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A software platform controlling an MRI guided focused ultrasound system

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Abstract - A software platform written in MATLAB has been developed in order to control an MRI guided Focused ultrasound system. The software serves 7 main tasks: a) MRI imaging, b) transducer movement (the user may move the robot manually or automatically by specifying the pattern, the step and the number of steps), c) messaging (starting time, treatment time left etc), d) Camera control, e) Patient data (age, weight, etc), f) Controlling the parameters and activation of a signal generator and g) Temperature measurement. The motors are activated using a 24 V DC supply which is incorporate in an enclosure that includes the drivers of the motors. The motors are interfaced using a USB card (National instruments NI-6251). Feedback is provided using a timer card. The software controls a positioning device which can be used to treat patients with brain, liver, kidney, thyroid, pancreas and prostate cancer.

Keywords - software; HIFU; MRI

I. INTRODUCTION

High intensity focused ultrasound (HIFU) has the potential to induce thermal changes in tissue and therefore it is used extensively for medical applications. Nowadays HIFU is utilized to selectively heat biological tissues for oncological applications with minimal invasiveness by using MRI to provide, to the operator performing the procedure, images of a region within the subject being heated.

The idea of using HIFU was proposed in the middle of this century by Lynn JG et. al. [1]. The first complete system for the use of HIFU was developed by Fry W et. al. [2]. However, at that time MRI did not exist and therefore the previous systems were not guided effectively, and therefore had not survived in the clinical setting.

HIFU was explored in almost every tissue that is accessible by ultrasound. The following literature represents some examples of some applications explored: eye [3], prostate [4], liver [5], brain [2], [6]-[7]) and kidney [8]-[9].

In the recent commercial systems HIFU [4], [10], and [11] is either guided by ultrasound or MRI. Ultrasonic imaging is the simplest and most inexpensive method to guide HIFU; however MRI offers superior contrast than ultrasound, especially when imaging of thermal lesions is needed.

The combination of ultrasound and MRI was first cited by Jolesz and Jakab [12] who demonstrated that an ultrasonic transducer can be used inside a MRI scanner. The concept of using MRI to monitor the necrosis produced by HIFU was demonstrated in the early nineties by Hynynen K et. al. [13] in canine muscle. In the following years additional studies have been conducted [14] - [15], showing that the contrast between necrotic tissue and normal tissue was excellent. This was a great enhancement for the HIFU systems because the therapeutic protocols can be accurately monitored. Therefore the interest of using MRI as the diagnostic modality of guiding HIFU was increased.

In order to gain all the advantages coming from the use of MRI imaging guidance; robotics systems have been developed during the past years. Also, software platforms that control the robotics systems and the treatment plans have been developed. The software platform supports the MRI compatible robotics systems during the treatment in an easy and friendly manner. The main advantage of using software is the precision of the robot movements and also the control of treatment protocol during the treatment. Hao Sua et. al. [16] developed a software platform that controls an MRI compatible robot that performs prostate biopsy. The software [16] controls the MRI images, the robot movements and the treatment plan.

In this paper, the software that controls an MRI guided HIFU system is presented. The software is developed using MATLAB (The Mathworks Inc., Natick, MA, USA). MATLAB has compatibility with all the components that are used to implement this system. The development of the following subprograms is presented:

a). Ultrasound control, b) MRI Compatible camera control, c) Control of MRI compatible robot, d) Application command history, and e) Patient Data record.

II. MATERIALS AND METHODS

In order to implement this software, MATLAB has been used. MATLAB is powerful programming language that helps the programmers to develop friendly graphical user interface (GUI) applications.

