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Using Electrical Impedance Tomography to Control a Robot

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***Abstract*—**Electrical impedance tomography is a non-invasive medical imaging technique suitable for medical applications. This paper describes an electrical impedance tomography device with the ability to navigate a robotic arm to manipulate a target object. The design of the device includes various hardware and software sections to perform medical imaging and control the robotic arm. In its hardware section an image is formed by 16 electrodes which are located around a container. This image is used to navigate a 3DOF robotic arm to reach the exact location of the target object. The data set to form the impedance imaging is obtained by having repeated current injections and voltage measurements between all electrode pairs. After performing the necessary calculations to obtain the impedance, information is transmitted to the computer. This data is fed and then executed in MATLAB which is interfaced with EIDORS (Electrical Impedance Tomography Reconstruction Software) to reconstruct the image based on the acquired data. In the next step, the coordinates of the center of the target object are calculated by image processing toolbox of MATLAB (IPT). Finally, these coordinates are used to calculate the angles of each joint of the robotic arm. The robotic arm moves to the desired tissue with the user command.

***Keywords*—**Electrical impedance tomography, EIT, Surgeon robot, image processing of Electrical impedance tomography.

I. Introduction

NUMEROUS efforts have been made towards the development of more accurate, reliable and faster methods of EIT imaging. This non-invasive imaging technique due to its unique performance can be relatively low cost and easy to operate and maintain. This system and image reconstruction algorithm can be used to obtain breast tissue imaging for diagnostics and screening, in particular for malignant tumor detection. It can also be more practical in order to monitor lung functions after surgery. Although the skull has high resistance, recent studies provide the possibility of EIT imaging of brain function. This type of imaging has merits rather than other imaging methods like X-rays or Magnetic Resonance Imaging (MRI) such as the possibility of long-term imaging, imaging at the patient's bedside and less side effects compared to CT [1]. The low cost and portability of the EIT hardware cannot be overlooked. Because of the profits of EIT imaging, it is being used in this project to control the robotic arm (similar to a surgeon robot). In this new approach, a robotic arm is navigated to a target object based on information obtained from impedance imaging (EIT). The device made in this study includes a robotic arm with three degrees of freedom, EIT imaging system and different software on the computer. The hardware section of this device has 16 electrodes. These electrodes are surround a cylindrical like container that resembles a human head. The device by applying an electric current with predefined frequency between the pair of electrode samples the voltage and by repeating this process between all pair of electrodes, the required row of data is provided for forming the image. After performing the calculations to obtain the impedance, the data set is transmitted to the computer and the coordinates of the center of the target object is calculated by the image processing toolbox of MATLAB (IPT). Finally, these coordinates are used to calculate the angle of the robotic arm which can be navigated to the desired target by the user command.

There has been a lot of researches to develop the EIT imaging in the last three decades. The development of this technique has been used to build devices with high accuracy and provided the possibility of clinical usage. For instance, the device was made by Taras Dudykevych for lung function monitoring was tested in hospital environment [2]. Many devices have been built for breast imaging and some of them have become a suitable device for clinical usages [3]. Because of the high resistance, the skull does not permit sufficient current to enter the brain. Therefore, imaging of the brain can be faced with difficulties; however, recent research has been done in this area, leading to the construction of devices for this purpose [4]. Most of the devices have been made and developed for diagnostic proposes, post-operative care or screening. EIT imaging as a result of its features can be located at patient's bedsides during a surgery and performs real time EIT imaging by connecting electrodes of the device to the patient body, it can be used to navigate a surgeon robot during a surgery. The robot can find its path through the tissue by analyzing the imaging data and if necessary, it can eliminate the target, which may be a tumor. The development of this system allows the complete elimination of tumor targets and it will reduce the need for further surgery. With this system, it is possible to detect the parts of the brain that are more active than others (such as the visual cortex) the robot can be programmed to move in a direction that has the least harm to these active parts. Although the prototype made is not capable of surgery, it shows its abilities to navigate a robotic arm and paves the way for future work and the development of the device. Such a surgeon robot can perform accurate and complete surgery even in places where the

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surgeon is not present.

