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Abstract of the thesis submitted for the degree of Doctor of Information Technology

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Algorithms for processing and comparing digital X-ray images

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1. The aim and scope of the work

This document is a summary of the doctoral thesis titled *Algorithms for processing and comparing digital X-ray images*. It presents the key issues of the full text of the doctoral thesis.

The aim of this work is to develop and test a set of algorithms that enable the analysis and comparison of digital X-ray images of the bone. The analysis and comparison of images is based on the objects extracted from the background and their geometric properties that enable them to be presented as basic geometric shapes.

The following sections of the abstract correspond to the following chapters of the doctoral thesis and are presented according to the order of research. The titles of the most key chapters are presented below.

– *Introduction to medical imaging*

– *Introduction to the methods of processing and comparing X-ray images*

– *New iterative background extraction algorithm based on a single X-ray image*

– *Modification of the edge detection algorithm on digital X-ray images*

– *New algorithm for the description of digital bone area on X-ray images*

The following chapters of the doctoral thesis concern the course of research and work in the order in which they took place in reality, preceded by a theoretical introduction. The theoretical introduction concerns both the medical imaging and the algorithms used to process medical images.

2. Key chapters - summary

Below is a summary of the key chapters of doctoral thesis, including their original titles, in the form of the most important information to which the chapters relate.

2.1. Introduction to medical imaging

This chapter covers the basics of the science field of medical imaging. Its content touches upon issues both in the field of medicine and computer science. It also presents the essence of medical imaging in combination with modern IT methods. The chapter introduces medical imaging historically from the discovery of X-rays in 1895 to the present day.

In the context of modern times, the chapter describes the issues explaining the various medical imaging techniques, taking into account the important differences between them. In addition to the key X-ray imaging in this thesis, computed tomography, ultrasound, magnetic resonance and positron emission tomography are also discussed.

This chapter aims to introduce issues related to medical imaging in the context of explaining the imaging techniques, the method of image acquisition and subsequent processing, including computer-aided diagnostic imaging.

2.2. Introduction to the methods of processing and comparing X-ray images

This part of the doctoral thesis deals with the processing and comparison of digital images as a very broad field of science, taking into account specific methods of image analysis. Information about the methods that can be used depends on the nature of the issue requiring image processing mechanisms. The next issue is medical X-ray imaging, which is one of the best-known medical visualization techniques in the world. X-ray imaging has also been described in the context of the current state of science and the methods described in the literature.
The chapter describes methods such as:

1. Medical image analysis based on color space, as one of the basic issues of processing and comparing digital images.

2. Edge detection in digital images can definitely be considered one of the key methods of vision processing and comparison.

3. Methods of detecting key points, methods of recognizing and matching shapes.

4. Image segmentation as the separation of important features from it, in the form of areas representing a specific class / object.

5. Object extraction methods, which consist in separating them from the image based on appropriate algorithms and object properties.

6. Image comparison methods, closely related to IR (Image Retrieval) search algorithms, methods of semantic description and comparison of images.

2.3. New iterative background extraction algorithm based on a single X-ray image

This section covers the background removal algorithm that was first described in [1]. It was included there as a pre-processing stage for the algorithm of edge detection of digital X-ray images. It was used as a step to facilitate further processing of digital X-ray images in order to "denoise" the sample. A denoised sample is one that shows as many, the most clear bone areas as possible, which will result in increasing the effectiveness of subsequent algorithms.

The research method described in this chapter results from the need for a specific method of pre-processing of the digital X-ray image. Due to the fact that bone objects are the most important area of the image, there was a need to separate the background of the image from the areas of interest. Soft tissues as well as other noise generated during image acquisition are considered the background. During the implementation of the algorithm for research, a problem related to the quality of X-ray images was encountered. Images with different brightness, different degrees of exposure of areas of one image are caused by the acquisition of different devices and human error. The differences in the captured images result from the differences in the technology of the image obtained, which is often directly related to the age of the X-ray apparatus used for this purpose. The result is a significant number of images that are bright, and in many of them it is practically impossible to detect the boundary between soft tissue and bone - even to the human eye.

