## **Purdue ECE Senior Design Semester Report**

## **(Team Section)**

| **Course Number and Title** | ECE 47700 *Digital Systems Senior Design Project* |
| --- | --- |
| **Semester / Year** | Fall 2023 |
| **Advisors** | Phil Walter |
| **Team Number** | 5 |
| **Project Title** | Smart Air Hockey Table |

| Senior Design Students – Team Composition |
| --- |
| **Name** | **Major** | **Area(s) of Expertise Utilized in Project** | **Expected Graduation Date** |
| Alan Chung Ma | CompE | Firmware, Hardware | December 2023 |
| Ben Owen | CompE | Firmware, Hardware | May 2024 |
| Trevor Moorman | CompE | Firmware, Hardware | December 2023 |
| William Dobert | CompE | Firmware, Hardware | May 2024 |

**Project Description:** Provide a brief (2-3 page) technical description of the design project, as outlined below:

1. Provide a general description of the product to be delivered by this design project.

## The Smart Air Hockey Table redefines the classic arcade game, offering an immersive experience like no other. Central to its advanced gameplay is a vibrant grid of RGB LEDs, dynamically illustrating the puck’s position and game events. This real-time interactivity is made possible by a carefully arrayed set of hall effect sensors, pinpointing the puck’s every move. The Smart Air Hockey Table also incorporates photoresistor and LED pairs at each goal slot, ensuring precise goal detection and accurate score registration. An integrated OLED display shows the game score during matches, and a rotary encoder-controlled menu for customizing settings outside matches.

1. What is the purpose of this product? For whom is it intended?

## The Smart Air Hockey Table seeks to push forward the boundaries of residential air hockey tables. The team hopes the Smart Air Hockey Table will increase interest in the sport of air hockey through its eye-catching graphics. The Smart Air Hockey Table is intended for all ages.

1. Describe how the engineering design process used to create your product was utilized in this project. Include how you were able to develop and conduct appropriate experiments, analyze and interpret data, and use engineering judgment to draw conclusions related to the development of your product.

## There were several alternatives to consider when deciding on the means to achieve specific goals of the project, such as hardware requirements, electrical characteristics, and software functionality. The team used our understanding of the engineering process to prototype several possibilities for achieving specific goals. We experimentally evaluated the performance of these possibilities and weighed their benefits and drawbacks. These experiments typically involved measuring the key differentiators between alternatives and how well they met the target need.

## For example, the project’s viability hinges upon being able to quickly and accurately detect the magnet embedded within the puck. The team researched the strength and shape of magnetic fields generated by different shapes and types of magnets. Once determining the best magnet to use, the team experimented with the timing and ranges of various digital and analog hall effect sensors to determine the best component for our use case.

1. Describe the design constraints, and resulting specifications, incorporated into your product (list a minimum of 3).

## One of our design constraints was the overall size of the table. Due to budget limitations and material availability, we had to ensure fun gameplay while minimizing the footprint of the final table. Because of this, the resulting specification for the table was 160 by 80 cm. This allows for a large enough table for fun play without resulting in a project of such scale that it would be impossible to complete.Another design constraint was that we needed a single power delivery source. Because of this, we needed to take wall power and create multiple power rails for various components in our design. This resulted in implementing an AC to DC power supply and a buck converter to produce multiple voltage levels.Finally, we had a design constraint of real-time puck tracking. This meant that we needed fast-refreshing sensors and the ability to process this data quickly. Because of this, we incorporated a fast microcontroller and fast digital hall effect sensors, allowing for refresh rates in the tens of kilohertz.

1. Describe how each of the following factors influenced your design specifications and constraints.

## **Public Health, Safety, and Welfare:** We made sure that user injury and environmental impact was minimized through robust mechanical design and use of recycled materials.

## **Global Factors:** Sourcing materials and labor from other countries influenced the component selection during the design phase of the product.

## **Cultural Factors:** Some cultures may not be familiar with the sport of air hockey. Therefore, the team made sure that the project’s user manual relies minimally on a priori knowledge.

## **Social Factors:** We wanted to create a product that could be used in day-to-day life and provide a positive entertainment value to users. This influenced our gameplay considerations for the table.

