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Virtual magnetic resonance imaging as a didactic aid

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1. Introduction

Magnetic Resonance Imaging

Images obtained by Nuclear Magnetic Resonance (NMR) are the graphical representation of the distribution of certain physical properties of the object. In practice, Magnetic Resonance Imaging (MRI) is based on the nuclei of hydrogen atoms. They have half-spin, so they are susceptible to NMR phenomena. Furthermore, there are commonly present in the human body [1]. This allows identifying three parameters characterizing studied tissues that determine MRI contrast obtained [2]:

- PD - the density of protons (proton density, ρ). This is the amount of nuclei (due to the use of hydrogen nuclei, the term density of protons has been used) that are subject to the phenomenon of resonance, in a unit volume;
- T1 - time of longitudinal relaxation. This is the time constant describing the rate of re-growth of the longitudinal magnetization component of the atomic nucleus;
- T2 - transverse relaxation time. This is the time constant describing how rapidly the component of transverse magnetization disappears.

The signal carrying information about the above mentioned properties of the test subject is obtained in response to the specific excitation sequence. It consists of radio frequency (RF) pulses that change the magnetization vector of the particles susceptible to the NMR phenomenon. Reading of the signal (echo) from the currently projected section is made possible by controlling the magnetic field gradient and excitation sequence parameters. The use of gradients allows choosing the appropriate cross-section [3,4]. By manipulating the excitation sequence, contrast can be weighted by various tissue parameters (PD, T1 and T2). The spin echo sequence is presented on Figure 1. It can be described by two parameters:

- TR - repetition time. This is the time between the RF pulse bursts;

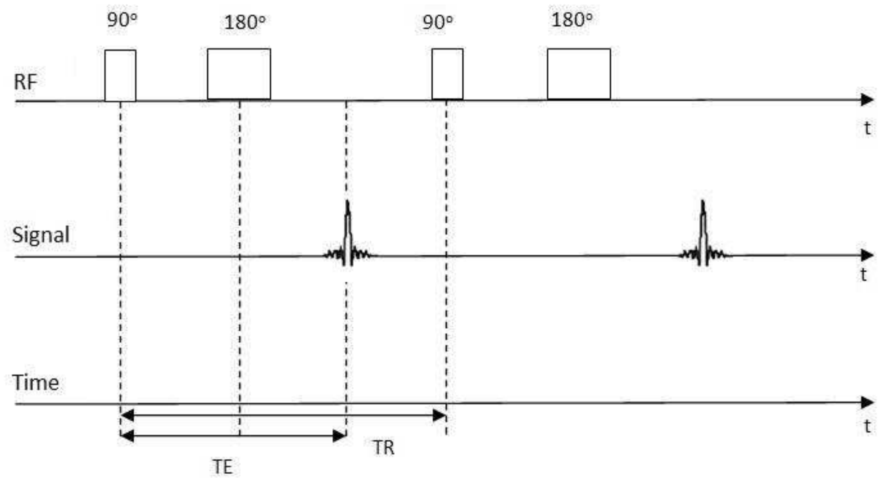

Figure 1. RF pulse sequence for the SE method

- TE - echo time. This is the time after which the signal is read (echo).

The use of SE sequence allows obtaining an image in which the contrast is weighted by any of the parameters of the tissue. Depending on the values of TR and TE, the image shows the distribution of PD, T1 or T2. The impact of individual parameters on the imaging results describes a mathematical formula available in the literature [5]:

$$S = \rho(1 - e^{-\frac{t}{T_1}})e^{-\frac{t}{T_2}} \quad (1)$$

Virtual MRI

Virtual Magnetic Resonance Imaging is carried out by means of computer data processing which determines the contrast obtained. This way, it is possible to obtain an image of any desired contrast. VMRI achieves this effect by performing appropriate calculations, without the use of an MRI scanner and involvement of the patient.

The idea of developed VMRI technique is presented on Figure 2 [6]. The first block contains the data necessary to create the model of the patient. These should include data for three images (PD, T1 and T2 weighted contrasts) as well as TR and TE parameters for each of three pictures. This information is saved as DICOM data, and reading them does not constitute any problem. Mathcad software was used for VMRI simulation in our research.

