CIS II Final Report

Title

Patch Ultrasound

Mentors

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Background

Ultrasound is critical in many medical applications, such as fetal ultrasound measurement. It can show how the baby is growing and detect abnormalities, which is a significant step for testing the health of the mother and baby. However, during the whole pregnancy, mothers must take fetal ultrasound measurements multiple times by revisiting the exam room. The frequency of visits would increase a lot if the baby were in the wrong position, or the mother was obese. Such frequent revisiting would influence the efficiency of the exam room, and mothers could get uncomfortable during the trip to the hospital. Under the consideration of making mothers more comfortable when getting ultrasound measurements during the pregnancy, the patch ultrasound will include the feature of controlling remotely by the expert through a user interface (UI) so that mothers are not required to show up in the hospital to get the ultrasound measurement. Instead, they could enjoy the time staying at home while the measurement is done.

Problem Statement

Ultrasound has been widely used in clinical practice for decades, but the devices used for diagnoses are usually huge. The first generation of ultrasound machines is cart ultrasound, which is clumsy and inconvenient to move. Later the Laptop Ultrasound and phone ultrasound came out. Even though they are much more portable, they still need the operator to hold the probe to detect the patient's body. Therefore, we want to build a new generation of medical ultrasound called patch ultrasound, which enables the operator to use both hands to focus more on their operations and reduce hand-eye coordination requirements during the operation.

Technical Approaches

The project is divided into two parts, the mechanical design of patch ultrasound and the user interface (UI). Both parts are moving forward at the same time. The hand-free feature was accomplished by using an acoustic mirror to modify the angle of the image plane and securing the ultrasound probe with a mechanical lock, the patch ultrasound prototype intends to free the doctor's hands while doing ultrasound for the patient. The feature of tele-sonography capability was implemented by creating a user interface that can display real-time ultrasound images and allow professionals to remotely operate the patch ultrasonography.

1. Patch ultrasound design

The patch ultrasound itself is using an acoustic mirror to reflect ultrasound waves coming from the transducer so that the operator could image the patient from multiple angles. An acoustic mirror is a part that could reflect the ultrasound wave to a specific angle without losing too much energy, as shown in Fig 1. The green section from the probe and the yellow section reflected by the mirror represents the ultrasound waves. The angle of reflected waves could be adjusted by changing the angle of the acoustic mirror M. The mirror is made from stainless steel. A detailed reason of mirror selection will be introduced in the following section. Here, with the application of an acoustic mirror, the patch ultrasound could detect the target from multiple angles without moving the probe.

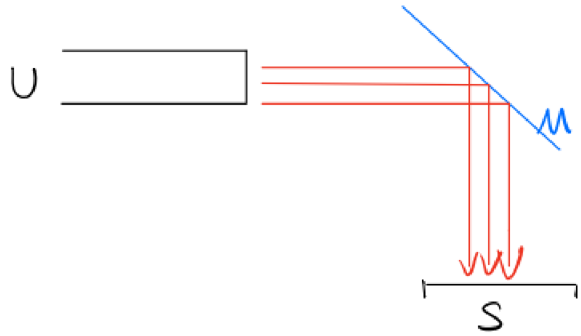

Fig 1. Example showing how an acoustic mirror works. [1] (M is the acoustic mirror, U is the ultrasound probe, red lines are the ultrasound waves emitted by the probe, and S is the target)

Furthermore, a mechanical lock is designed for the patch ultrasound in order to hold the probe and make the patch ultrasound wearable, which frees doctor's hands during the fetal measurement, enabling operator to work remotely. The communication between the patch ultrasound and the user interface was accomplished through web socket. A block diagram shown in Fig 2 could help illustrate the technical approaches more clearly.

