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Increasing the diagnostic capabilities of existing digital radiography systems using multilayer image reconstruction from few projections

Abstract. *The potential for increasing the diagnostic capabilities of digital radiography systems in terms of medical screening is described in this work. The solution is based on limited angle reconstruction from projections taken at different angle, which results in multilayer image (quazi 3D reconstruction). Existing digital radiography systems are supposed to be used so that the cost of upgrade is minimal. The procedure would be cost and time effective contributing to increased number of sufficiently evaluated patients.*

Streszczenie. *W pracy przedstawiono potencjał zwiększenia możliwości diagnostycznych cyfrowych systemów radiograficznych jako urządzeń do badań przesiewowych. Proponowane rozwiązanie oparte jest o rekonstrukcję obrazu z projekcji uzyskanych pod różnymi kątami, czego wynikiem jest obraz wielowarstwowy (pseudo trójwymiarowa rekonstrukcja). Zakłada się rozbudowę systemów radiograficznych - już obecnych w placówkach medycznych, ażeby koszt wdrożenia proponowanego rozwiązania był możliwie minimalny.* ***(Zwiększenie możliwości diagnostycznych systemów radiografii cyfrowej przy użyciu wielowarstwowej rekonstrukcji obrazu z kilku projekcji).***

Keywords: digital radiography, limited angle tomography, tomosynthesis
Słowa kluczowe: radiografia cyfrowa, tomografia z ograniczonym zakresem kątowym, tomosynteza

Introduction

Nowadays, radiological imaging is one of the most common diagnostic techniques used in medical practice. The continuous technological development allows to minimize the X-ray dose absorbed by the patient. It makes the radiological patient examination safer. The introduction of digital radiography (DR) was the essential breakthrough. The digitization includes image acquisition, processing, visualization and storage [1]. It has contributed to the cost and the radiation dose reduction, and therefore, made DR more popular in health care units.

On the other hand the technologies of three-dimensional imaging have been developed lately, including Cone-Beam Computed Tomography (CBCT) [2]. Yet cost of purchase of the CBCT imaging system, as well as the cost of daily use of such a system is much higher than the cost of using DR systems. Therefore, in practice, patients have limited access to three-dimensional computerized tomography (see Fig. 1).

These factors indicate the need for research on finding middle way solution, such as extending of diagnostic possibilities of existing DR systems which are currently used in medical practice. This could be achieved through modification of the projection data acquisition procedures and creating additional image reconstruction software, which is able to perform limited angle image reconstruction from projections [3]. The goal is to obtain (at least partially) the diagnostic effects comparable to fully three-dimensional computed tomography. This would allow to extend the capacity of diagnostic apparatus already in use, without significant financial cost spent on modernization of the equipment [4,5].

Therefore, the aim of this article is to introduce the potential technological solution and to analyse advantages of implementing the proposed methodology in clinical practice. Thoroughly, the following issues should be considered: the possibility of introduction of new diagnostic procedures such as, the modification of the way the projection data are acquired, the way they are processed, and finally, how the final image is reconstructed from projections. Such attempts are supposed to results in significant improvement of the examination quality, mainly through the reconstruction of multi-layered image from several projections. Therefore, the potential advantages in the context of Poland will be discussed in separate section.

Methods

There are DR systems with motorized source detector systems already existing in the medical practice, their geometry and the projection acquisition scheme is presented in Fig. 2. The aim of that investigation is to propose the extension in the form of software programs and the data acquisition procedures. In principle, the solution is based on tomography with the limited angular range of projections or linear tomography (compare Fig. 3). These two are suitable for implementation in the diagnostic systems already in use [3,5,6,7].

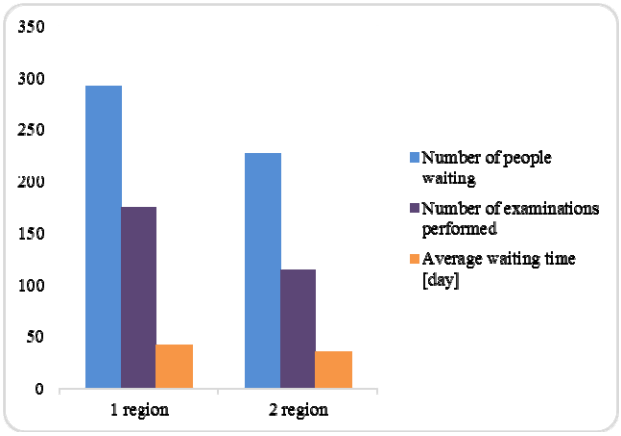

Fig.1. The time of waiting on CT examination in two regions of Poland (April 2014); Source: NFZ, April 2014

Limited angle reconstruction resulting in multilayer image

A set of layers (an approximate volume) can be reconstructed from acquired projections using either analytical or iterative algorithms. The latter algorithms have been observed to produce superior results. Therefore, iterative approach will be shortly described here.