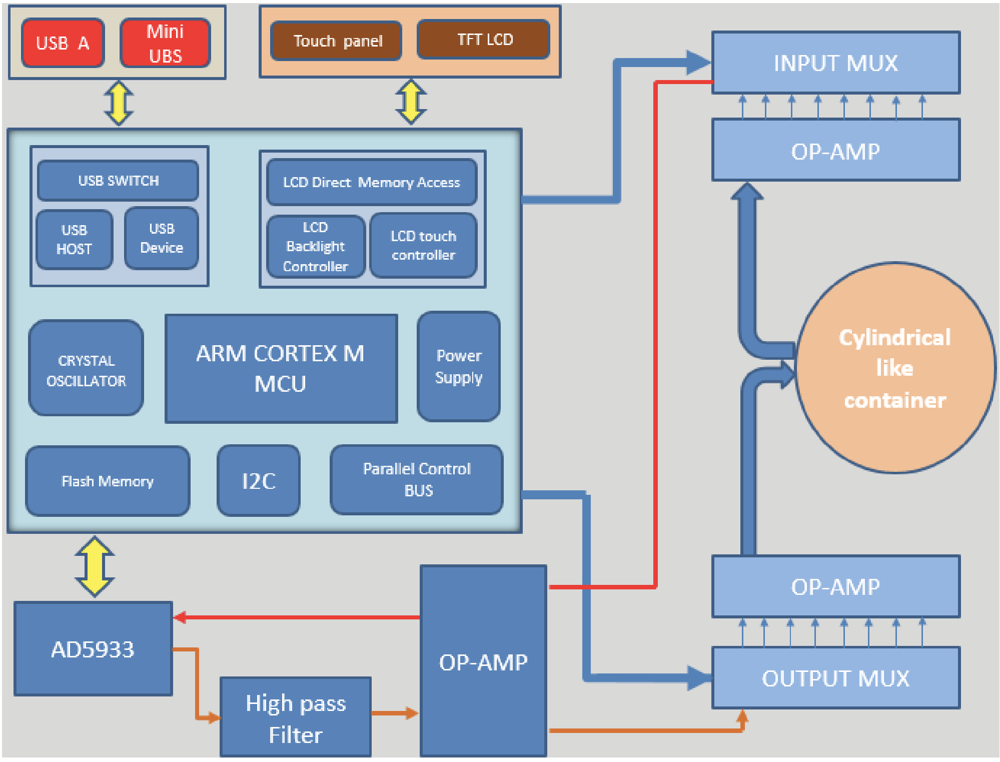

Fig. 1 Device hardware block diagram

II. Impedance Imaging Device

The EIT hardware device designed based on Analog Device network analyzer AD5933 which is a high precision impedance converter that combines an on-board frequency generator with a 12-bit, 1MSPS, analog to digital converter (ADC) [5]. The EIT device is controlled via an ARM Cortex M3 microcontroller LPC1768. This microcontroller operates at CPU frequencies of up to 100 MHz that allows the system to control lots of peripherals such as a touch screen TFT LCD, a SPI Flash Storage, and USB-Device to communicate with PC [6].

Various steps are needed to execute an EIT imaging of a substance or tissue. Firstly, the device should be calibrated with known resistance at different frequencies. The results of this step are stored in the SPI Flash of the device. Setting the excitation frequency, the excitation duration, gain of amplifiers and patterns of stimulation and measurement of 16 electrodes are done with the help of the graphical user interface (GUI) of the device. The results of the measurement are transferred to the PC through the USB port and all device settings and calibration gain factor values can be set by the user via touch screen of the device. Also during data acquisition, comprehensive status information is displayed on the device screen.

Device hardware design splits into analog and digital parts. The digital one consists of a SPI Flash memory, a TFT Display, a touch screen controller and other hardware related to USB-Device. The analog section is made up of the AD5933 network analyzer, multiplexers, amplifiers, high-pass filters and a precision power supply. In the PCB design of this section, various cases are intended to increase its accuracy. The diagram (Fig. 1) illustrates various hardware of the device. Four main components of the analog section of the device are described here.

A. High-Pass Filter

The AD5933 has four programmable output voltage ranges and each range has an output dc bias associated with it. However, the current-to-voltage (I-V) receive stage of the AD5933 is set to a fixed bias of VDD/2. This potential difference polarizes the impedance under test and can cause inaccuracies in the impedance measurement. The solution is to add a simple high-pass filter with a corner frequency in the low hertz range. Removing the dc bias from the transmit stage and rebiasing the ac signal to VDD/2 keeps the dc level constant throughout the signal chain [7].

B. Output Amplifier

Each four output voltage range of AD5933 has an output impedance associated with it. The output impedance affects the impedance measurement accuracy and the calibration of the device. A simple buffer in the signal chain reduces the output impedance from affecting the phantom impedance measurement. This buffer has a low output impedance and covers the frequency range of AD5933 [7].

C. Multiplexer

The device has 16 electrodes where each of them is connected to two analog multiplexer channels, one for input and the other for output. So each electrode is used in two directions. The analog multiplexer that is used in this device has low cross-talk between channel and low output impedance.

D. Input Amplifier

The I-V amplifier stage of the AD5933 adds minor inaccuracies to the signal chain. The proper external discrete amplifier is selected to perform the I-V conversion; an amplifier with lower bias current is chosen and offset voltage specifications along with excellent CMRR, making the I-V conversion more accurate [7].

III. Reconstructing EIT Image with EIDORS

After receiving measurements data from the device, EIDORS in MATLAB is used to produce EIT image. This software sets based on the shape of the container, the way the electrodes stimulate and the number of electrodes. In the first step EIDORS makes forward model and then with entering the measurement data, constructs the image. The produced image is used to find the coordinates of the target material. Fig. 2 is shown as a sample.