The main goal of this algorithm is to properly prepare the image for the next stage, which is edge detection. Appropriate preparation is defined as increasing the quality of hardly visible edges in the areas of soft tissue and bone. The consecutive steps of the algorithm extract parts of the image that are not bone tissue, i.e. folds of skin, fat and muscles. Ideally, all parts of the x-ray image, other than bone, should be removed. A very important issue of applying such an approach is its influence on the edge of the edge, which is crucial in the context of the detection of a bone object. The overlapping skin folds and fat often have a brightness similar to that of potential hard tissue edge areas. The additional inaccuracies in image acquisition, which also occur, make it even more difficult to recognize the areas of interest. It

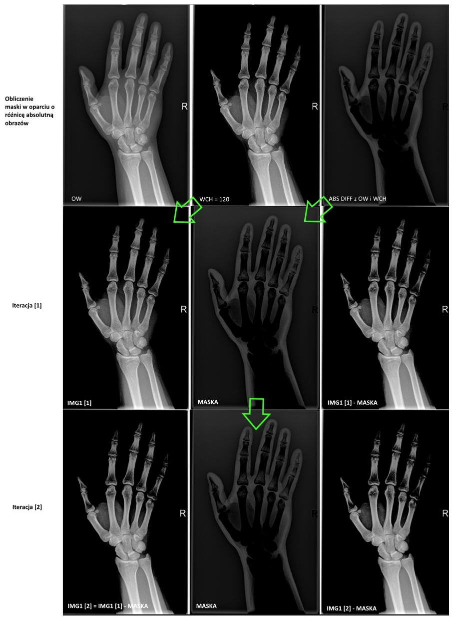

Figure 2.1: Iterative method of absolute difference between pictures. The absolute difference is calculated based on the image in the previous step and the mask calculated at the beginning of the process.

is important, however, that the bone area, and especially their edges, are characterized by a much lower permeability of X-rays in relation to the overlapping soft tissues. Thanks to this property, the chance of detecting the appropriate hard tissue border increases, even in photos of poor quality. Despite the fact that the human eye may have a problem with clearly defining the border between the types of tissues, their numerical brightness values will be noticeable in most cases. It will be possible to distinguish the boundaries due to the differences in the densities of the tissues under consideration and their absorption of X rays.

A detailed description of the algorithm's operation can be found in the full version of the doctoral dissertation, and an example of the result is shown in the fig. 2.1.

2.4. Modification of the algorithm of edge detection of digital X-ray images

The research problem described in this chapter concerns the quality and effectiveness in the detection of edges between different types of tissues visible on digital X-ray images. Due to the fact that X-ray images are valid in grayscale and, apart from the brightness of the colors, there is no color distinguishing feature that defines specific tissues, only a properly detected edge allows for the outline of tissue areas and their separation from each other. The cases of images that should be emphasized in the context of this issue are those in which soft tissues are of the same or very similar brightness as hard tissues. This is a common case because it is caused by overlapping skin folds, fat and muscles. It is also caused by the device for making X-ray and the accuracy of the operator performing tests. As a result, the occurrence of such a phenomenon at the border of soft tissues with the bone edge generates the research problem discussed here. It is possible that such a situation may occur in the dominant image area, which is a