When processing previously obtained images with the VMRI technique, other problem occurs. Due to the high cost of the MRI examinations, generally images of the same cross-section are not recorded in all three contrasts. Skipping images with the lowest diagnostic value for a given medical purpose can reduce time and thus keep the cost at appropriate level. Unfortunately, it prevents full use of the VMRI technique. However, analysis of some cases in our previous studies (neurology, orthopedics) allowed determining that it is possible to omit the missing image at the stage of creating a model of the patient. This topic requires further research on optimization of the VMRI technology [6,7].

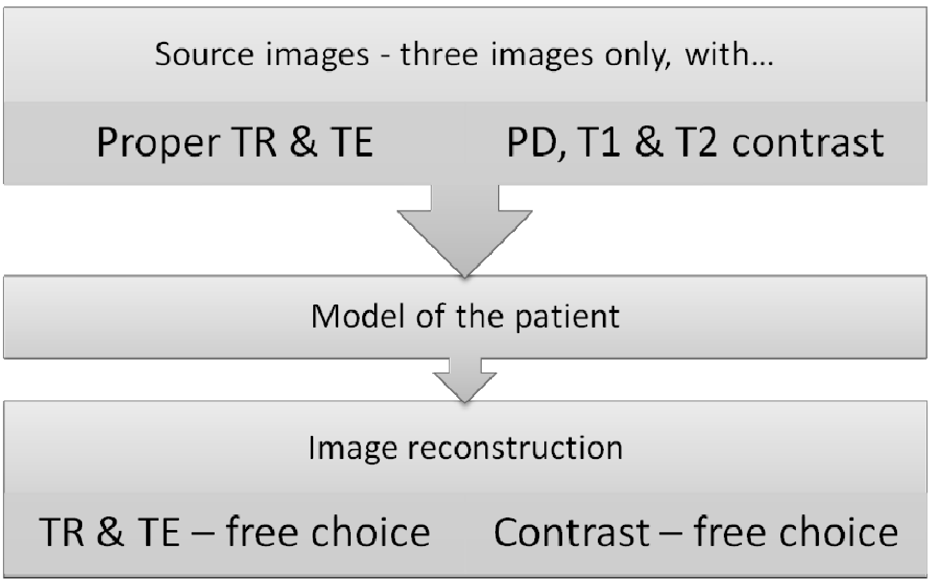

Figure 2. Idea of VMRI

The advantage of VMRI simulation is the ability to generate images in real-time and without involving the equipment and the patient. The user is not limited in any way in selection of the excitation sequence timing parameters. It is an exciting prospect for both the student who wants to better understand the rules governing the MRI, and the doctor who wants to examine the patient as accurately as possible.

Use of the VMRI simulation for teaching purposes allows continuous changing of the TR and TE parameters, in order to observe their effect on obtained contrast. For example, a student can observe the result of simulation for a short TR time and long TE time. Such sequence is never applied in clinical practice. This is justified by the fact that with such set of parameters, it is not possible to obtain a good contrast. In the picture, a significant effect of all three parameters of the tissue will be present. As a result, the image is of little diagnostic value. With the simulation, students can easily see that in fact such set of parameters is useless. Figure 3 [8,9] shows image generated with VMRI technique. Such images have both didactical and diagnostic value.