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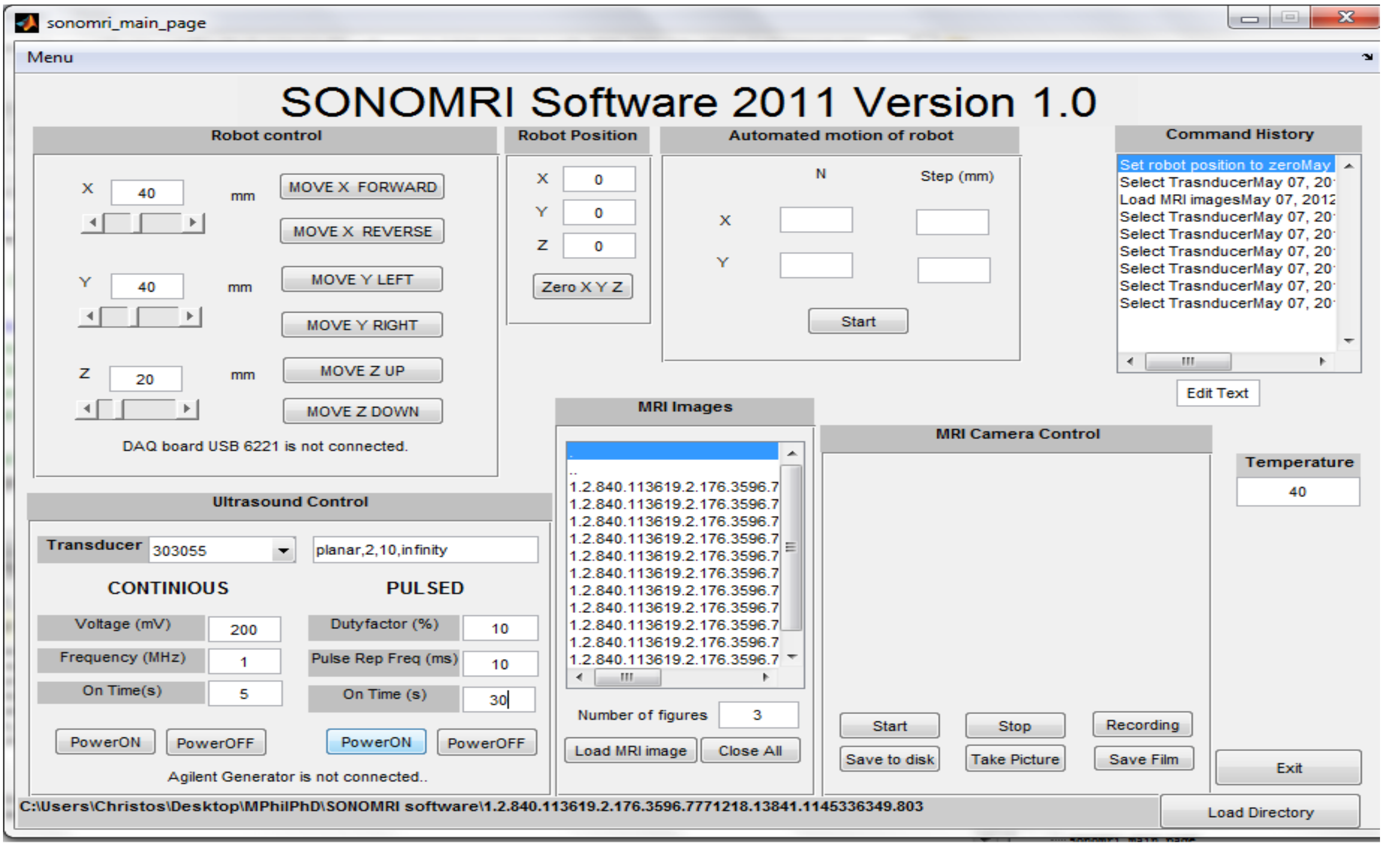

Figure 1 The main window of software platform controlling an MRI guided Focused ultrasound for cancer therapy

Since the application controls a 2D robot, a data acquisition device (USB-6251, National instruments, Austin, Texas, USA) has been employed. MATLAB DAQ has the ability of interfacing with NI USB 6251 card. The motors are activated using a 24 V DC supply which is incorporated in an enclosure that includes the drivers of the motors.

