Computer Aided Surgery and Medical Robotics (CASMR)

Automatic Echography Process for Pregnant Women

Project Report

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1 Introduction

Ultrasound, pivotal in echography, serves as a widely utilized technique for real-time visualization of internal organs through the use of high-frequency sound waves. This method boasts several advantages including its cost-effectiveness, non-invasive nature, and absence of long-term radiation risks. However, a significant challenge arises from the reliance on the expertise of medical professionals, particularly in remote or underserved regions where access to skilled physicians is limited. Recent research efforts have thus focused on combining robotic technology with advanced ultrasound techniques to address these challenges. The goal is to improve remote ultrasound diagnosis, opening new avenues to democratize access to precise medical treatments, particularly in areas with scarce healthcare resources or geographical constraints.

1.1 Project Explanation

Our proposed project involves a robotic-assisted echography system utilizing a universal robot for ultrasound examinations. The focal point of our approach is to precisely replicate a physician's hand movements when manipulating the ultrasound probe. Ensuring accurate motion replication, especially during encounters with obstacles or transitions between free space and contact, aims to mitigate sudden force peaks or irregular behaviors, thereby enhancing the safety and precision of remote ultrasound diagnosis.

The primary objective is to automate the echography procedure, particularly for pregnant women. Leveraging the capabilities of the lab's collaborative robot, real-time monitoring of applied force on the patient's abdomen will be possible, ensuring cautious movement execution without causing harm.

The initial phase of our project involves:

- Defining the specific movements by utilizing the universal robot's functionalities.
- Setting an initial starting point manually.
- Subsequently, the robot autonomously maneuvered to execute a predefined movement pattern across the patient's belly, while pressure-sensing feedback from the robot will enable precise surface tracking.
- Upon completion of this movement, the robot returns to its initial position, constituting one comprehensive iteration of our echography procedure.
- Three distinct movement patterns are devised to constitute a complete and comprehensive echography procedure.

1.2 Universal Robot and Tools

The Universal Robots UR3e is a compact and collaborative robotic solution designed for versatile tasks in constrained workspaces. With a payload of 3 kilograms and a reach radius of 500 millimeters, it offers precise and agile operation. Its user-friendly interface simplifies programming, allowing easy integration into diverse production environments. Known for its safety features and ability to work alongside humans, the UR3e embodies efficiency, reliability, and adaptability, making it an ideal choice for industries seeking a compact yet powerful automation solution.

Figure 1: Universal Robot used for the project.

In tandem with the robotic system:

(i) A transducer tool replicating the shape of the ultrasound probe (see Figure 2) attached to the universal robot's extremities to facilitate the accurate replication of echography movements and contribute to the development and validation of our automated echography system.

(ii) Given the project's prototype nature and the paramount importance of patient safety, an artificial belly provided by the lab (see Figure 3) simulates the patient's belly during the experimentation phase.

Figure 2: Transducer tool attached to the extremity of the robot.

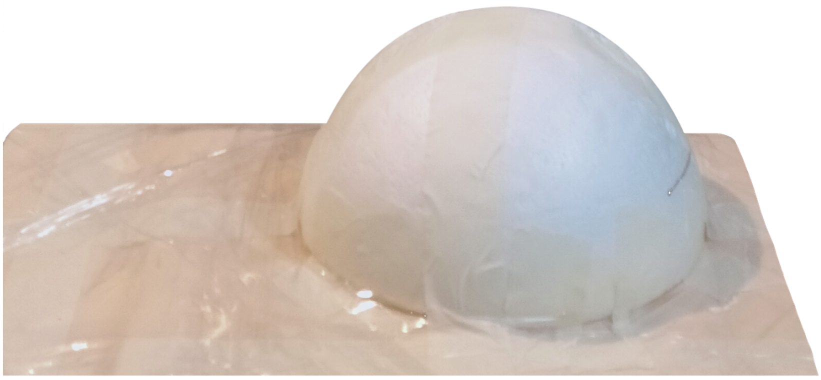

Figure 3: Artificial belly used to develop this project.

