WIP: A 3D-printed speaker and audio system project for teaching interdisciplinary engineering design

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Work in Progress: A 3D-printed speaker and audio system project for teaching interdisciplinary engineering design

Introduction

This work-in-progress paper details an innovative and newly taught design project within the first-year course ENGR10006 Engineering Modelling & Design at The University of Melbourne. Through project-based learning (PBL), which has been widely embraced as an effective method to better equip students for the real-world demands of the engineering industry [1], the course's goal is to develop students' understanding of the modelling and design processes by taking them through the life cycle of a real-world engineering project, using a combination of lectures and integrated hands-on workshop sessions. Students work in teams of three and choose one of three possible projects at the start of semester. We asked ourselves: how can first-year students learn core aspects of both electrical and mechanical engineering through a unique, fun, and engaging design project? Our solution was the interdisciplinary "speaker project", with the core physical principle of energy conversion from electrical to mechanical; namely, Faraday's Law, resulting in speaker cone movement to generate acoustic waves. As speakers are common consumer products, students could readily relate what they were doing to a concrete, real-world example.

Course and Project Structure, Constraints, and Assessment

Our students have no declared major during their first year, and a majority need some experience to help determine their pathway going forward. ENGR10006 is a 12.5-point (equivalent to 4 credits at a U.S. institution) course that is not required, but strongly suggested for students considering engineering. The only prerequisite is standard high school mathematics, and student backgrounds can range from little or no physics to those having previously studied mechanics and/or electricity and magnetism. Our semesters have just 12 teaching weeks, and due to start of semester logistics, students only have 10 weeks (9 teaching weeks + 1 break week) for their project work before the final demonstration in Week 12.

The speaker project within ENGR10006 finished the semester with 151 students split into 52 teams. Due to the varied student backgrounds, in-depth theory could not be taught, and alternative approaches that abstract away some details were instead employed. For example, only very basic circuit theory concepts (KVL, KCL, voltage division) were taught, while more advanced concepts, such as active and passive filters and op amps, were taught with a "functional depth". Students learned a systems-based approach, whereby they view filters and summing amplifiers as basic sub-system blocks that can be designed and interconnected provided loading effects are properly minimized using a buffer amplifier.

On the mechanical engineering side, students designed and built a physical speaker (driver plus enclosure) comprised mainly of 3D-printed parts, magnets, fabric, wire, and laser-cut MDF for an enclosure. The cone, due to weight and surface issues, was pre-made using injection molding of plastic. Students used CAD software (SolidWorks) to draw their design (see Figure 1) and laser cut an enclosure that could house their driver. They had the option to 3D-print the chassis and spider holder or use provided printed parts as explained in Outcomes and Discussion.

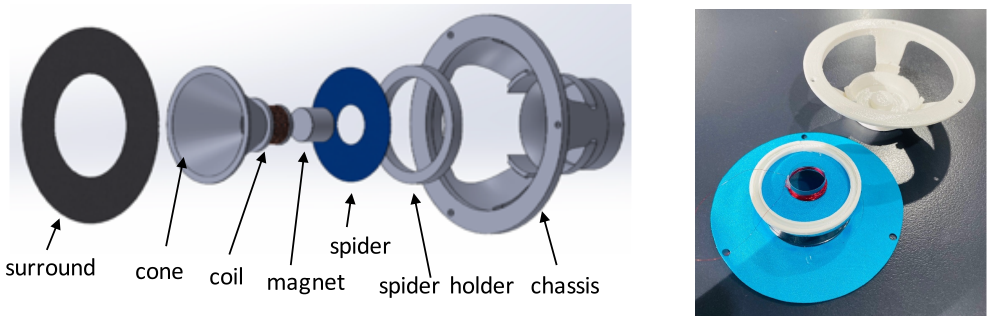

Figure 1: (left) Solidworks drawing of the constructed midrange driver. The chassis and spider holder are 3D-printed parts. (right) Midrange driver with the chassis unconnected.

On the electrical engineering side, students designed and constructed circuits for an audio equalizer, a left+right mixer (stereo-to-mono), a crossover unit for a two-way speaker and some additional analog filtering. Students built and tested these circuits on breadboards. A small battery-powered amplifier module was provided to boost the audio power for the speaker. Students learned to measure their speakers' performance using a sound-isolation box, measurement microphone and open-source software [2]. Using frequency response plots of their constructed midrange driver and a provided commercial tweeter, students chose a crossover frequency and designed the crossover circuitry to provide each driver with the appropriate range of frequencies. Figure 2 shows a block diagram of the audio system.