In iterative image reconstruction the image function is found by repeating the sequence of: (i) current image

projection computation, (ii) comparison of the computation result with the measured projection and (iii) backprojection of the comparison result. The comparison and the correction application can be made either in additive of multiplicative way. The additive way can be realized as Algebraic Reconstruction Technique (ART) [8]. The ART correction formula is presented below

$$v_j^{(k+1)} = v_j^{(k)} + \lambda \frac{p_i - \sum_{n=1}^{N} w_{in} v_n^{(k)}}{\sum_{n=1}^{N} w_{in}^2} w_{ij} \quad (1)$$

where v_j is a reconstructed volume element, p_i is a projection element, w_{in} is an element of the system matrix and λ is a relaxation coefficient and N is a number of relevant v_j that contribute to the line integral p_i.

Recently weighting have been proposed for additive schemes, which improves their performance. It should be mentioned, however, that multiplicative schemes should not be neglected because they proved to intrinsically remove artifacts outside the reconstructed objects [8]. The method of choice among methods with multiplicative scheme would be Ordered Subsets-Expectation Maximization algorithm [9] widely used in emission tomography. The correction formula for that method is as follows

$$v_j^{(k+1)} = \frac{v_j^{(k)}}{\sum_{i \in D_m} w_{ij}} \sum_{i \in D_m} \frac{w_{ij} p_i}{\sum_{n=1}^{N} w_{in} v_n^{(k)}} \quad (2)$$

where v_j is a reconstructed volume element, p_i is a projection element, w_{in} is an element of the system matrix and λ is a relaxation coefficient and N is a number of relevant v_j that contribute to the line integral p_i. D_m is a set of projections chosen according to the determined subset level.

Preliminary research conducted previously [4] related to the use of linear tomography with the limited number of the projections in nondestructive testing showed the strong influence of the reconstruction parameter settings on the final result of image reconstruction.

In some unfavorable cases poorly chosen initial parameters may cause gradual error accumulation during the iterative process. In particular, there is strong dependence of final results on the conditions of X-ray exposure of objects, the number of the projection acquired or the geometrical configuration of the system elements.

This could be achieved through modification of the projection data acquisition procedures and creating additional image reconstruction software, which is able to perform limited angle image reconstruction from projections.

Potential advantages of upgrading DR systems

The growing number of cancer disease cases and demographic change result in higher patients expectations concerning quick and precise diagnosis. The upgrade would contribute to shortening of the waiting time for examinations and reduce the overall cost. These methods propose here are an attempt to address the growing interest on both groups the doctors and the patients.

Despite the continuous development of research systems, increase in the number of cameras (both in Poland and in the world as presented in Fig. 4, Fig. 5 and in Table 1) the cost of purchase and using of the equipment does not significantly decrease. For instance, the cost of performing the study is currently as high as several hundred polish zloty. The growing number of diseases, particularly cases of cancer, and demographic change have contributed to the fact that patients' expectations are focused on the diagnosis that was quick and precise. Such diagnostic method will shorten the treatment time. At the same time, progress in this area means a larger number of patients diagnosed and shorter waiting time for research.

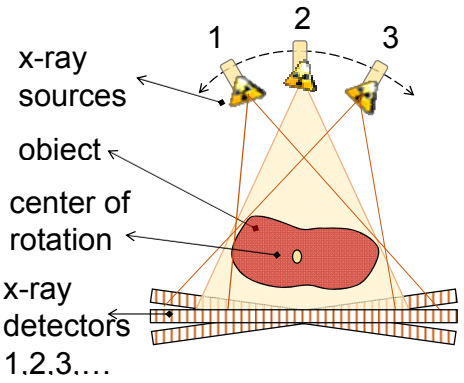

Fig 2. The geometry of Digital TomoSynthesis (DTS)

Currently in Poland, there are about 30 million examinations using ionizing radiation per year [10]. This corresponds to almost one examination per citizen annually. These data represent only the examinations paid by the

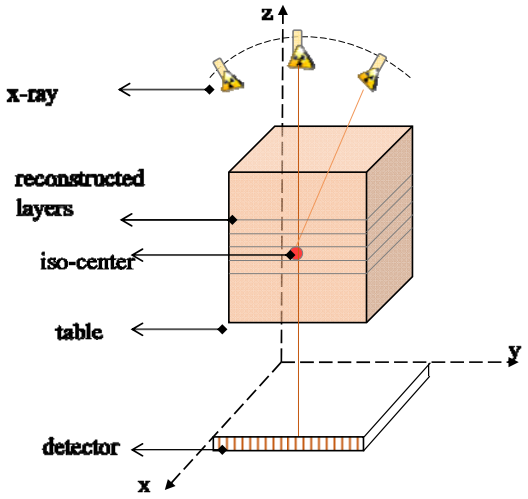

Fig.3. The principle of image acquisition and image reconstruction proposed in this work