2 Methodology

Our methodology section encompasses the definition of tools and frames utilized in the study. Tool specifications, detailed in Table 1, outline the coordinates and orientations of the transducer. Frame specifications, as presented in Table 2, define the positional and rotational attributes of the body plane frame. Additionally, variable descriptions in Table 3 provide insights into key parameters like joint positions, frame approximations, and flags used in the experimentation process, crucial for the robot-assisted echography system's development.

2.1 Tool Definition

Table 1: Transducer definition

Tool Name	**X**	**Y**	**Z**	**RX**	**RY**	**RZ**
Transducer	63.46mm	-88.62mm	117.45mm	0	0	0

The values listed in the Table 1 represent the positional coordinates and rotations of the transducer tool attached to the universal robot's extremities. The X, Y, and Z values (63.46mm, -88.62mm, 117.45mm) denote the spatial positioning of the transducer in three-dimensional space. The RX, RY, and RZ values (0, 0, 0) refer to the rotations around the X, Y, and Z axes respectively, indicating no rotation from the default orientation. An example of the tool definition with its corresponding axes can be found in Fig. 4.

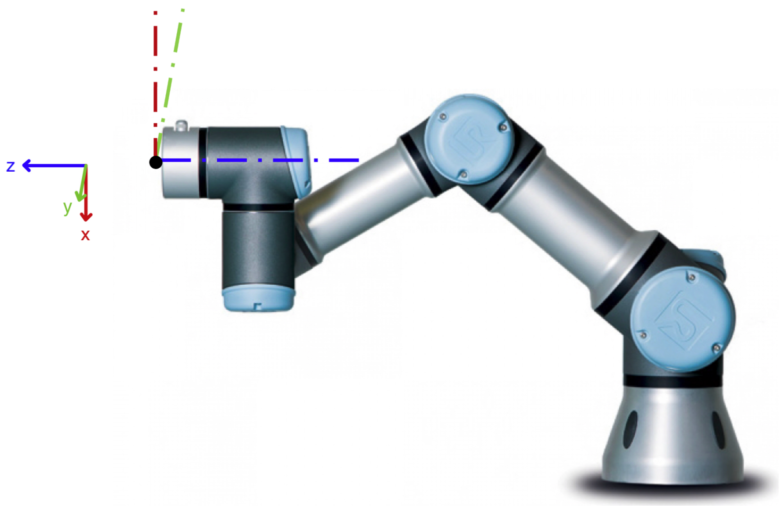

Figure 4: Example of X (red), Y (green) and Z (blue) of the tool definition used for this project.

2.2 Frame Definition

Table 2: Frame Definition

Frame name	X	Y	Z	RX	RY	RZ
Body Plane	-30.02 mm	-398.93 mm	237.97 mm	2.243 rad	-2.124 rad	-0.036 rad

The Frame Definition Table 2 provides specific positional and rotational attributes of the Body Plane frame, crucial in a collaborative project utilizing robotics. The X, Y, and Z values (-30.02 mm, -398.93 mm, 237.97 mm) denote the spatial coordinates, representing the frame's position relative to a reference point. Additionally, the RX, RY, and RZ values (2.243 rad, -2.124 rad, -0.036 rad) describe the frame's orientation or rotational angles around the X, Y, and Z axes respectively. These precise specifications are utilized in our project to establish a standardized reference frame for accurate robot operation and coordination within the project's tasks. An example of the frame definition with its corresponding axes can be found in Fig. 5.