The software platform controls the signal generator. For this purpose, the Agilent Signal generator (33220A, HP 33120A, Agilent technologies, Englewood, CO, USA) has been employed. The generator has the ability of communicate with the computer via a USB interface. Additionally, an MRI compatible camera is used to record the animal's welfare during the experiments. For this purpose, the MRC camera 12M (MRC Systems GmbH, Germany) was employed. The MR camera can operate inside the MRI scanner room.

The software was designed and developed in subprograms. Each subprogram was tested separately and then, all the subprograms were merged in a single software platform.

III. RESULTS

A. Graphical User Interface (GUI) design

The main reason of using MATLAB for creating the interface of this task was the ability to communicate with the various devices (camera, signal generator, robot, MRI, etc) but also its ability to create graphical user interface. In fig. 1, the main window of the software is shown. The main window of the software consists of various menus and options of controlling the MRI guided HIFU system.

B. Ultrasound control panel

This part of the software controls and sends the correct parameters to the signal generator that drives an RF amplifier. Fig. 2 shows the ultrasound control panel GUI. There are six textboxes helping the users to provide the correct parameters to the signal generator. Also buttons of turning ON and OFF the signals have been utilized. The interface is separated into two groups, continuous and pulsed ultrasound generation.

C. Display transducer information

Inside the ultrasound control panel, there is a combo box that enables the user to select and display useful information about the transducer selected (see fig. 2). The combo box is filled by the serial number of all available transducers in an excel file. MATLAB has the ability to open and read column data from a Microsoft Excel file.

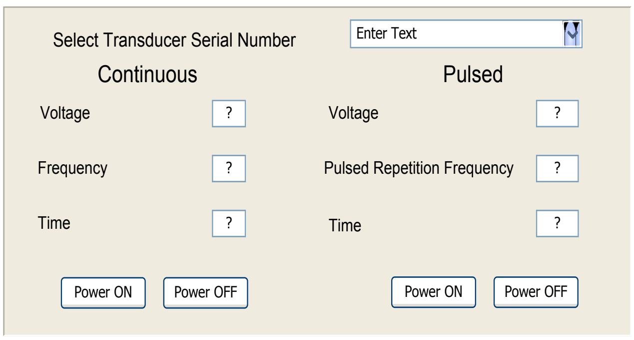

Figure 2 MATLAB interface for controlling the signal generator

D. *MRI Compatible Camera Control Panel*

For monitoring the welfare of animal, the utilization of an MRI compatible camera is needed. MATLAB programming environment has the ability to call specific functions from the abstract that enable the user to control the MR camera within a MATLAB window. The camera performs the following operations: 1) preview, 2) take picture, 3) recording video.

Since the camera operates within the MRI scanner the camera has to be MRI compatible (figure 3). The MRC camera consists of three parts: the camera (fig. 3A), the filter box (fig 3B), and the video grabber (fig 3C),). The analogue signal coming from the camera is transformed to digital signal using a video grabber.

A B C

Figure 3 the MR Camera consists of three parts: A) Camera, B) Filter box, C) Video grabber