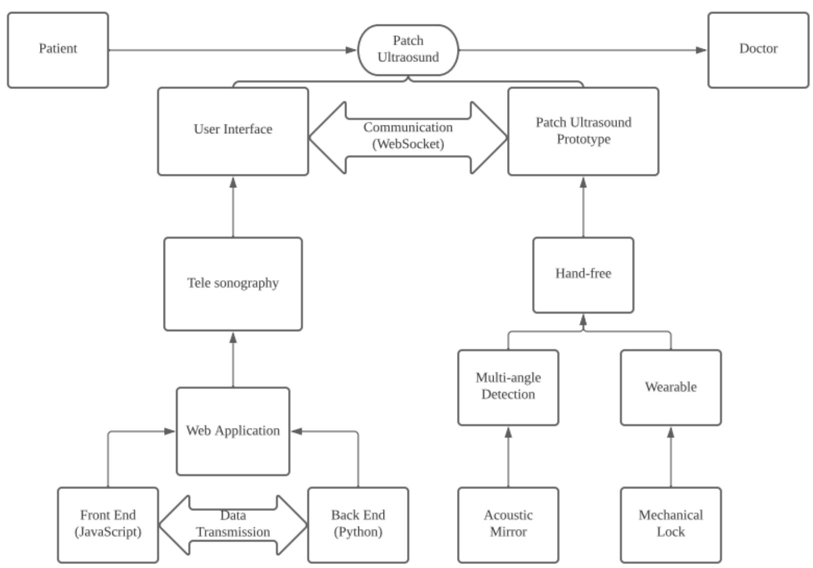

Fig 2. Technical approaches and their purpose.

The selection of the material of acoustic mirror is depending on the acoustic impedance of different material. The acoustic impedance is a physical property of the material that describes how much resistance an ultrasound beam encounters as it passes through a material. When the sound waves transmit from one material to another, some waves will be absorbed by the material itself and others reflected by the material surface, as shown in Fig 3.

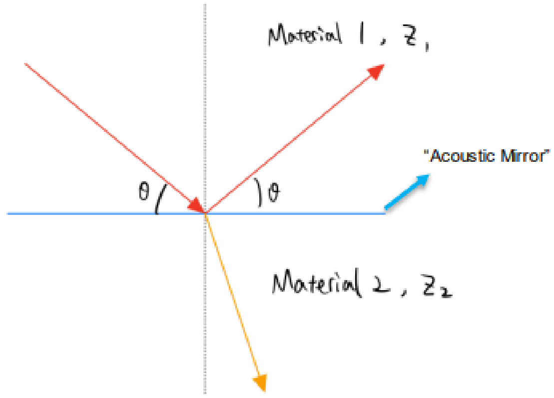

Fig 3. Ultrasound waves reflection sketch

The reflection fraction is calculated by the equation:

$$Reflection\ fraction = \frac{Z_2 - Z_1}{Z_2 + Z_1} \quad (1)$$

Here we list the acoustic impedance of some materials in Table 1 that we might need to consider in this project. According to Equation (1), the larger the difference between material 1 (which is the medium inside the patch, water) and material 2, the lower reflection fraction there will be, and the lower the energy loss there will be during the reflection. Thus, we picked stainless steel to be the material of our acoustic mirror. A more manufacture-friendly material like a glass microscope slide could also work, but they might cost more energy loss and result in ambiguous imaging.

Table 1. Acoustic Impedance

Material	Acoustic Impedance
Air	340 Rayl
Water	1.5 MRayl
Ultrasound Gel	1.5 MRayl
Glass	13 MRayl
Stainless Steel	45.5MRayl

2. User Interface

The user interface is a web application whose front end is realized by HTML, CSS, and JavaScript, and the back end is built with Python. The front-end interface interacts with a patch ultrasound on the back end to get the images in real-time and transmit the images to the interface. We used the WebSocket protocol to enable interaction between the user interface and the patch ultrasound. At first, we testes the WebSocket in a simulated scenario, and then we connect our WebSocket to the real ultrasound device that displays the images in real-time.

As for remote control of the patch ultrasound, we can acquire the intended moving direction with buttons in the user interface, and then the back end moves the patch ultrasound to the desired position. Based on the Patch Ultrasound we already have, we designed four directions of the ultrasound probe remote control, including left, right, clockwise, and counterclockwise. Each direction has a corresponding button in our user interface. And the ultrasound probe would move one centimeter to the left or right with each click of the left or right button, one degree to CCW or CW with each click.

In the final demo, we used the patch ultrasound the lab already has shown in Fig 4. The black motor in Fig 4 controls the direction of the ultrasound probe. This patch ultrasound has two degrees of freedom. We put the patch ultrasound on a bone model, shown in Fig 5. Through our user interface, we can see the real-time ultrasound images obtained by this ultrasound probe and move the probe by clicking the button on our user interface. The operation scenario is shown in Fig 6.

