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Work in progress: cost-effective table-top ultrasound systems as platform for biomedical engineering education

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Abstract

Ultrasound is a relatively low-cost and safe imaging modality, and is widely used in various applications in healthcare. The principles associated with ultrasound imaging represent an interplay between math, physics, engineering, and medicine. As such, it has the potential to act as an educational platform that integrates many different fundamental disciplines, particularly those that may be initially daunting for students, into a real-world application. Our team is currently developing a low-cost, high-precision, table-top ultrasound system optimized for education and student-led research. In parallel to hardware design, we are also creating an integrated curriculum for fundamental engineering concepts relevant to undergraduates in biomedical, mechanical, and general engineering programs. To evaluate the ultrasound system and educational materials, we will run courses and evaluate learning outcomes in at least two Boston area educational institutions.

Introduction

There has been a recent acknowledgement by the academy and engineering industry of the need to prepare students in undergraduate engineering programs to tackle interdisciplinary problems (Van den Beemt, et al., 2020). In addition, engineering topics that are initially daunting for students, including but not limited to, signal processing, acoustics, mechatronics, imaging, and machine learning, are often taught in heavily theoretical ways that are neither connected to real-world applications, nor integrated between disciplines.

Ultrasound is a relatively low-cost imaging modality that is used widely for various applications in healthcare, and has the potential to bridge the disconnect between theory and application in the engineering education curriculum (Zhao et al. 2021). In various levels of graduate and undergraduate curricula, ultrasound has been used as a tool in biomedical engineering education since it provides a concrete example of how engineering and physical principles are applied in a real-world clinical device. At the low-level, ultrasound can tangibly demonstrate the aforementioned engineering principles by visualizing and manipulating signals collected from real-world data acquisitions. However, in the engineering classroom, ultrasound is usually taught passively with equations. This is due in large part because diagnostic ultrasound machines are typically only kept in clinical settings, and are cost-prohibitive (Paschal et al. 2003). Moreover, ultrasound machines are typically built as a “black box” – intermediate processes of generating an image within the device are proprietary and therefore not accessible. Therefore, there is a need to devise deployable ultrasound hardware that could act as an educational kit for undergraduate engineering courses.

Furthermore, there is opportunity to create innovative project-based learning modules that will be associated with the ultrasound hardware. These modules will touch a variety of fundamental engineering topics, in an applied manner and leverage active learning principles, which have been validated as a preferred teaching practice in the classroom (Freeman et al. 2014). The hardware and modules will be piloted as part of an upcoming course for undergraduates on medical imaging signals and systems, and students' engagement with the developing technology and perceptions of the course will be evaluated in addition to the course learning outcomes. Following the completion of the pilot we will expand to a multi-institutional evaluation.

Ultrasound Educational Hardware Development

Our team is developing a low-cost, high-precision, table-top ultrasound system optimized for education and student-led research. A CAD rendering of the first iteration of the system is shown in **Figure 1**. This is a modified version of ultrasound tank systems designed for limb imaging as part of our research groups (Zhang et al 2015; Ranger et al. 2019). The system will consist of a low-cost ultrasound transducer, linear rail and stepper motor for transducer positioning, data acquisition setup, and immersion imaging tank. The tank will be designed to support scanning of small objects and phantoms. As a platform, this configuration offers the most flexibility while maintaining scalability to investigate and teach more complex data acquisition scenarios by changing the transducer and positioning configurations. Demonstrating accurate characterization of the positioning mechanism combined with data processing techniques while imaging calibrated objects reflects on the importance of testing and validation in the device design process, which are particularly important in healthcare scenarios. There is a fundamental need for students to connect theoretical knowledge to the real-world and understand the nuances and challenges associated with physical systems. More specifically, testing and validation is an aspect of the engineering curriculum that is presently lacking. Most project courses are process focused with limited time allocated for validation after the design and fabrication phase.

We are adopting a human-centered and iterative design approach to ensure that the system meets the needs of educators and students, and adheres to strict functional requirements to minimize cost. This project has two primary goals: understanding how the system can support hands-on interdisciplinary learning in a variety of educational contexts, and developing the system using a design-driven research approach in iterative cycles along with student researchers enrolled in different educational contexts. The end result will be an ultrasound kit that could be used a variety of educational and broader settings.