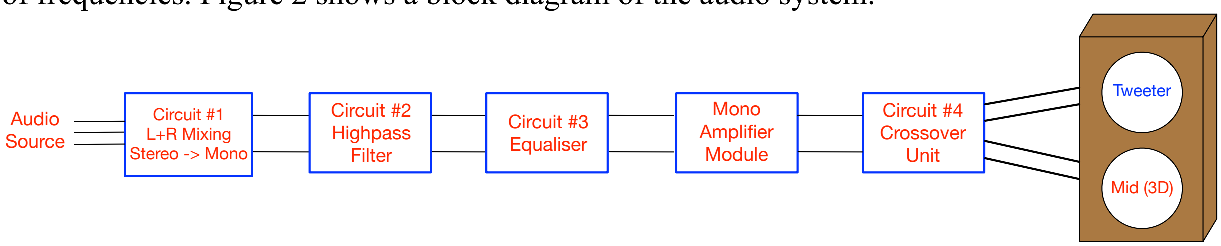

Figure 2: Block diagram of the speaker project.

Assessment was 22% individual (online prep activities 4%, overall project quiz 6%, and peer assessment 2%) and 78% group (18% = 9 x 2% workshops, 10% project plan, 5% project video presentation, 35% project final report, and 10% project final demo), with the larger team components also having peer moderation to ensure equal contribution within the team.

Outcomes and Discussion

Electrical designs, on paper, were relatively good overall with a majority of groups grasping the sub-system design approach. The most significant (and somewhat expected) issue was breadboarding problems. There were a fair number of components in a basic working design: 11 two-terminal components (resistors, capacitors and an inductor), 2 three-terminal components (trimpots), 5 eight-pin 741 op amp ICs, and jumper wires for connecting. Students had insufficient experience in debugging circuits, and teaching staff had to provide much more help than anticipated. Even the best teams struggled at times, and the primary reason was connecting circuits in a compact, unstructured way without considering the need to debug. Another problem was the "home run" approach, whereby students wired everything up in hopes that it just worked, as opposed to constructing and testing each sub-system before interconnecting them.

In the first week of semester, our maker space staff informed us there would be insufficient 3D-printing capacity in Weeks 5 and 6, especially if teams needed to do multiple print iterations due to design flaws or print failures. There was a high risk that a number of teams would not have a working speaker for preliminary testing and impedance measurements in Week 7. We quickly pivoted to provide students with the two 3D-printed parts (chassis and spider holder) by Week 5 so they could construct a driver prototype, but still required and assessed them on an original SolidWorks design like in Figure 1. Teams were encouraged to print their designs and construct another prototype for a potentially higher grade. Only 12 of the 52 teams did just this at the final demo, and of those, 8 worked well enough to be used in place of the initial prototype.

Students performed relatively well in the 3D-CAD tasks as approximately 80% of the teams managed to draw parts in 3D and conduct proper assembly. About 10% of the teams did exceptional work and were able to draw complex parts. Unfortunately, despite the great work with 3D drawings, many students seemed to struggle conducting 2D drawings that included proper dimensioning (drafting). Despite our efforts in dedicating an entire lecture and workshop to teaching this, many students still made mistakes. Another notable issue was more than 25% of groups damaging the constructed driver and/or soldered wire joints in transport to/from class or from excessive force in assembly of the components. We provided a step-by-step assembly manual and a plastic container for the driver and parts, but the range and amount of problems the occurred exceeded our predictions.

Conclusion and Future Direction

The speaker project had successes in students developing 3D-CAD skills and systems engineering principles, as well as hands-on building and measurement experience. For the upcoming second offering, a few key improvements will enhance student learning and project outcomes. Pre-workshop videos are being developed along with corresponding preparatory online exercises so that students achieve more in their workshop sessions and have less issues. This will be particularly useful for helping them develop better drafting skills and avoiding common mistakes we saw in the first offering. The existing systems-based design approach will be emphasized for breadboard construction as well. We may give students a template in Tinkercad for each of the basic sub-systems so that breadboarding is more uniform and less mistakes are made. Ultimately, less debugging will give students more time to tackle the more advanced design options, further develop their early engineering skills, and earn a higher grade.

Future work will include surveying students pre- and post-project to assess how their skills have been developed during the course, particularly in terms of knowledge and experience of engineering modelling and design processes and exposure to interdisciplinary engineering.

References

[1] J. E. Mills and D. F. Treagust, "Engineering education—Is problem-based or project-based learning the answer," Australasian journal of engineering education, vol. 3, no. 2, pp. 2-16, 2003.

[2] "REW – Room EQ Wizard Room Acoustics Software." https://www.roomeqwizard.com (accessed May 1, 2023).