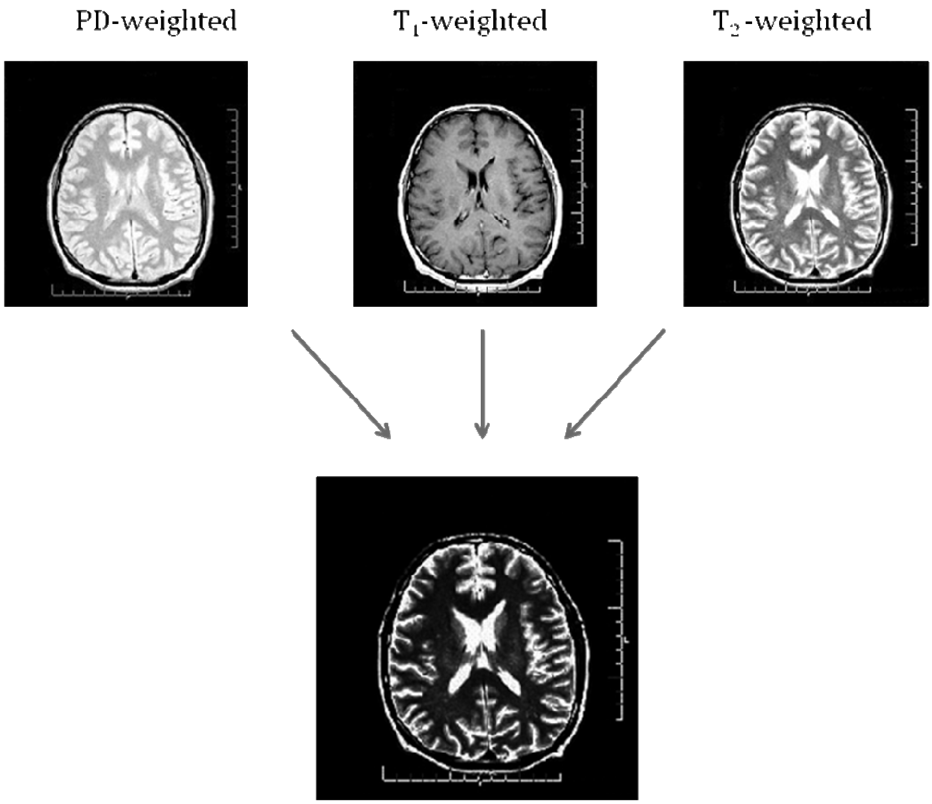

Figure 3. Example of VMRI generated image (TR = 25 s, TE = 1,25 s)

2. Conclusions

The aim of this study was to develop a method for creating a model or a digital phantom of the patient on the basis of three MRI images. After reading the source materials, the VMRI system automatically calculates the values that produce a phantom of the patient. Then the simulation tool can generate images from the model, for any selected time parameters of the excitation sequence.

The main expectation to the simulation was to demonstrate the impact of TR and TE parameters on MRI results. Simulation has the didactic value for those involved in the field of Biomedical Engineering. It allows much better way to introduce Magnetic

Resonance Imaging measures to the students studying technical fields. However, it is particularly important also for medical students. They are not familiar with analyzing equations as well as complicated diagrams, and draw conclusions from them. Therefore, the ability to manipulate imaging parameters and observe immediately, on-line, their effects on image on the computer screen, is a very useful teaching aid.

The value of VMRI simulation in teaching has been verified by the first author of the work. Within the framework of the Erasmus program, he spent a semester scholarship at the Fachhochsule Stralsund, Germany, where he presented simulations described in this study to the students of Biomedical Engineering. In consultation with the lecturer responsible for the subject of "Medical Imaging Systems", author of a series of lectures supplemented the activities carried out based on the simulation. All persons participating in the classes confirmed that VMRI description of the SE method makes it much easier to learn the principles of MRI as well as image contrast manipulation.

Recently, the method of VMRI has been included also in the course of "Medical Informatics and Telemedicine" at the Faculty of Electrical Engineering of the West Pomeranian University of Technology, Szczecin. It is a facultative course for students of Electronics and Telecommunications, with specialization in Electronic Systems.

It is also planned to develop a teaching platform for medical students from the Pomeranian Medical University in Szczecin. First tests carried out with the staff from the Department of Radiology of the PMU have demonstrated very good teaching outcomes.

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Abstract

The paper concerns aspects of using Nuclear Magnetic Resonance in medicine. The phenomenon of NMR is basis for the Magnetic Resonance Imaging (MRI). Simulation of creating an image in spin echo (SE) method of MRI is used to obtain additional, arbitrary chosen images of the patient. Virtual MRI technique allows changing contrast of images in real time without use of any special equipment. Despite diagnostic benefits, VMRI is very helpful in didactics. Performing of such simulations greatly improves understanding of MRI principles and image contrast manipulation by the students.

Streszczenie

Artykuł dotyczy aspektów zastosowań magnetycznego rezonansu jądrowego w medycynie Symulacja tworzenia obrazu echa spinowego (SE) w metodzie MRI jest używana w celu uzyskania dodatkowych, dowolne wybranych obrazów pacjenta. Wirtualna technika MRI pozwala na zmianę kontrastu obrazów w czasie rzeczywistym, bez użycia specjalnego sprzętu. Pomimo świadczeń diagnostycznych, VMRI jest bardzo pomocna w dydaktyce. Przeprowadzenie takich symulacji znacznie poprawia zrozumienie zasad MRI i manipulacji kontrastu obrazu przez uczniów.

Słowa kluczowe: NMR, MRI, VMRI, metoda echa spinowego SE, symulacje komputerowe, dydaktyka