CIS II Project

Laboratory for Computational Sensing and Robotics

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Whiting School of Engineering, Johns Hopkins University

CIS II Critical Review

Title

Patch Ultrasound

Mentors

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Project Summary:

The goal of this project is to create a patch ultrasound prototype with hands-free and tele-sonography features for OB/GYN applications. 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 will be accomplished by using an acoustic mirror to modify the angle of measurements 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 will be implemented by creating a user interface that can display real-time ultrasound images and allow professionals to remotely operate the patch ultrasonography.

Paper Selection:

Since the project is divided into two parts, finding papers targeting each part separately will be helpful for the project development. The first paper selected is related to the design of patch ultrasound, where the method of improving the quality of the ultrasound images will be introduced and discussed. The second paper corresponds to the user interface. The concepts of both remote control of ultrasound and real-time image display are included in this paper. And this paper provides a new scenario for remote control and demonstrates the reliability of remote diagnosis using real-time ultrasound images.

Paper #1: Optimizing the light delivery of linear-array-based photoacoustic systems by double acoustic reflectors [1]

Authors: Yuehang Wang, Rachel Su Ann Lim, Huijuan Zhang, Nikhila Nyayapathi, Kwang W. Oh, Jun Xia

Journal: Scientific Reports 8, 13004 *Year*: 2018

Summary of problems:

Despite its widespread use in photoacoustic imaging, linear transducer arrays' physical form limits light illumination. Most photoacoustic systems based on linear arrays today use side-illumination geometry, which consists of two-line fiber bundles linked to the probe's side. The increased light travel distance in deep tissue caused by the slanted light illumination limits the imaging depth. By placing a right-angle prism in front of the transducer, this problem was partially solved. The light illumination and sound detection are co-axial in this design, but the transducer and fiber bundles are orthogonal, making the device uncomfortable for handheld use.

Technical approaches:

To circumvent the constraint that the transducer and fiber bundles are orthogonal, the paper suggests a double-reflector system in which the second reflector redirects the acoustic waves by additional 90 degrees, bringing the transducer and fiber bundle into alignment. The transducer and fiber bundle output are both placed into a compact housing in this configuration for easy handheld imaging.

The project conducted several phantom and human in vivo studies to assess the efficacy of their design. A 10-ns-pulsed Nd:YAG laser with a 10 Hz pulse repetition rate and a 1064 nm output wavelength, an ATL L7-4 transducer array with a 5 MHz central frequency and 128 elements, and a Verasonics' Vantage data collecting system with 128 receive channels make up the Photoacoustic (PA) imaging (PAI) system employed in this study. The researchers may modify the temporal gain compensation (TGC) at different depths with the Vantage system to reduce the strong skin signals created by bright-field illuminations. Three different PA imaging systems are tested in the paper, as shown in the Fig 1. The acoustic reflector used in the paper is a high-performance TECHSPEC ® cold mirror (Edmund Optics Inc.), which could avoid optical reflection on the acoustic reflector.

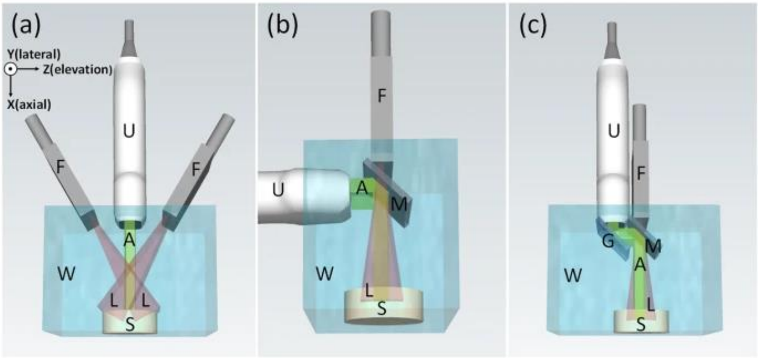


Fig 1: Schematic drawing of three different PA imaging systems. (a) Conventional side-illumination PAI system. (b) Single-reflector PAI system. (c) Double-reflector PAI system. U, ultrasound transducer array; F, fiber bundle; L, light beam; A, acoustic wave; W, water tank; S, sample; M, cold mirror; and G, glass. The laser beam is in red, and the acoustic wave is in green.