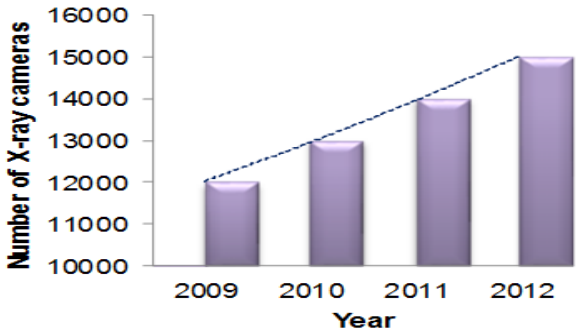

Fig.4. The number of X-ray cameras in Poland (2008-2012) [8]

National Health Fund (polish abbreviation - NFZ), so the actual number of examinations including the non-public sector is certainly much higher [10].

The waiting time for execution of the examination depends on its characteristics and varies from a few to

several days. Most dates back several months. The private sector medical services offers the possibility to carry out the study for consideration, but due to the costs involved, it becomes impossible for the average patient. Indicators describing the situation in Poland allow us to conclude that, despite the noteworthy increase in investments in health care sector for Polish and European patients it is still difficult access highly specialized equipment. The net effect of that situation is prolonged time of diagnosis and therapy [11].

Table 1. Computer Tomography scanners, total X-ray machines per 1 million population. Source: OECD Health Statistics, October 2013r. (http://dx.doi.org/10.1787/ct-exams-tot-table-2013-2-en)

	2006	2007	2008	2009	2010	2011	2012
Australia	56,0	-	-	39,0	43,0	44,4	50,6
Austria	29,9	30,0	29,6	29,3	29,8	29,5	-
Canada	12,0	12,7	-	13,8	14,2	14,6	14,6
Czech Republic	13,1	12,9	13,3	14,1	14,5	14,8	12,9
Denmark	15,8	18,5	21,5	23,7	27,6	29,3	-
Finland	14,8	16,5	-	20,4	21,1	21,3	21,8
France	10,4	10,3	10,8	11,1	11,8	12,5	13,5
Ireland	127	4,2	14,5	15,3	15,5	15,7	17,3
Italy	28,9	30,1	30,4	3,3	31,5	32,1	-
Mexico	3,5	4,0	4,2	4,3	4,9	4,8	-
Netherlands	8,4	7,8	10,2	11,3	12,3	12,5	-
Poland	9,2	9,7	10,9	12,4	14,2	13,5	-
United Kingdom	7,7	-	7,4	-	8,3	8,9	-
United States	34,0	34,3	-	-	-	40,9	-

It is therefore important to ensure both comfort and availability of medical tests for patients. This can be achieved by innovative solutions, shortening the waiting time for examinations and reduce the cost of diagnosis.

For instance digital tomosynthesis, which is a particular case of the approach proposed here, is a promising tool for screening diseases and lung cancer [3] and mammography [5,7,12]. Advantages of DTS compared to one projection radiography have been confirmed clinically. The most important benefits are better lesion detection (thanks to partial recovery of the third dimension - resulting in anatomical noise reduction and depth localization) and improved contrast resolution.

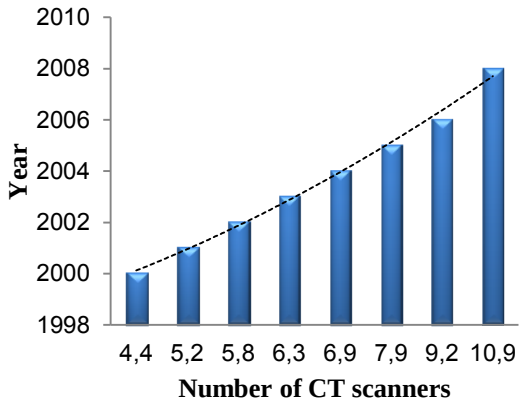

Fig.5. The number of CT scanners per 1 million population in Poland (2000-2008). Source: OECD Health, October 2008

Conclusions

The proposed solution, which is based on the extension of existing DR systems located in health care units seems to be promising, particularly for screening of larger number of patients. It would replace costly three-dimensional tomographic evaluation. The procedure would be cost and time effective contributing to increased number of sufficiently evaluated patients. Further work is required as to determine the critical parameters such as minimal angular range [13] in order to ensure diagnostically valuable image resolution.

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