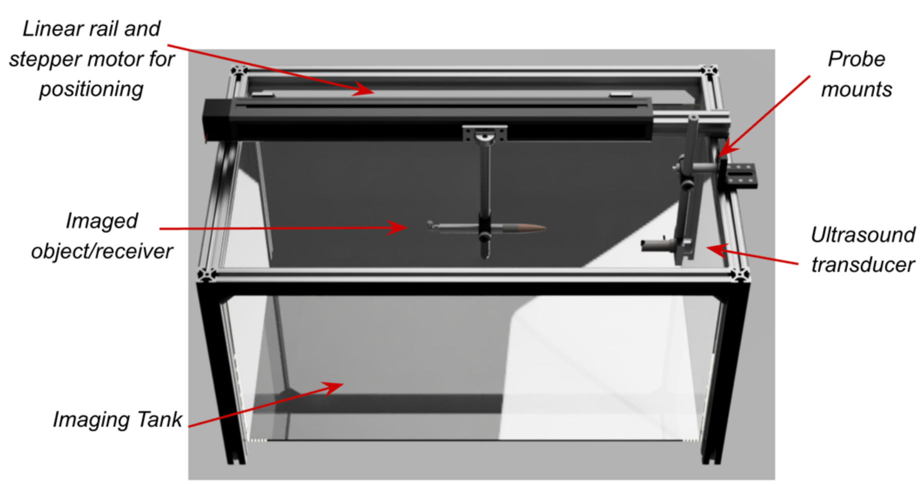

Figure 1: CAD rendering of first iteration of the table-top ultrasound system optimized for education and student-led research.

Curriculum Development

In parallel to hardware design, our team is developing integrated curriculum for fundamental engineering concepts relevant to undergraduates in biomedical, mechanical, and general engineering programs. We are creating the instructional materials such that after learning initially relevant concepts, the students participate in the iterative research and development of the system. Following our initial work with fundamental first-year and sophomore courses, the project will be extended to include junior and senior students taking relevant elective and capstone courses.

Ultrasound imaging represents a complex interplay between physical principles and signal processing. As such, it provides educational opportunities to apply acoustic and signal processing techniques to engineering problems. Topics that could be integrated as part of the course curriculum will include: linear wave propagation, Fourier analysis/filtering, analog-to-digital sampling, electromechanical design, mechatronics, and introduction to machine learning for image analysis. The hardware is designed to enable demonstration of core engineering principles with variable complexity to adapt to the needs of the curriculum and the educational audience.

Evaluation

To evaluate the educational aspects of this project, we will run courses and evaluate students' engagement, perception, and course learning outcomes in at least two different Boston area educational institutions. Research questions for this evolving work in progress include:

- How and in what ways does engagement with a novel tabletop ultrasound system impact students' engagement with course materials and activities?
- How does hands-on authentic engagement with the tabletop ultrasound system inform students' perceptions of traditionally daunting engineering concepts?

Evaluation of the proposed project will involve quantitative, qualitative, and mixed research methodologies, using a longitudinal design with formative and summative assessments to compare outcomes over time for participating leaners and instructors/faculty. Our large-scale multi-institutional evaluation and dissemination plan will also allow our teams to contribute to and advance current conversations in engineering education around low-resource making/tinkering practices, valuing individual and community ingenuity, and project-based learning.

Contributions

The ultrasound educational system and associated teaching methods developed in this project are being designed with broad accessibility in mind. It will be low-cost so that engineering educators (ranging from K-12, technical colleges, and professional schools) around the world, even those with limited resources and/or working in more remote environments, will be able to incorporate it as part of their course curriculum. For students interested in the biomedical applications of engineering, our courses will offer them a means to consider future professional opportunities in STEM that can have an impact on healthcare and wider society.

References

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the national academy of sciences*, *111*(23), 8410-8415.

Paschal, C. B. (2003). The need for effective biomedical imaging education. IEEE engineering in medicine and biology magazine, 22(4), 88-91.

Ranger, B. J., Feigin, M., Zhang, X., Moerman, K. M., Herr, H., & Anthony, B. W. (2019). 3D ultrasound imaging of residual limbs with camera-based motion compensation. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, *27*(2), 207-217.

Van den Beemt, A., MacLeod, M., Van der Veen, J., Van de Ven, A., van Baalen, S., Klaassen, R., & Boon, M. (2020). Interdisciplinary engineering education: A review of vision, teaching, and support. *Journal of engineering education*, *109*(3), 508-555.

Zhang, X., Fincke, J., Kuzmin, A., Lempitsky, V., & Anthony, B. (2015, August). A single element 3D ultrasound tomography system. In *2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)* (pp. 5541-5544).

Zhao, X., Hebden, J., & Yerworth, R. (2021). Ultrasound scanner—Teaching tool. European Journal of Physics, 42(5), 055703.