## **Environmental Factors:** We sourced recyclable materials and implemented a modular design to improve reliability and repairability, reducing the long-term environmental impact.

## **Economic Factors:** Modular design allows for easy repairability, reducing the need for total product replacement. This results in lower long-term cost of ownership, reducing the economic impact on end users.

1. Describe the appropriate engineering standards incorporated into the creation of your product.

Our project incorporated IEEE standards for ethics, floating point numbers, and the software development lifecycle. Adhering to ethical standards is important to avoid harming others, making false claims, or conducting illegal activities. Ethical standards are the responsibility of any engineer, and we chose to base our personal standards on those set forth by IEEE. One of the better known IEEE standards, floating point arithmetic makes it possible to perform mathematical operations on fractional numbers through computation.
2. Describe the final status of your product.

The final state of the product was an assembled air hockey table with backlighting, puck tracking, and goal detection. The table has airflow through holes in an acrylic top layer, and the 3D-printed puck has an embedded magnet. The grid of sensor PCBs, mounted under the acrylic layer, contain hall effect sensors and LEDs which track and display the position of the puck on the table. All of these sensors are wired through digital logic to a central microcontroller, which tracks game information, displays lighting effects, and displays information on an OLED display. Users can play games of air hockey with score tracking and under-table animations.

1. Describe the makeup of your project team and how you were organized to establish goals, plan tasks, and meet the objectives of this project.

## The makeup of our project team is diverse, with members from different backgrounds and with different experiences. We organized using Github and splitting work up according to our skills. We planned out the project by splitting it into smaller tasks and then working on them separately. To meet the objectives of the project, we made sure to meet the course requirements first, and then build on top of that to refine our product.

1. Did your project require the production of any written documentation other than this document (i.e., manuals, educational materials, etc.)? If so, describe the types, composition, and nature of the audiences for whom these materials were intended.

Initial Project Proposal: Overview of planned project and analysis of related products.
Final Project Proposal: Detailed description of project and team member introductions.
Functional Specification: Functional description of project and description of design constraints.
Software Overview: Overview of firmware, including description of algorithms and data structures used.
Electrical Overview: Overview of electrical design constraints and considerations.
Component Analysis: Analysis of key components used in project’s design.
Mechanical Overview: Analysis of mechanical design and packaging.
Bill of Materials: Overview of components implemented and their costs.
Software Formalization: Overview of software implementation of the product.
Legal and Regulatory Analysis: Analysis of legal implications and standards to abide by.
Reliability and Safety Analysis: Analysis of component reliability and mean time to failure.
Ethical and Environmental Analysis: Environmental analysis during manufacturing, normal operation, and end of life and ethical analysis of the project.
User Manual: End-user manual for operation of the product.
2. Describe the types, composition, and nature of the audiences in attendance for the final oral design review. Discuss how you prepared for this audience.

## The persons present at the final oral design review are other members of the senior design class, as well as instructors. This means that although everyone is in a related field of study, they all have unique skills, background, and experiences. We prepared for this audience by simplifying our description of our design for better understanding while still using engineering terminology to effectively transmit our information. Combined with breaking down our project into easier to understand sections, we created an effective oral presentation.

## **Purdue ECE Senior Design Semester Report**

## **(Individual Reflections Section)**

| **Course Number and Title** | ECE 47700 *Digital Systems Senior Design Project* |
| --- | --- |
| **Semester / Year** | Fall 2023 |
| **Advisors** | Phil Walter |
| **Team Number** | 5  |
| **Project Title** | Smart Air Hockey Table |

| Senior Design Student Completing This Section |
| --- |
| **Name** | **Major** | **Area(s) of Expertise Utilized in Project** | **Expected Graduation Date** |
| Alan Chung Ma | CompE | Software, Hardware | December 2023 |

**Individual Reflection:** Provide a brief (1-2 page) individual reflection of the design project, as outlined below:

1. Describe your personal contributions to the project.

I took the lead in establishing our digital presence by setting up and managing the team's website and GitHub repository and organizing logistical aspects such as scheduling team meetings. I engaged in brainstorming sessions with my team, which conceptualized solutions that were eventually implemented in the air hockey table. My role was pivotal in the design and assembly of the physical table, a task undertaken with considerable support from my team at the BIDC and our lab. Furthermore, I was involved in the technical aspects, working alongside my teammates to solder numerous components and wires and playing a key role in wiring and troubleshooting the entire system. Regarding software development, I was responsible for integrating various systems, including incorporating hall-effect sensors with LEDs, OLEDs, and the encoder. Additionally, I focused on optimizing the firmware.
2. Describe how your contributions to this project built on the knowledge and skills you acquired in earlier course work.