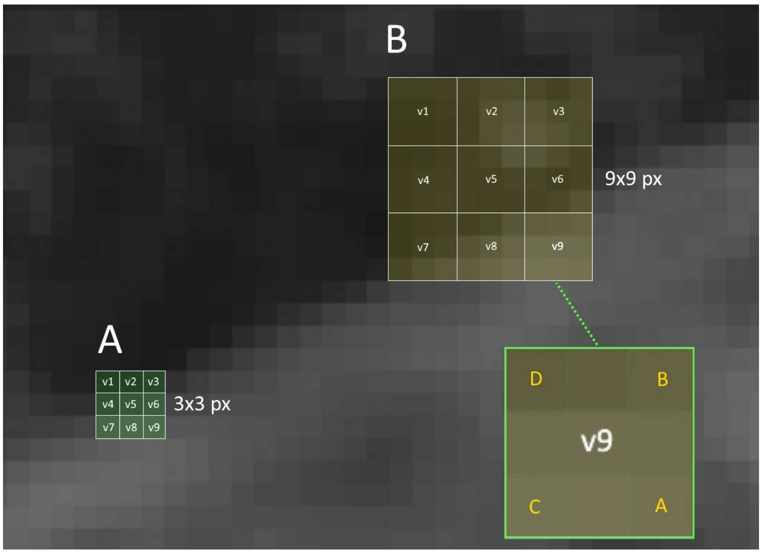

Figure 2.2: Comparison of the traditional size of the edge detection filter mask 3×3 px A to the filter proposed in this paper with an example size of 9×9 px B. The values of individual filter cells were marked sequentially from $v1$ to $v9$. The $v9$ value of the B filter is also zoomed in, taking into account the A, B, C, and D coordinates to calculate the average pixel value for the mask cell.

significant problem in its interpretation. It is necessary to use a specific edge filter that allows the image to be processed at a specific level of detail - edge “perception”. The focus should be on the possibility of detecting less distinct edges simultaneously in larger areas studied by the edge filters, which is almost the opposite of what is the case with the commonly used edge methods.

The main idea of the algorithm is to enable edge detection in a more general “perception” than the commonly used edge detection filters. This does not question the assumptions and effectiveness of popular edge algorithms, but their standard form, where the size of the edge filter, e.g. 3×3 pixels, will not give the expected result in such a research problem. The assumption is that the area examined by the filter should be large enough to cover a specific part of the image. The edge filter cells should be of a specific size that covers certain ranges of pixels. The problem may be the representation of the pixel area as a value for the selected filter cell and the time required to calculate it (average value from the area). In the approach proposed here, the performance and speed of the edge detection algorithm is a very important feature. By using appropriate algorithms for calculating the average pixel values from a given image area in combination with the specific structure of the edge detection filter mask, it gives very satisfactory results.

The edge detection approach proposed in this work can be applied to any type of edge detection mask as its modification to focus on the edges of the largest image objects. The more general perception of edges allows you to focus on the main objects in the image, which is the general goal of the algorithm presented here. The edges of the main objects or even parts of these edges allow you to determine their position in the image. Therefore, it is unnecessary to use a small size of the filter cells, which would detect “micro edges”, which are here some kind of noise. The figure 2.2 shows the way in which the cells of the edge filter mask are built in the traditional A approach where each cell corresponds to one pixel and the method proposed in this dissertation. In the second approach, each cell consists of a matrix of pixels $n \times m$, depending on the fixed size of the mask and its cells. The case B presented in fig. 2.2 is a filter of size 9×9 pixels where each cell of the mask is the matrix 3×3 pixels. Both the A and B cases have filter cell values represented by the markings $v1$ to $v9$, because after all they reduce the algorithms to the form of edge operators such as Sobel or Prewitt.

2.5. A new algorithm for the description of the bone area in digital X-ray images

The bone area description algorithm was developed as an extension of the entire process of X-ray image processing presented in the previous chapters of this doctoral thesis . This approach also enables the result of the operation of a number of algorithms to be saved in the final format developed in this work. The description of the bone area in this issue does not refer directly to the edge between soft and bone tissues, but to the overall content of the image. The purpose of this type of descriptor is to pre-classify an image to a specific group of memberships. As a result, the detailed image processing in the form of the analysis of individual pixels, depending on the final need, will be subject to a narrow group of X-ray images. It is an approach that definitely makes it possible to apply it in the processing of large data sets, e.g. between many medical facilities where similar medical cases are searched. Saving an additional photo description in the form of a descriptor developed in this work allows for speed up the selection of a set of images from the pool of all available images. This does not generate the need to process them again based on pixel analysis, but only on how similar the photos are through the content that their descriptors present.

