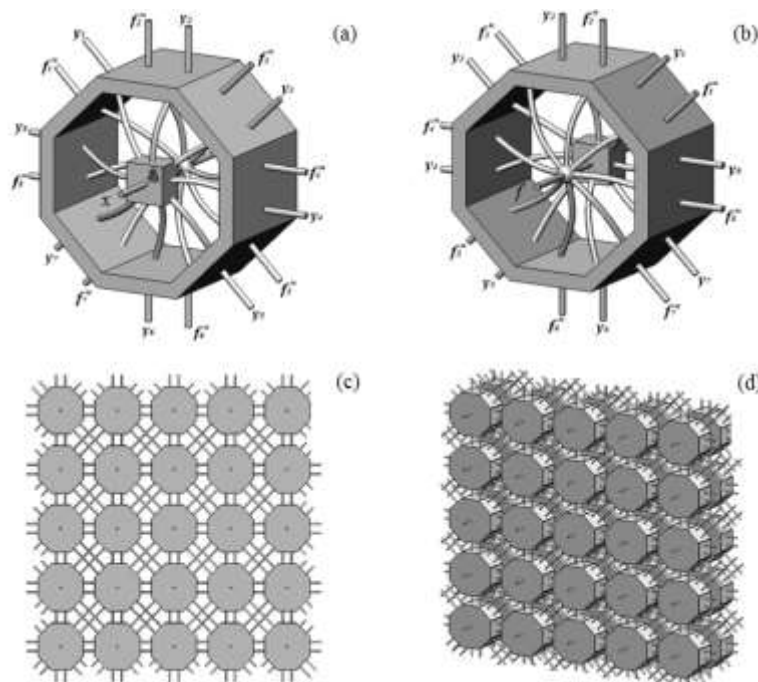


Figure 2. Abstract 3D-model of an RCE and a generic RCE scheme.

It should be noted that as seen in figure 2(d), the RCE may have a multi-layered structure. Such structure is conditioned by the complexity of performed operations.

2.1. Morphological binary image processing methods

In the frameworks of this paper, of interest are the morphological methods used for image processing, e.g. morphological filtering, refinement, contouring of a given object.

Mathematical morphology enables the view of a binary image (i.e. the one containing pixels with brightness values of 0 and 1 for background pixels and object pixels respectively) as a multitude of foreground pixels (having brightness values of 1), contained in the space of Z^2 [6]. Accordingly, the operations with multitudes can be performed with images.

Morphological operations are performed with two images: the one being processed and the special, which depends on the kind of operation and the given problem. Such special image in mathematical morphology is called a structure element or a primitive. The size of the structure element is usually 3×3 , 4×4 , and 5×5 pixels. This is conditioned by the very idea of morphological processing wherein typical details of an image are searched for. The sought-for detail is described by a primitive and morphological processing allows for highlighting or deleting such details in the whole of the processed image.

Set-theoretic operations form the main morphological image processing operations: erosion, dilation, open, close [6–8].

The operations of *dilation* and *erosion* are fundamental for morphological image treatment.

2.1.1. Erosion. Let us assume that A and B are multitudes from the space of Z^2 . Erosion of multitude A with respect to B is denoted $A ! B$ and is determined as

$$A ! B = \{z | (B)_z \cap A^c = \emptyset\},$$

where A^c – negation of A ; $(B)_z$ – parallel transfer of multitude B into point $z = (z_1, z_2)$ (shift to point z), i.e. the narrowing of multitude A with respect to primitive B is the multitude of all such z points, that primitive B would entirely be contained in A if shifted into them. In practice the operation of

erosion ‘narrows’ or ‘details’ binary image objects. The method and the degree of narrowing is controlled by primitive B .

2.1.2. Dilation. Let us assume that A and B are multitudes from the space of Z^2 . The dilation of multitude A with respect to multitude B is denoted and determined as follows:

$$A \oplus B = \left\{ z \mid (\hat{B})_z \cap A \neq \emptyset \right\},$$

where \hat{B}_z – central reflection of B (with respect to its origin of coordinates) with subsequent parallel transfer to point $z = (z_1, z_2)$ (shift into point z), i.e. the dilation of multitude A with respect to primitive B is the multitude of all such shifts of z , when the multitudes of \hat{B} and A coincide at least in one element. In practice the operation of dilation ‘builds-up’ or ‘thickens’ binary image objects. It should be noted that more often than not the operations of erosion and dilation are used together when processing the image. This is why morphological operations are also joined by the operations of *open* and *close*.

2.1.3. Open. The open of multitude A with respect to primitive B is denoted as $A \circ B$ and determined by the equation

$$A \circ B = (A ! B) \oplus B$$

or by the equivalent formula

$$A \circ B = \bigcap \left\{ (B)_z \mid (B)_z \subseteq A \right\}.$$

In practice the operation of open smoothes the outlines of an object, quenches straits, and eliminates thin peaks.

2.1.4. Close. The close of multitude A with respect to primitive B is denoted $A \bullet B$ and determined by equation

$$A \bullet B = (A \oplus B) ! B.$$

In practice the operation of close smoothes the outlines of an object and in general ‘fills’ narrow gaps and long and thin cavities, it also eliminates small apertures and fills the gaps in the outline.

2.2. Modeling results

The reconfigurable computing environment for morphological binary image processing purposes was built and modeled in MATLAB Simulink software.

The general arrangement of an RCE computer and its structure in MATLAB Simulink are shown in figure 3.