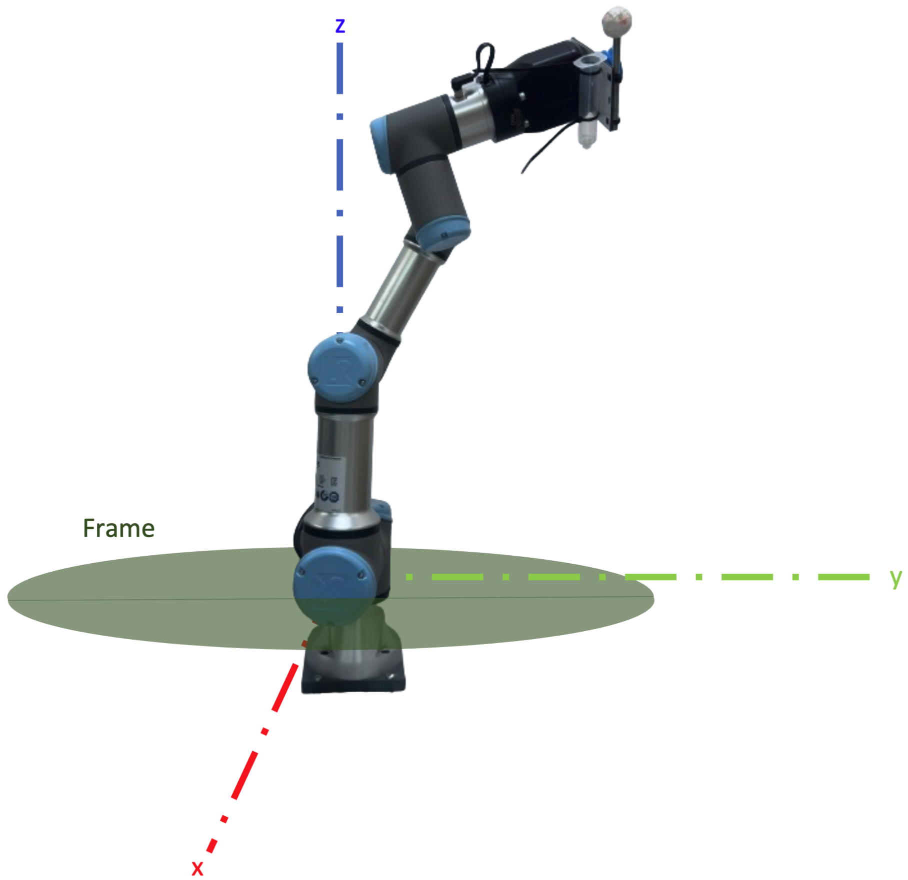

Figure 5: Example of X (red), Y (green) and Z (blue) of the frame definition used for this project.

2.3 Force

Our program utilizes the force command with a limit of 5 N and a speed limit of 150 mm/s along the z-axis. In force mode, the robot has freedom in all selected movements to apply the specified force within these given limitations. The force command is programmed to react dynamically to external forces encountered during the robot's operation. When the applied force exceeds the set limit of 5 N, the robot will adjust its movement to maintain the force below the threshold, ensuring precision and compliance in its tasks.

Table 3: Force Command and Speed Limit

Command	**X**	**Y**	**Z**	**RX**	**RY**	**RZ**
Force	0	0	5N	0	0	0
Speed Limit	0	0	150mm/s	0	0	0

2.4 List of Variables and Points

The different variables used to implement this project, are defined in Table 4.

The variable *digital_input* is pointing to a set of buttons attached to the robot. In order to implement a user-friendly project, we have used them as inputs for our project. By checking which of the buttons is pressed, a specific setting of the program is run. In Fig.6 we can see an example of the set of buttons together with their corresponding setting programs.

Figure 6: Example of the button box we have in the laboratory. Button 1 executes the whole program to perform General Exploration Movements + Zig Zag + Pivoting Movements. Button 2 executes only General Exploration Movements. Button 3 executes only Zig Zag Movements. Button 4 ends the program.