To investigate if the second reflector impacts the PA signal intensity, the researchers first test the signal intensity for both single-reflector and double-reflector PAI systems, as shown in Fig 1(b) and Fig1(c). The result indicates that the second reflector does not have much effect on the PA signal intensity, so they proceeded to test whether the double-reflector PAI system has better images than the side-illumination PAI system by doing a four tubes phantom experiment. This experiment will prove the feasibility of a double-reflector PAI system in optimizing the light delivery of a linear-array-based system. Furthermore, they experimented on human forearms and uneven surfaces to justify their results from the four tubes phantom experiment.

Results & conclusions:

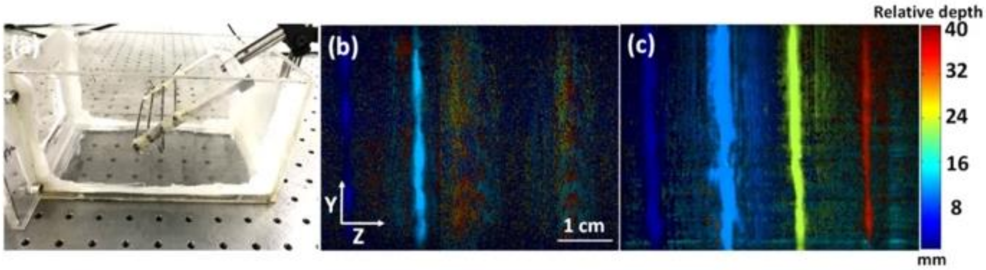


Fig 2. Four tubes phantom experiment. (a) Photo of four tubes phantom. (b) Depth-encoded MAP result of the side-illumination method. (c) Depth-encoded MAP result of the double-reflector method.

The results of the four tubes phantom experiment are shown in Fig 2. Apparently, from Fig 2(b) and Fig 2(c), the de-reflector method exhibits a greater penetration depth and a more uniform light fluency. The results are the same for the experiments of human forearm and uneven surfaces.

Relevance to the project:

The quality of images is a critical consideration once patch ultrasound is designed since the reflection of sound waves could reduce the intensity of those waves, which could lead to the ambiguity of ultrasound images. A higher quality of images is commonly desired. In patch ultrasound, we will be accomplishing multi-angle detection by using an acoustic mirror, the same role as the acoustic reflector used in [1], to reflect the sound wave so that more areas could be captured through ultrasound. The double-reflector along with a fiber bundle could illuminate the targets more clearly and the penetration depth will be much higher than the side-illumination method. Even though the current conceptual design of patch ultrasound does not use illumination system, it could be improved in the future by adding an illumination system to intensify the signals in order to get higher quality images.

Critical Reviews:

The paper has a clear clue comparing three different PAI systems and it is easy to follow. First, they did a comparison between the single-reflector design and double-reflector design to see if the additional reflector will impact on the result. Then, after ensuring the second reflector does not have an obvious impact on the outcome, they make the comparison between the side-illumination system, which is the most widely used system nowadays, and their double-reflector design. They also conducted three different types of experiments, which is fair enough to justify the feasibility of their design in optimizing the light delivery of linear-array-based photoacoustic systems.

The paper did a great job in introducing their double-reflector design, but they do not have a configuration of how their double-reflector design was actually tested. In other words, they only included the geometry of their design, without including how such design was utilized to capture the signals.

Overall, this study suggests a design that could enhance the quality of ultrasound images captured by linear-array probes. Since we have done the phantom study on our potential acoustic mirrors, we are aware of the poor quality of images that patch ultrasound might bring to us. The double-reflector along with illumination system could be an improvement on the design of our patch ultrasound if the quality of the images captured from our prototype is below expectations.