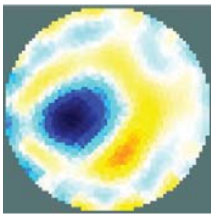

Fig. 2 The image is reconstructed by EIDORS

IV. Find the Coordinates of the Target Objects

For navigating the robotic arm to the desired object place, the coordinates of the center of the target object in EIDORS reconstructed image should be find. In this study, image processing toolbox of MATLAB is used to find the coordinate. Firstly, weak connections of the image are removed by this toolbox and after that, smoothening the edges of the image. In the next step, thresholding is used to separate the desired object from the background of the image. Finally, the central coordination of the target object is calculated. To remove weak connection and smoothen the edges, imopen function of MATLAB is used [8]. This function performs morphological opening on the grayscale or binary image with the preselected structuring element and in this study a flat disk shape is used as the structure element. The morphological open operation is an erosion followed by a dilation, using the same structuring element for both operations [9]. In the next step the graythresh function is used to find the threshold level value of the image [8], this function uses Otsu's method, which chooses the threshold to minimize the intraclass variance of the black and white pixels [10]. After that, this level value is used to separate the target object from the background of the image. Then to identify the target object in the image bwconncomp function is used and this function finds all the connected components in the binary image. Finally, regionprops function is utilized to obtain the coordinates of the center of the target object.

V. Robotic Arm Control and Navigation

The robotic arm used in this project has three degrees of freedom and each joint moves with a digital servomotor that has the ability to turn 180 degrees. The robotic arm is controlled via an Arduino UNO prototyping platform. Arduino gets the joints angle from the PC and commands the servos to go to that angle. Inverse kinematic calculates the angle of each joint to navigate the end-effector of the robotic arm to the target object coordinate.

VI. Results

To test the device a piece of carrot was placed in different parts of the container and measures the impedance in electrodes. The data set was transferred to the computer and with the help of EIDORS, raw data was converted to EIT image. The image obtained demonstrates the coordinates of the carrot stick witch was marked in the Fig. 3 with a white circle. After this stage, joint angles of the robot arm with inverse kinematics was calculated and sent to the Arduino board.

VII. Conclusion

The prototype built in this study illustrates the capabilities of EIT imaging to navigate a robotic arm; however, it requires a lot of development to become a practical surgeon robot. One of the initial steps for the development of this device is upgrading its EIT imaging section. This section should have the ability to capture high resolution 3D images with appropriate speed to navigate the robotic arm. To characterize tissue better, it is also possible to perform multi frequencies EIT, since different tissues have different spectral properties [11].

Another thing that can be developed in this project is the robotic arm. One of the best kind of robotic arms that can be used for this purpose is a cable transmission robotic arm with multiple joints. This type of arm has high degrees of freedom and small volume too. These benefits can cause less damage to surrounding tissues while the robotic arm is operating. It also possible to cover the robotic arm with electrodes and it can increase the resolution of EIT images during the surgery. It is possible to add electrodes to the end-effector of robotic arm to characterize the target tissue before eliminating it to prevent damage to healthy tissues.

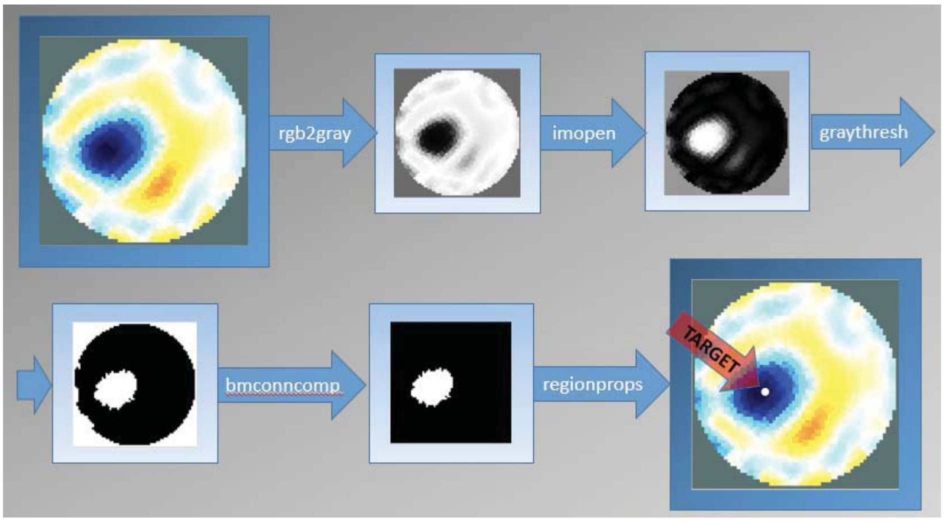

Fig. 3 The process of finding the target

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