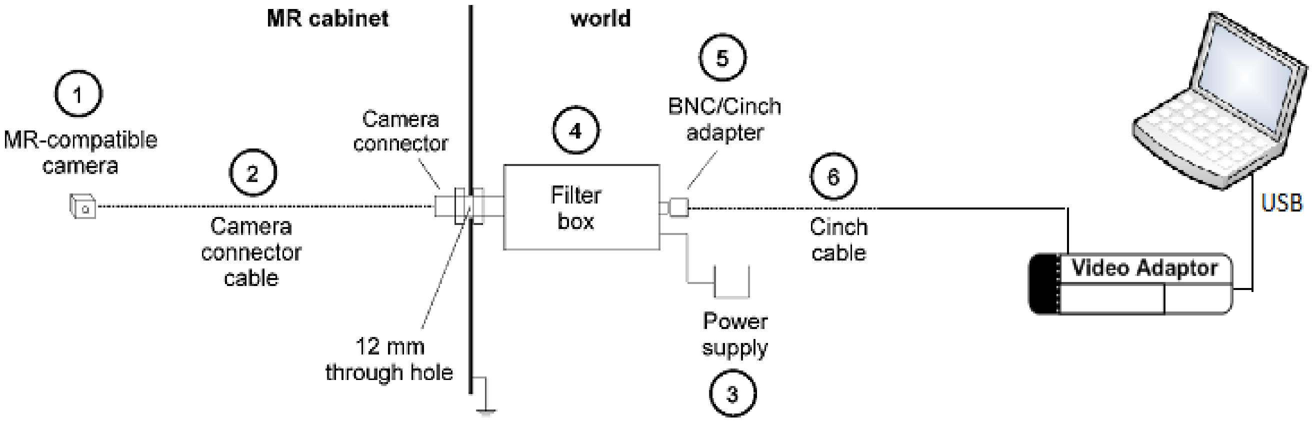

Figure 4 Schematic showing the interconnection of the camera

Fig. 4 shows the MRI compatible camera (1) which is placed inside the MRI room and it is connected via camera cable (2) to filter box (4) that is placed outside the MRI room. Filter box (4) is connected also with power cable to wall power socket (3). Additionally, filter box BNC/Cinch adapter (5) is connected via cinch cable (6) to a video adaptor.

In fig. 5 the design of the interface is shown. There are six buttons. The first button is used to start the MRI camera, the second button is used to stop the MRI camera, the third button is used to start the recording, and the fourth button is used for taking snapshot images from the camera. The remaining buttons is used for saving the captured images and for saving the movie file also to selected directory.

The snapshot image object is used for displaying the image computed by the MRI camera. Also, while the camera records a movie, the movie will displayed like a live streaming video.

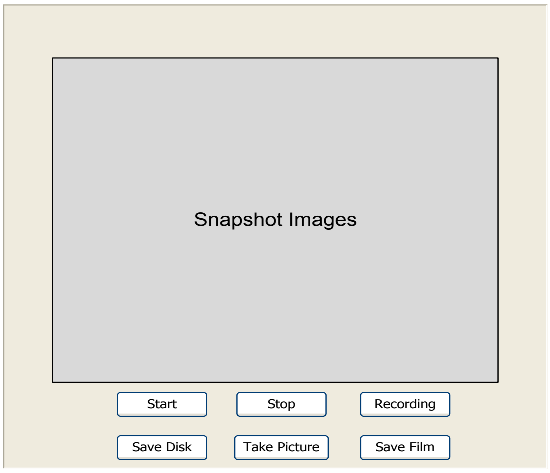

Figure 5 MRI Camera Interface

E. *Control of MRI compatible motor*

This part of the software controls the robot movements during the HIFU treatment. The software needs to have the ability to control the robot from outside the MRI room. In order to achieve this, the software must have the ability of sending and receiving data to/from the actuators (USR 60 – E3N, SHINSEI – Rotary encoder) by using a data acquisition board which has the ability of interfacing with MATLAB data acquisition tool box.

This card is connected with the computer using a USB interface. A special driver (NI DAQ mx 9.3) must be installed on the destination computer. By using the test panel software driver, the NI USB 6251 card can be tested and see if the card has been connected with the computer successfully.