The research problem concerns the possibility of comparing X-ray images based on their content, i.e. the arrangement of bones, their type, fracture, presence of a prosthesis or other identifiable elements. In order to be able to compare photos based on the shapes represented by their edges, they must be fully processed each time. The processed images are compared in the form of specific characteristics, such as the already mentioned edges.
In order to process the image each time in terms of the selected feature on the basis of which its comparison will be carried out both time and hardware resources are required for calculations. Single cases, e.g. comparing a set of several or a dozen X-ray images at the request of one user, will not be a significant problem. However, if the assumptions are based on information exchange systems between medical units or other medical imaging organizations based on large data sets, the approach in the form of recalculating the image is unacceptable. Another solution is to store information, copies of images in a processed form (for certain features), but it is still troublesome due to the increasing amount of data related to the same image.
An alternative to this complex approach is to create an image descriptor in the form of specific code. The specific image codes would then be compared. The efficiency of comparing strings in relation to image processing is obvious, the more so that the publication [2] presents the advantage of searching for specific strings, the so-called “hash” over dictionary expressions in the database engine, on an example

of PostgreSQL.

These are the arguments that definitely prevail in order to develop a solution that allows for pre-classify images in terms of their content.

The assumption of this algorithm is to reduce the X-ray image from its basic form to a “text” form, enabling the presentation of selected features and properties of the image indicating the presence of characteristic objects. The areas represented by the descriptor should be able to describe the image object in such a way that they can indicate the approximate content of the image, in the way that a human would see it in general. Storage of selected information about the image in the form of a text or a feature vector is negligible in terms of the size of the data, comparing it with the size of a digital X-ray image. Consequently, the processing of small data sizes favors new circumstances, such as the processing of large sets of X-ray images. The processing would be de facto based not on a digital image, but on descriptors representing the images. The use of this method in its basic form will allow for the initial classification of images, significantly narrowing down the sets of images that require full processing in order to extract features for comparison. Reducing an image to the form of a descriptor has consequences both in the deterministic approach, where the affiliations of images to defined sets are conditionally determined, and in the case of machine learning. In the second case, smaller sets of data will positively affect the training and propagation time of the created models. As a result, it allows for a step towards automatic image classification. The fig. 2.3 shows the points of intersection of the rays derived from the center of gravity of the blob area with the blob contour segments as an example presenting the approach to image description in the form of a descriptor.

2.6. Research, simulations and further research directions

In the chapter on tests and simulations, the results of tests on specific sets of test samples are presented, taking into account various stages of algorithm operation. The results for each of the stages are presented for each of the issues. The results of tests and simulations are presented mainly in a graphical form, supplemented by tables with the results at certain stages of the research.

Further research directions concern the potential possibilities of developing the algorithms presented in the doctoral thesis. This includes both the development of deterministic methods and the use of machine learning methods as an alternative to certain stages of work.

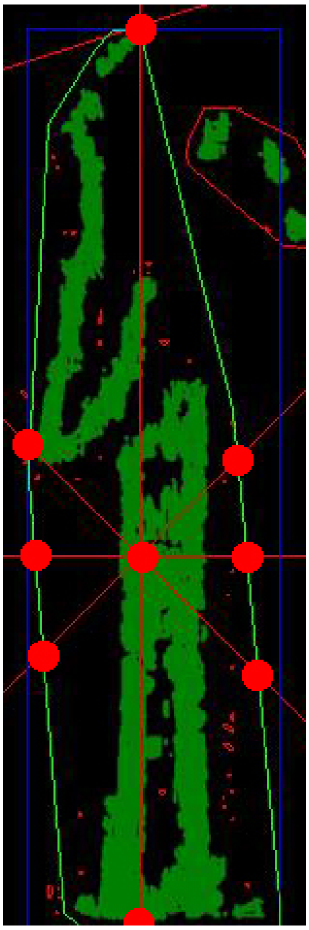

Figure 2.3: The intersection of the edges of the blob with the rays derived from the centroid of the enclosed area.

3. Summary

Summarizing the shortened version of the full doctoral thesis - it aims to present the idea of the undertaken research, its main assumptions and research problems. Block diagrams and details of algorithm operation are described in detail in the chapters of the full doctoral thesis. Similarly, in terms of data sets and the author's research environment, it is described in detail in the full content of the thesis.

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