Figure 4. Patch Ultrasound

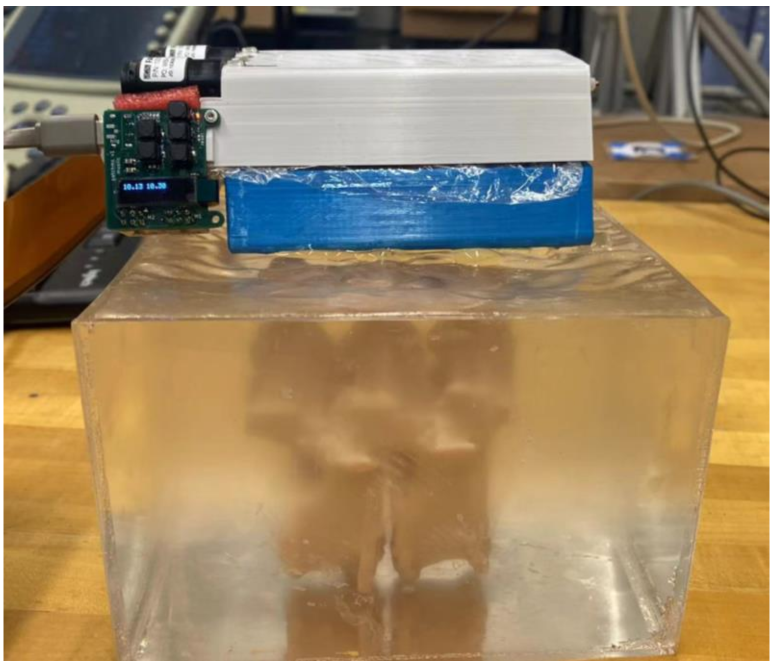

Figure 5. Patch Ultrasound is put on the bone model

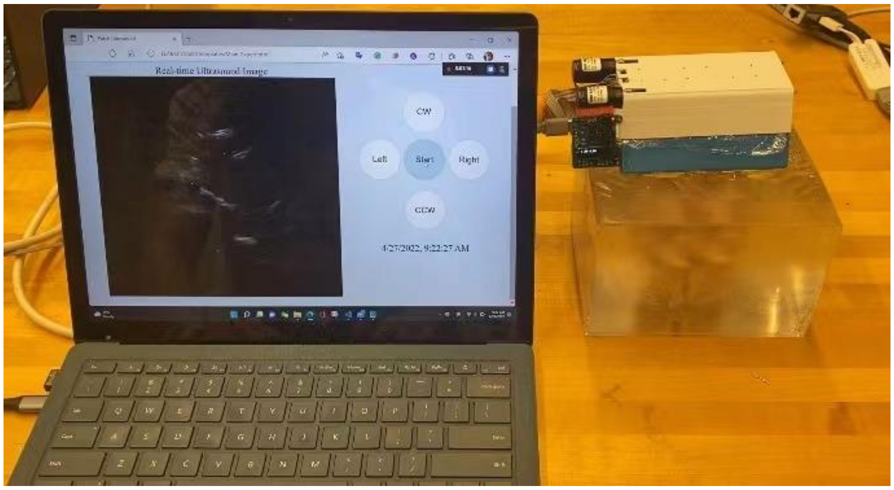

Fig 6. Demo scenario

Current Results

1. Patch Ultrasound Design

We have developed our manufacturable design for the patch ultrasound, as shown in Fig 7. The transparent part is the outer frame of our patch ultrasound, where the ultrasound probe could be placed at the top curved area of the frame. A belt will be tied around the handles on two sides of the outer frame so that the whole patch could be attached to the patient. There is also a hole on the back of the outer frame, which is used to inject the water to the inner space so that ultrasound waves can have a medium to transmit. A piece of TPX material will be attached to the top surface of the

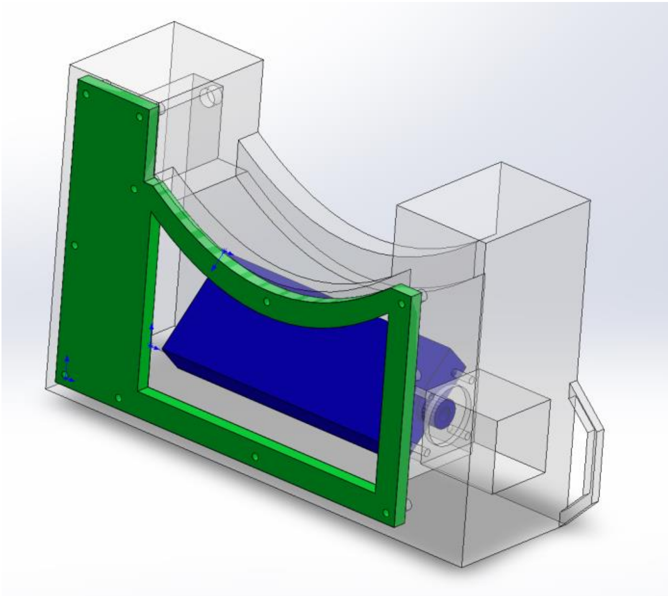

Figure 7. Manufacturable design of the patch ultrasound (the green part is the lid of the patch ultrasound, the transparent part is the outer frame of the patch ultrasound, the blue part is the frame of acoustic mirror)