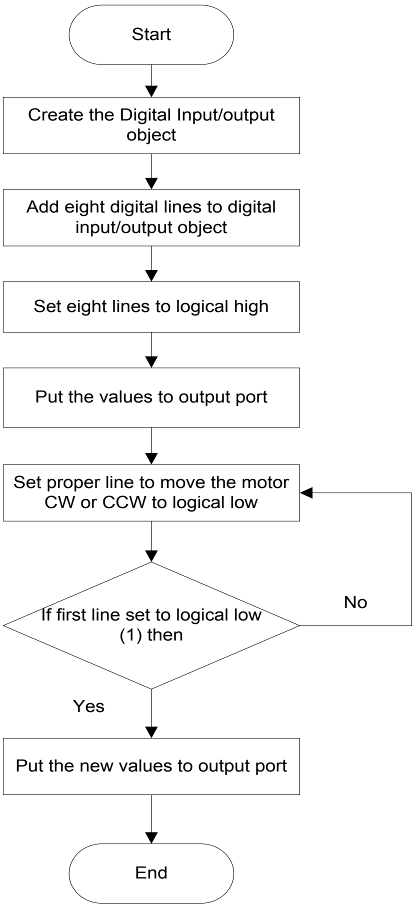

Figure 6 Flowchart for motor control

The accurancy of the robot is secured using a counter that exist in the USB-6251 interface card. The counter value is acquired using the *Edge Count* value from NI instruments USB card. The Edge Count value is the necessary feedback required from the motor; in order to know the time that the rotary encoder is activated. The robot has two degrees of freedom (X - Θ) (see motor interaction in fig. 6).

Another part of the robot control is the initial position. The robot position must be initialized to zero in order to know how far the robot from the initial point is; at any time. This helps to know the reference position of the arm with respect to the initial position. Two variables have been created into the GUI handles array. The names of the variables are X and Θ. The programme automatically stored the robot position to these variables, after any motor movement, by adding or subtracting from the current value. As you can see in figure 8, the user is able to set the initial position of the robot equals to zero and also the user can follow the position of the robot at any time.

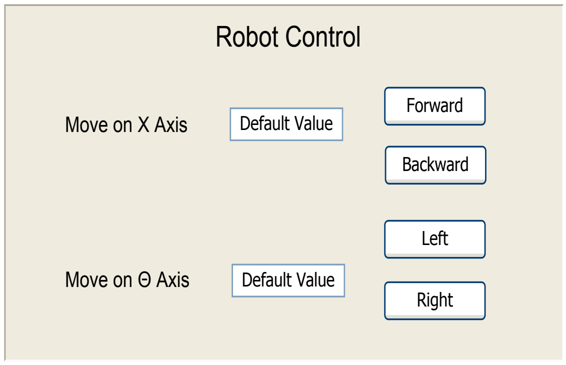

Figure 7 Design of robot control interface

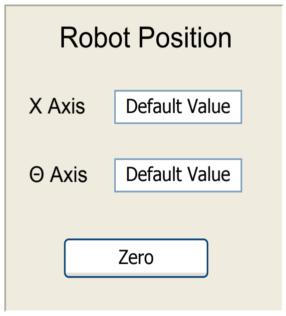

Figure 8 Design of robot position interface

F. *Application command history*

Application command history is a list box that is located in upper right corner of the interface. This function helps us to follow what actions have been performed within the software. Two fields store in the list box, the name of operation and the date/time. In order to get date/time from the system, a specific MATLAB function is called.

G. *Patient data form*

In this section, a function that gives the ability to the user to store useful information about the patient is described. The end user can open a window that contains a menu with the following options:

a). Patient data b). Enter information about a particular operation to a patient, c) Search for a patient, d) Edit data that has been already stored, e) Delete data, f) Navigate through all patients records.

In order to achieve the above tasks, a friendly special design form was developed by using VB .NET 2010 (Microsoft Visual Studio .NET 2010). It was decided to use the MS Visual Studio, because is a proper choice of developing an application database system. This is because Visual Studio has embedded libraries that give the ability of better quality interface design.