Table 4: Description of Variables

Variable	**Type**	**Description**
Home	Joint	Home position
runProgram	Bool	Boolean to control the program execution
digital_in[1]	Bool	Digital input 1 status
digital_in[2]	Bool	Digital input 2 status
digital_in[3]	Bool	Digital input 3 status
digital_in[4]	Bool	Digital input 4 status
DO[1]	Output	Switch on the corresponding light to the button 1
DO[2]	Output	Switch on the corresponding light to the button 2
DO[3]	Output	Switch on the corresponding light to the button 3
DO[4]	Output	Switch on the corresponding light to the button 4
belly_button	Point	Point corresponding to the belly button of the patient
expo1	Point	First point involved in the General Exploration Movement
expo2	Point	Second point involved in the General Exploration Movement
expo3	Point	Third point involved in the General Exploration Movement
expo4	Point	Fourth point involved in the General Exploration Movement
zigzag1	Point	First point involved in the Zig-Zag Movement
zigzag2	Point	Second point involved in the Zig-Zag Movement
zigzag3	Point	Third point involved in the Zig-Zag Movement
zigzag4	Point	Fourth point involved in the Zig-Zag Movement
zigzag5	Point	Fifth point involved in the Zig-Zag Movement
zigzag6	Point	Sixth point involved in the Zig-Zag Movement
pivot1	Point	First point involved in the Pivot Operation on Belly Surface
pivot2	Point	Second point involved in the Pivot Operation on Belly Surface
pivot3	Point	Third point involved in the Pivot Operation on Belly Surface
pivot4	Point	Fourth point involved in the Pivot Operation on Belly Surface
pivot5	Point	Fifth point involved in the Pivot Operation on Belly Surface
vacuum	Bool	Boolean to control the vacuum ability of the robot