curved area to connect the probe and the water inside the patch. A motor will be placed at the left-hand side square space on the outer frame to generate the rotation of acoustic mirror (which is made from stainless steel). The green part is a lid used to cover at the surface of the patch ultrasound on patient-side. It has a window that will be covered by a piece of TPX material, which could transmit ultrasound waves. We will use several screws to attach the TPX material to the outer frame of the patch ultrasound through the holes on the lid. The blue part is the frame of our acoustic mirror, which will be used to hold the acoustic mirror. The frame is connected to the rod of the motor so that it could be rotated per operator's request.

2. User Interface

We have realized the real-time ultrasound image display and remote control. We tested the real-time display of the WebSocket using a series of PNG images at first, and there is no latency in this simulated scenario. When we changed the scenario into the real ultrasound, the real-time image display can display the images exactly as the cart ultrasound, except for a one-second latency. Same latency is showed during the remote control. The user interface is as Fig 8. The demo video is shown on our wiki page.

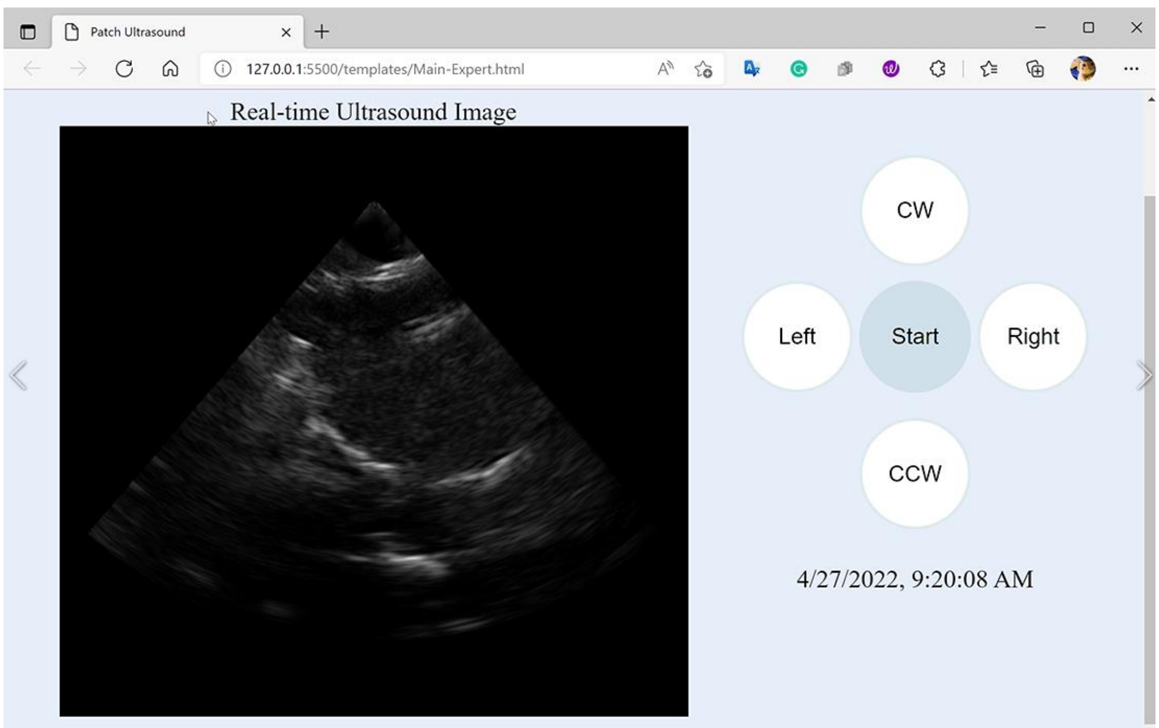

Figure 8. User Interface for Real-time Ultrasound image display and remote control