Also RDBMS (Relational Database Management System) software has been used (Microsoft Access 2007). To establish a connection between these two platforms, a connection library named ***OLEDbConnection*** (see below in more detail) has been used. Two more libraries named ***bindingsource*** and ***bindingnavigator*** are also used.

In any relational database system, data is organized in tables. In this particular case, the data is separated in two tables named *patient* and *operations*. Patient data table accepts the personal information about the patients and the operations tables accepts the details about the particular operation. So, two tables have been created in MS Office Access database system. In table 1 the data for each table is presented:

Patient Table		**Operations Table**	
Field	**Data Type**	**Field**	**Data Type**
ID	Text	Operation ID	Auto Number
Last Name	Text	ID	Text
First Name	Text	Operation	Date/Time
Address	Text	Description	Memo
City	Text		
Country	Text		
Phone	Text		
Age	Text		

Table 1 Patient parameters used

According to the needs of this form, a list of GUI controls is located in the patient data form. Text boxes, command buttons, labels, group boxes and a data grid are used. Text boxes are used to enter and display data. The labels describe what is bind to a text box. Group box separate the patient data and the operation data. Command buttons actually perform the operations and a data grid that displays the operation according to the selected patient. Figure 9 shows the patient data form.

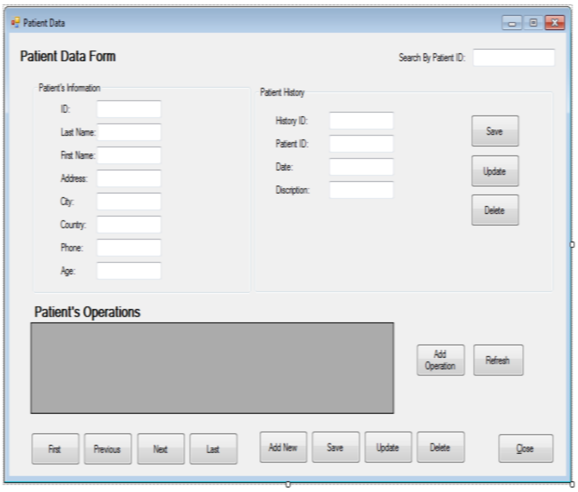

Figure 9 Patient Data Interface

Command buttons are grouped to navigation buttons and action buttons. Navigation buttons allow us navigating through all records of data table that form is bind. Navigation buttons are named as follow: First, Previous, Next and Last record. Action buttons allow us to perform operations on the table data. Actions buttons are named Add New, Save, Update, Delete. Actually, the patient data form performs the group of operations that is named *CRUD* (Create, Read, Update, and Delete). A search text box located at the upper right corner allows us to make a search for a particular patient.

IV. CONCLUSION

A software platform written in MATLAB has been developed in order to control an MRI guided Focused ultrasound. The software serves 7 main tasks through various windows or menus: a) MRI imaging, b) transducer movement (the user may move the robotic arm in a specific direction or customise the automatic movement of the robotic arm in any formation by specifying the pattern, the step and the number of steps), c) messaging (starting time, treatment time left etc), d) Camera control, e) Patient data (age, weight, etc), f) Controlling the parameters and activation of a signal generators) and g) Temperature measurement. Feedback is provided using a timer card. The software controls a positioning device which can be used to treat patients with brain, liver, kidney, thyroid, pancreas and prostate cancer.

This software platform has been control the MRI compatible robot that performs in vitro and in vivo experiments in real MRI scanner room environment. The software controls a positioning device which can be used to treat patients with brain, liver, kidney, thyroid, pancreas, prostate cancer, and also for sonothrombolysis.

For future work, we have planning to develop a better DICOM[1] viewer in order to control and display the images

[1] DICOM = Digital Imaging and Communications in Medicine

coming from the MRI in a better way and also for creating the treatment plan during the treatment process. Additionally, the software will be tested for motion control accuracy (according to optical encoder measurements) during an experiment in vivo inside the MRI scanner.

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