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Intelligent image content semantic description for cardiac 3D visualisations

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ABSTRACT

In these days of the rapid development of diagnostic equipment with increasingly sophisticated technology it is necessary to put more emphasis on implementing processes for the computer support of medical diagnostics, which are more and more often used to automate diagnostic procedures carried out in healthcare. Current research shows that a significant part of diagnostic imaging, including e.g. of coronary arteries, is still difficult to automatically assess using computer analysis techniques aimed at extracting information having semantic meaning. This mainly applies to images that show many structures simultaneously, as well as 3D images. In this context, this publication presents new capabilities to formulate semantic descriptions of 3D structures of coronary vascularisation using graph formalisms. The proposed syntactic semantic description makes it possible to intelligently model the examined structure and then to automatically find the locations of significant stenoses in coronary arteries and identify their morphometric diagnostic parameters. In this research, images originating from diagnostic examinations with 64-slice spiral computed tomography were used.

1. Introduction

Heart and circulatory diseases are among the most serious and frequent threats to life in developed countries and at the same time constitute a crucial diagnostic problem of the 21st century. Every year, over 19 million people globally suffer sudden, severe coronary incidents (Yusuf et al., 2001). The increasing number of hospitalised patients drives the search for tools capable of helping the physician take therapeutic decisions (second-opinion assistance). This is particularly significant e.g. in the case of screening a selected part of the population, where the physician analysing a large set of diagnostic image data might, because of fatigue leading to poor concentration, miss a detail that could turn out to be medically significant in the process of formulating the diagnosis, the prognosis or the current treatment, and this may bring about significant consequences for the continued correct hospitalisation of the patient. What is more, the impressive progress in apparatuses for acquiring medical images means that new generations of diagnostic apparatuses enter the market. As a result, the images analysed so far, familiar to the physician, are replaced with other, better ones. Although the latter contain more information, they are unfortunately unfamiliar. In the present situation it is also increasingly difficult to be an expert who could efficiently assess all the currently available types of medical images. The reason is that the wide range of diagnostic apparatuses for visualising the same organ makes it possible to present the organ in various visual forms depending on the technique used to acquire the image. All these and many other circumstances have led the authors of this publication to carry out wide-ranging research to find new solutions that could help develop intelligent systems for medical diagnostic support (CAD—computer-aided diagnosis) and also significantly contribute to solving this very important problem.

The impressive technological progress in medical image diagnostics and the wide opportunities for 3D visualisation of human organs have significantly improved the efficiency of medical diagnostic tasks. The 3D reconstructions of examined medical structures obtained by rendering make it possible to truly represent the selected organ (including the changes in its texture), allowing its external and internal morphology to be observed precisely (Lewandowski et al., 2007). Such high technologies of image processing are today used in almost all types of diagnostic examinations based on digital technologies and of surgical jobs performed with the use of medical robots. As a result, it has become possible to identify a greater number of qualitative parameters of the examined structure (e.g. in the case of coronary arteries), which may be significant for making the correct diagnosis, and which could not be identified if the examination was made using a conventional method (2D imaging; Katritsis et al., 2008; Sirol et al., 2009). Diagnostic examinations of coronary vascularisation obtained from various image modalities (conventional angiography, intra-vascular USG, computed tomography or magnetic resonance) constitute complementary examinations (Bob Meijboom et al., 2008) and depending on the type of complaint the patient suffers, the physician decides which of the diagnostic apparatuses is to be

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used. However, it is obvious that all these achievements in the visualisation technology field offer limited opportunities for automating the interpretation of the diagnostic images acquired. This is mainly due to the difficulties that informatics encounters in formally describing and modelling complex thought processes taking place in the human mind which enable the semantic interpretation of analysed medical images.