Discussion

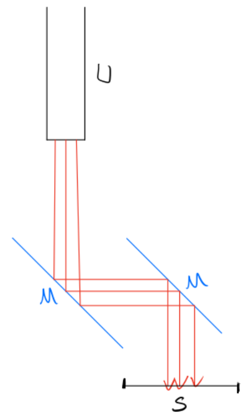

Fig 9. Double-reflector system [1]. (M is the acoustic mirror, U is the ultrasound probe, red lines are the ultrasound waves emitted by the probe, and S is the target)

Our current device uses one acoustic mirror, which is defined as a single-reflector system. The single-reflector system is simple and easy to build. However, the window of the ultrasound waves and where the probe will be placed is parallel, which makes it hard to keep the probe attached to the patch firmly when the patient lays down. Thus, we could replace our single-reflector system by a double-reflector system, which could align the probe and the projected area on the same line, as shown in Fig 9 [1]. Such design could make the probe attached to the patch more firmly when the patient lays down, but on the other hand, it will require one more motor to generate the second reflector, which will make the patch design huger than the current single-reflector system. As far as this project is concerned, we want the whole patch to be as small as possible. Therefore, the single-reflector system is still a good option for our design.

Our user interface still has a latency problem, which could be caused by the image format conversion or the image transfer speed. We are still working on fixing this problem. With the user interface we've built, we can at least realize the remote diagnosis for fetal measurement. By further developing the functions of our user interface, we can finally make the patch ultrasound come into use!

Reference

[1] Wang, Y., Lim, R.S.A., Zhang, H. et al. Optimizing the light delivery of linear-array-based photoacoustic systems by double acoustic reflectors. Sci Rep 8, 13004 (2018). https://doi.org/10.1038/s41598-018-31430-5

[2] Black, David; Yazdi, Yas Oloumi; Hadi Hosseinabadi, Amir Hossein; Salcudean, Septimiu (2021): Human Teleoperation - A Haptically Enabled Mixed Reality System for Teleultrasound. TechRxiv. https://doi.org/10.36227/techrxiv.15175869.v1

Management Summary

1. Commitment:

Yuanwu He is responsible for the patch ultrasound design. He developed a manufacturable design for the patch ultrasound, as well as the acoustic mirror used in this project.

Shuran Zhang built the user interface to realize the real-time ultrasound image display and remote control.

2. Accomplishment vs planned

Here is the list for all our deliverables set at the start of this semester.

Minimum Deliverable:

- A web page showing real-time ultrasound images with buttons to move the ultrasound probe in a simulated system.
- A conceptual mechanical design (mirror-based) of the patch ultrasound.
- A report on a phantom study of an acoustic mirror.

Expected Deliverable:

- Demo the UI on a real patch ultrasound prototype.
- Detailed manufacturable design (CAD).

Maximum Deliverable:

- A patient end interface.
- A prototype to demonstrate the feasibility of mirror-based patch ultrasound.
- The communication between the prototype and the UI.

Up to now, we have finished all of our minimum and expected deliverables, and we are moving forward on our maximum deliverable, the maximum deliverables are still working in progress.

3. **Discuss what might be next**

For the design part, we are trying to print the manufacturable design out by using a 3D printer and will be assembling small parts together soon. After building up the prototype, we will try to set up the communication between the UI and the prototype so that operators could manipulate the prototype remotely.

For the user interface part, the next step would be to build a patient side view so that the mothers can see the real-time ultrasound images of their baby when the doctor is doing the ultrasound measurement. Meanwhile, the expert-side user interface can be connected to the patients' database, so that the doctor can see patient's information quickly. Meanwhile, identity authentication should be added to guarantee the privacy of the patient information.

4. **What you learned**

Through the project, we learned how an ultrasound machine works and how we can detect the target by using the ultrasound probe. During designing the prototype and the acoustic mirror, we learned the new concept – acoustic impedance, and how we can improve the performance of our acoustic mirror based on this new concept. During building the user interface, we learnt to use the WebSocket to communicate with the front-end and advanced the development skill for a web application.

More importantly, we learned how to accommodate with mentors and teammates and how we could work in group efficiently through the busy semester.

Technical appendices

Our technical appendices can be found on our Wiki page: courses:456:2022:projects:456-2022-12:project-12 – CIIS Wiki (jhu.edu)

The uploaded file includes the CAD files for our manufacturable design. The videos for demonstrations of UI are included in the Wiki page as well.