3 Block Diagram

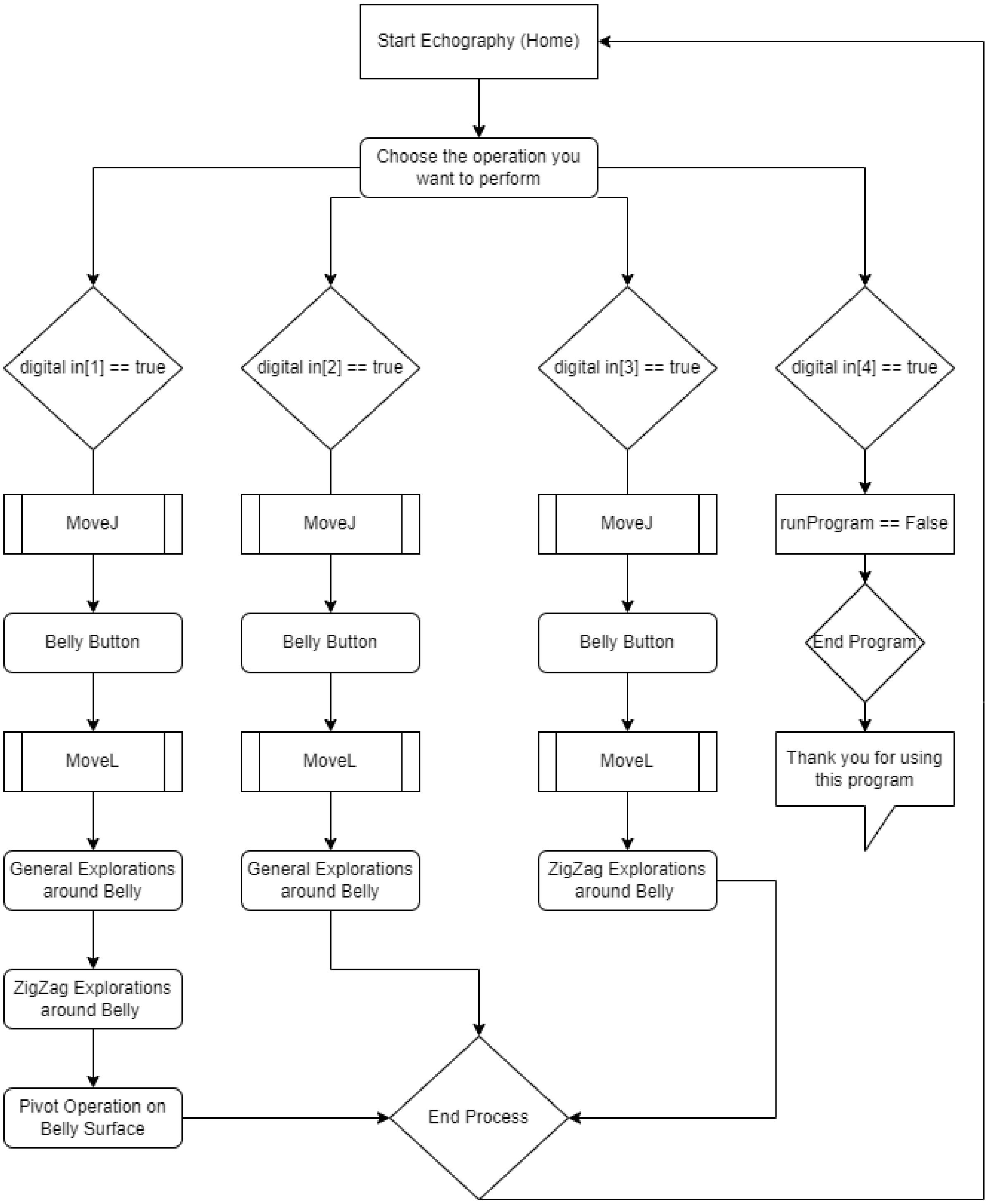

Figure 7: Block Diagram of this Project.

4 Code

Algorithm 1: Robot Program Pseudo Code.

```
MoveJ  Home;
runProgram ← true;
while runProgram == true do
    Popup "Hi, which program do you want to run?" ;
    Wait digital_in[1] == true or digital_in[2] == true or digital_in[3] == true or digital_in[4]
     == true ;
    if digital_in[1] == true then
        Set DO[1] = On ;
        Movj belly_button ;
        Force MoveL Exploration1 ;
        Force MoveL belly_button ;
        Force MoveL rot1 ;
        Force MoveL Exploration2 ... Exploration4 ;
        Force MoveL ZigZag1 ... ZigZag6 ;
        Force MoveL pivot1 ... pivot6 ;
        Movj home ;
        Set DO[1] = Off ;
    end
    if digital_in[2] == true then
        Set DO[2] = On ;
        Movj belly_button ;
        Force MoveL Exploration1 ;
        Force MoveL belly_button ;
        Force MoveL rot1 ;
        Force MoveL Exploration2 ... Exploration4 ;
        Movj home ;
        Set DO[2] = Off ;
    end
    if digital_in[3] == true then
        Set DO[3] = On ;
        Movj belly_button ;
        Force MoveL Exploration4 ;
        Force MoveL ZigZag1 ... ZigZag6 ;
        Movj home ;
        Set DO[3] = Off ;
    end
    if digital_in[4] == true then
        runProgram = false;
        Set DO[4] = On ;
        Popup "Thank you for using the program" ;
        Set DO[4] = Off ;
    end
end
```

References

[1] Felix von Haxthausen, Sven Böttger, Daniel Wulff, J. Hagenah, Veronica Garcia-Vázquez, and Svenja Ipsen. Medical robotics for ultrasound imaging: Current systems and future trends. Current Robotics Reports, 2021.

[2] S. Wang, J. Housden, Y. Noh, D. Singh, A. Singh, E. Skelton, J. Matthew, C. Tan, J. Back, L. Lindenroth, A. Gomez, N. Toussaint, V. Zimmer, C. Knight, T. Fletcher, D. Lloyd, J. Simpson, D. Pasupathy, H. Liu, and K. Rhode. Robotic-assisted ultrasound for fetal imaging: Evolution from single-arm to dual-arm system. ArXiv, 2019. https://arxiv.org/abs/1902.05458.