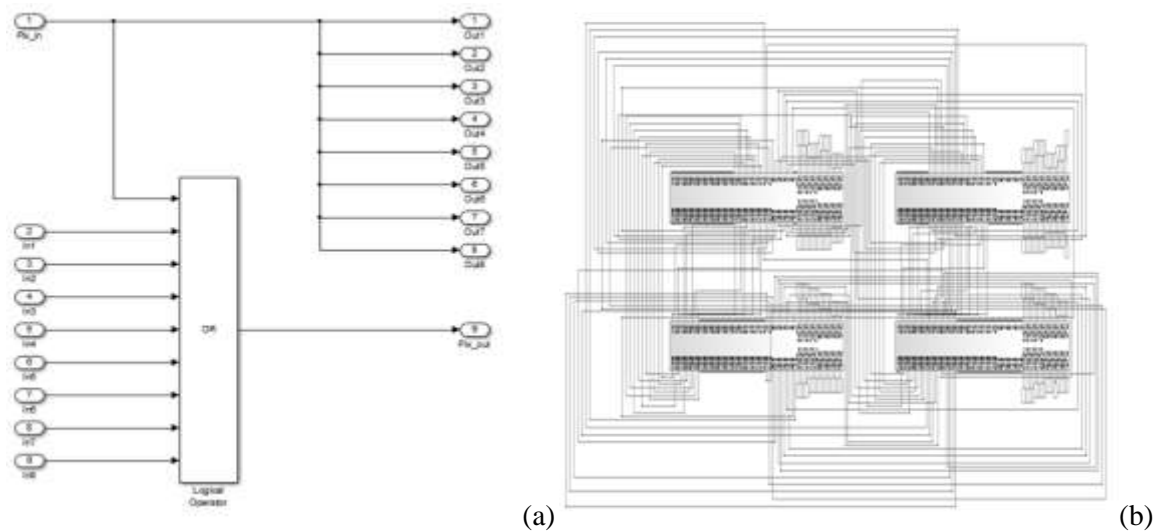


Figure 3. RCE general arrangement (a) and RCE model structure (b) in MATLAB

As seen in figure 3(a) the model of an RCE computer for image processing purposes is a structure where the central component is a given logical function – in the case depicted in the figure it is OR – but in general the computer may be given have a series of logical functions or complex structures made of logical functions. The structure of the computer also contains a series of input and output tie-lines the number of which may vary in a wide range, depending on the given problem. Based on the specific case shown in the figure, we have 1 input and 1 output (Pix_in and Pix_out respectively) for a pixel of processed image and 8 inputs and outputs each for the tie-lines interconnecting the computers of the RCE.

Thus the structure of the end RCE model adjusted for specific image processing problem looks as shown in figure 3(b). It includes a large number of computers, interconnected by tie-lines, and each of the computers processes 1 pixel of the source image during one operating cycle of the computer.

The resulting RCE model for morphological binary image processing was tested using an X-ray image of a defective welding seam (figure 4).

More often than not, the end goal of digital image processing is a high quality identification of the object of interest from the source image for its subsequent analysis and decision making in case of an automated system. As seen in figure 4 after binarization of a gray scale image (figure 4(b)) we got a nondistinct image of the seam itself having many additional ‘pixel’ objects. Using the model RCE we got a homogeneous and distinct from the background object of interest which is suitable for subsequent analysis.

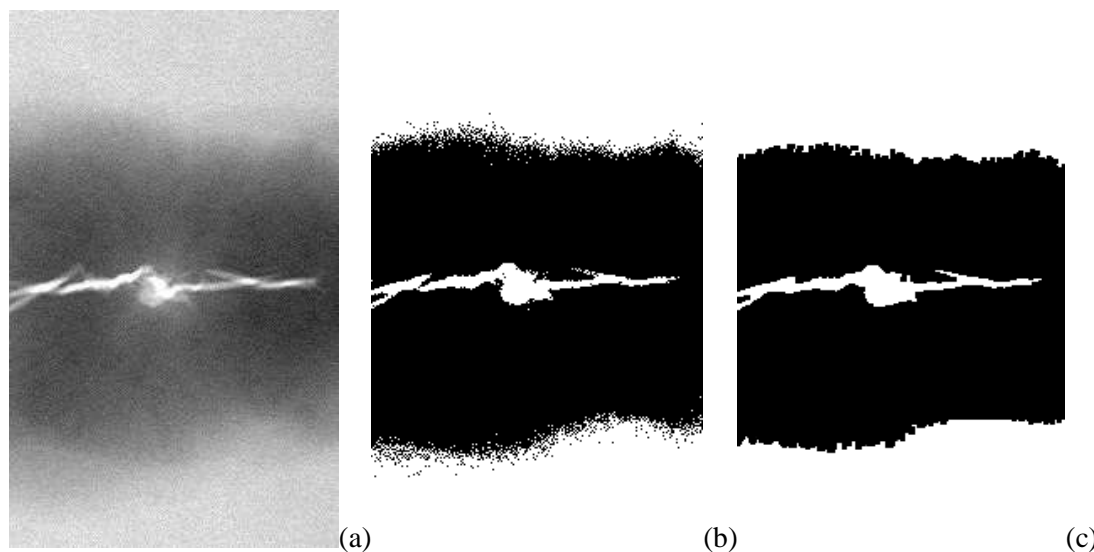


Figure 4. X-ray image of a defective welding seam: (a) source image; (b) binarized image; (c) image treated with morphological methods

3. Conclusion

Nowadays when solving a vast number of diverse problems one confronts a series of challenges such as: the use of high-performance computing systems with a parallel functioning architecture, the real-time processing of vast and voluminous flows of data.

A quality solution of these problems is achieved by the use of the concept of reconfigurable computing environments due to the advantages in the build-up of such systems. The article has shown an efficient use of RCE for binary image processing purposes with X-ray images.

This work was supported by the grant from the President of the Russian Federation (MD-411.2014.9) and was made on the program improving the competitiveness of National Research Tomsk State University.

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