2. Semantic image understanding technique

The number of IT tools developed to improve the capability of visual assessment of a given diagnostic image is high, and their operation can be considered satisfactory. However, there are no IT tools to be used for the automatic support of diagnostic or decision-making processes of physicians when they analyse an image and interpret it. Such intelligent IT systems supporting the thought processes of a physician analysing complex cases simply have not been developed yet. There are, however, tools that support the work of a diagnostician by making quantitative measurements of pathologies (e.g. stenoses in the case of coronary arteries) depicted in the image (Yin Wang and Liatsis, 2009; Oncel et al., 2007), which obviously makes his/her work easier, but only understanding the essence of the disease process allows the appropriate diagnosis to be made and the correct therapy to be prescribed. The reason for this deficit is a series of scientific and technical problems encountered by developers of intelligent diagnostic systems. One of the main difficulties in developing universal, intelligent systems for medical image diagnostics is the huge variety of images, both healthy and pathological, which have to be taken into account when intelligently supporting physicians interpreting them. In particular, the aforementioned varied shapes of morphological elements make it difficult to create a universal pattern defining the model shape of a healthy organ, or a pathological one. Yet the input of precisely such a pattern is required by a computer, using automatic image recognition technologies already well known and frequently used, as the IT technologies used are to a large extent based on the intuition of measuring the similarity of the case currently analysed to that abstract pattern. These technologies frequently fail if there are unexpected changes to the shapes of analysed organs caused by the disease process or individual variability. For this reason it is necessary to use those advanced artificial intelligence techniques and computational intelligence techniques that can generalise the recorded image patterns. What is particularly important is to use intelligent description methods that would ignore individual characteristics of the patient examined and characteristics dependant on the specific form of the disease unit considered, while at the same time making it possible to locate significant morphology changes and also to interpret and determine their diagnostic significance. Such methods, aimed at focusing the image description on diagnostically significant properties to the maximum extent can then be used in intelligent computer-aided diagnostics systems (CAD).

The last dozen or so years have mainly seen attempts to detect significant coronary artery stenoses (Yin Wang and Liatsis, 2009; Oncel et al., 2007) and coronary artery diseases using various techniques, e.g. neural networks (Kurgan et al., 2001), wavelet-based fuzzy neural networks (Akay et al., 1994), Bayesian methods (Cios et al., 1989). In this context one cannot find solutions in the form of intelligent systems that could imitate the thought processes taking place in the mind of the diagnosing physicians and thus generate a specific diagnosis, and not just a quantitative assessment of pathologies present. The problem presented is complicated. Such a system cannot be developed using classical methods of the traditional automatic recognition and classification (Meyer-Baese, 2003)—it is necessary to make use of a new technique of their automatic understanding leading to formulating semantic descriptions of analysed images. Methods presented here refer to earlier publications by the authors and use the concept of the automatic understanding of medical images (Tadeusiewicz and Ogiela, 2004). The authors' success in developing tools for automatically understanding flat images (Tadeusiewicz and Ogiela, 2004; Ogiela and Tadeusiewicz, 2002, 2008) has encouraged them to propose similar methods for 3D representations of biological structures provided by modern imaging systems. Considerations presented herein will particularly apply to 3D visualisations of coronary vessels, which will form the foundation of the detailed part of this publication, but the formulation of the problem itself and the solution methodology outlined here can have much wider application. At this stage we should note that we will consider a given computer interpretation of the 3D image analysed to exhaust the criteria of "automatic understanding" if this interpretation suggests directly what the 3D structure of the analysed organ is, what the spatial relationship of this structure to other organs and body parts is, and what the consequences of this structure and this relationship are. Taking into account the needs of the diagnostics and the therapy, it is expected that the automatic understanding process should be capable of indicating in what place, in what way and with what consequences the disease process has disturbed the 3D topology of the structure examined. Based on the understanding of a 3D medical image thus defined, we can give the physician far more and far more valuable premises for his/her therapeutic decisions than we could if we were using the traditional image recognition paradigm ending in a decision on the name of the diagnostic unit recognised by reference to an a-priori adopted taxonomy of diseases considered.

Adjective "semantic" is currently used in various context, e.g. in popular term "semantic web" and also in many other contexts. Therefore before discussion of our method of cognitive interpretation of coronary arteries medical visualisation we must first define, how we understand these adjective in proposed here term "semantic analysis of medical images". Especially we must compare terms **semantic web** and **semantic analysis of images**.

Semantic web is now a popular and a very general idea, proposed for intelligent information retrieval models. It is particularly effective for bag-of-words document representation, when user needs particular information, which is hidden in text, but the exact form of such information is not known and not predictable. Therefore in semantic web central point of consideration is concentration on relations between words and phrases, which can be different in form, but can have the same meaning. In semantic webs classic (most widely used) idea of the tool applied for this purpose is so called "ontology". Shortly speaking "ontology" is computer representation of our knowledge about relations between words and phrases—mostly represented in the form of edge labelled directed graphs. This relatively simple general idea can be enriched with many smart details and many useful tools, therefore ten years after introduction of "semantic web" and "ontology based approach" they are still the basis for many proposed and discussed detailed solutions. Recent advances in semantic web technologies have resulted in methods and tools that allow creating and managing domain knowledge. They influence the way and form of representing documents in the memory of computers, approaches to analyse documents, techniques to mine and retrieve, etc.

There are three main differences between mentioned above idea of "semantic web" and discussed in this paper idea "semantic analysis of medical images". First and most evident difference is related to the form of taken into account information. Despite