Paper #2: Remote just-in-time tele mentored trauma ultrasound: a double-factorial randomized controlled trial examining fluid detection and remote knobology control through an ultrasound graphic user interface display [1]

Authors: Andrew W. Kirkpatrick, M.D., F.R.C.S.C., Ian McKee, Jessica L. McKee, M.A., M.Sc., Irene Ma, M.D., Ph.D., F.R.C.P.C., Paul B. McBeth, M.D., M.A.Sc., F.R.C.S.C., Derek J. Roberts, M.D., Charles L. Wurster, M.D., Robbie Parfitt, Chad G. Ball, Scott Oberg, C.S.E., William Sevcik, B.Ed., M.D., F.R.C.P., Douglas R. Hamilton

Journal: The American Journal of Surgery, Volume 211, Issue 5, Pages 894-902.e1 *Year*: May 2016

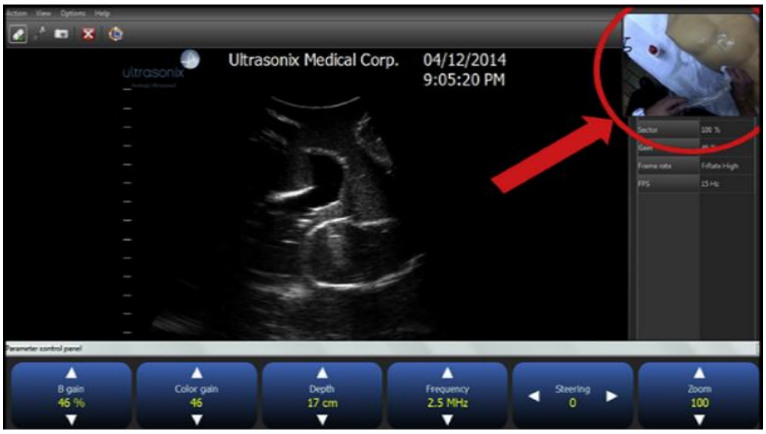
Summary of problems:

In contemporary society, traumatic injury continues to be the major cause of years of life lost that could have been avoided. Ultrasound, which has a nearly limitless range of applications for improving bedside care for the critically ill and injured, is a key tool in the early management of catastrophic trauma. We'd also like ultrasonography to be available at all times. But an ultrasound machine is the only medical-imaging capability onboard, for example, the International Space Station. Furthermore, past research has shown that knobology requirements can be deleterious to the learning task and unduly burden novices' cognitive load. We wanted to see if novices could perform RTMUS diagnoses of a large simulated hemoperitoneum while experts watched the exam via a remote ultrasound GUI interface and if remotely managing the knobology on behalf of inexperienced examiners enhanced accuracy and efficiency.

Technical approaches:

The study used an ultrasound phantom evaluated by firefighters who were unskilled and mentored remotely. A trauma surgeon/intensivist and an internist from separate countries served as remote mentors for these assessments. The ultrasound Phantom (FAST Exam Real-Time Ultrasound Training Model, CAE Healthcare, Sarasota, FL) allowed fluid introduction and removal. As for the result, the major output in this experiment is the remote mentor's diagnostic accuracy for free fluid identification. And the mentor would determine the presence/absence of significant fluid in the phantom's upper right quadrant and the capacity to adjust the ultrasound knobology remotely throughout the examination. Another result dealt with qualitative problems such as user perceptions and satisfaction with the RTMUS idea and the GUI's specific application.

The presence of 750 mL of fluid in the phantom and remote control of the ultrasound "knobology" (unblinded) were randomly allocated in this experiment. Before the remote inspection, the firefighters were simply shown the phantom and the ultrasound machine, and they were not allowed to practice. To replicate "just-in-time" emergency settings, each examination was limited to 5 minutes. The mentors used their own commercially available mobile computing devices to see ultrasound pictures in real time. Each firefighter wore a 1.3 Megapixel video camera on their heads, which allowed the remote mentor to see the firefighters' hands, ultrasound probe, and ultrasound phantom via Skype's "share my screen" feature. The mentor's computer overlooks this view (Fig 3.) of the firefighters handling the ultrasound probe.



Sector 100 %
Frame rate Fillrate High
FPS 15 Hz
B gain 46 %
Color gain 46
Depth 17 cm
Frequency 2.5 MHz
Steering 0
Zoom 100

Fig 3: Visual ultrasound information presented to the remote mentor guiding the firefighters focused ultrasound examination. Large image depicts the graphic user interface as displayed on the remote mentors portable computing device. The red arrow and circle emphasize the display of the firefighters' hands and ultrasound probe as imbedded onto the larger graphic user interface display. The imbedded window could be enlarged as desired by the mentor.

Results & conclusions:

The overall remote-telementored ultrasound accuracy for free-fluid detection for all of the examinations was as follows. For assessing the correct status of free fluid within the phantom, the remote mentor group was able to achieve an accuracy of 97% (95% confidence interval [CI], 91.6 to 99.4), a sensitivity of 94% (95% CI 83 to 99), specificity of 100% (95% CI 93 to 100), a positive predictive value of 100% (95% CI 92 to 100), a negative predictive value of 95% (95% CI 85 to 99). A positive test's likelihood ratio (LR) was infinite, while a negative test's LR was .06 (95% CI .01 to .3).

This study showed that, without prior training, ultrasound-naive first responders can be remotely mentored from far away to get potentially life-saving pathophysiologic information that would otherwise be unavailable without ultrasound. The need for a qualified operator often limits the use of point-of-care ultrasonography outside of hospital settings. A potential answer to this challenge is remote just-in-time tele mentoring.

Relevance to the project:

First of all, this paper demonstrates the reliability of remote fetal measurements, that is, the experts can provide accurate diagnosis through remote-controlled controlled ultrasound real-time images, which verify the effectiveness of our project. In our project, we eliminated the role of the firefighter by the hand-free patch ultrasound. And the problem focused on in this paper could also be another application of our patch ultrasound. Besides, the user interface layout can give us an example of the interface with remote control and real-time ultrasound images display. Last but not least, the camera with the firefighters provides us with the development direction that we can add the view of the mother's belly in our patch ultrasound user interface to help the experts conclude the fetal measurements.

Critical Reviews:

This paper gave us clear experiments methods, the subjects' backgrounds and information, and their statistical data. So we can see the urgent scenario they are simulating clearly. The result of the experiments can demonstrate if this remote control is feasible and its significance in the early management of catastrophic trauma. Also, this paper gave clear clues of the goal and outcomes of the experiments at the beginning of the method, which makes it's to be understood. The post-tests of the fire-\fighters and the remote mentors pointed out both the user experience and the application prospect of this user interface.

The paper demonstrates the feasibility of the ultrasound user interface, but they didn't introduce the interface. The paper mentioned those knobology requirements may be quite detrimental to the learning task and disproportionately burden the cognitive load of novices. But these features are not applied to the completely inexperienced 1st novice firefighters without the learning process. I think they would better list the specific difficulties of learning tasks and demonstrate why we need this emergency assumption in this experiment. Besides, the images in this paper are too few. It would be much more vivid to restore the experimental scene with more images.

Above all, this paper gives the data support for the reliability and significance of ultrasound remote control and real-time display and some development suggestions for our patch ultrasound.

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] Andrew W. Kirkpatrick, Ian McKee, Jessica L. McKee, et al. Remote just-in-time telementored trauma ultrasound: a double-factorial randomized controlled trial examining fluid detection and remote knobology control through an ultrasound graphic user interface display. The American Journal of Surgery, Volume 211, Issue 5, 2016, Pages 894-902.e1. https://doi.org/10.1016/j.amjsurg