Key knowledge to the project was ECE362, which laid the foundation in embedded systems programming, crucial for the project's technical aspects. My debugging abilities, refined through extensive breadboarding in various classes, were vital in system troubleshooting. Additionally, my experience in writing C code, a skill developed in multiple courses, directly supported the software development for our project. This combination of theoretical and practical learning from my academic journey significantly impacted my effective contribution to the project.
3. Describe how you acquired and applied new knowledge as needed to contribute to this project. What learning strategies did you employ to do so?

I learned CAD modeling to build the table, a skill crucial for designing and constructing the table. I acquired this new knowledge through self-study, online tutorials and forums, and ample help from BIDC TAs, and I applied it by practicing and refining my designs. This self-directed approach enabled me to integrate CAD modeling into our project successfully.
4. Discuss your ethical and professional responsibilities as they relate to this engineering design experience.

Throughout the design of the table, my ethical and professional responsibilities included critically evaluating team ideas for safety and effectiveness, and ensuring our design was both fun and safe for all parties involved. Additionally, we collectively fostered a culture of mutual accountability within the team, ensuring diligent completion of tasks and adherence to our standards.

1. Consider what the impact of the product of this engineering design experience could have in economic, environmental, societal, and global contexts. Discuss how you would make (or did make) an informed judgement as to your product’s impact in each of these four contexts?

Economically, the table has the potential to create a niche in the market due to its novelty and uniqueness, offering a fresh option for consumers. Environmentally, it would require significant refinement for commercialization. The current design's use of wood is sustainable, but mass production under the current model would be inefficient. Adopting more environmentally friendly materials and manufacturing techniques would be essential for future development. Societally, this innovative air hockey table could set a new trend in arcade games, offering a more interactive and modernized gaming experience. Globally, the project would face logistical challenges in scaling up for the market, considering the international origins of many components and the generic appeal of air hockey.

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| Senior Design Student Completing This Section |
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| **Name** | **Major** | **Area(s) of Expertise Utilized in Project** | **Expected Graduation Date** |
| Ben Owen | CompE | Firmware, Hardware | May 2024 |

**Individual Reflection:** Provide a brief (1-2 page) individual reflection of the design project, as outlined below:

1. Describe your personal contributions to the project.

## I focused mostly on hardware, primarily on PCB design. I created the master PCB schematic and PCB layout. I also spent lots of time with other team members researching appropriate parts and brainstorming various cost-saving measures. I also contributed to the sensor PCB during brainstorming, providing input on layout considerations. On the sensor PCB, after it was completed, I worked to help produce pick-and-place assembly files for automated assembly from our board provider. On the firmware side of the project, I helped develop various drivers for peripherals, such as goal detection and EEPROM. I also helped develop the game state machine for game flow. Mechanically, I helped assemble the table and mount various components, including PCBs and sensors.

1. Describe how your contributions to this project built on the knowledge and skills you acquired in earlier course work.

## Learning the basics of electronic devices and digital logic were critical to success in my work. Early labs from other courses helped with the low-level analog components in our project, such as light-dependent resistors, operational amplifiers, and power electronics. These early labs also helped during the debugging process, helping find issues. My contributions with the PCB design built on these fundamentals. On the firmware side of things, prior coursework taught me the basics of digital communication and microcontroller development. The drivers I helped work on implemented many of these signals, and built directly on past experience from these labs.

1. Describe how you acquired and applied new knowledge as needed to contribute to this project. What learning strategies did you employ to do so?

## Due to the scale of the project, we had to diverge from the components used in previous courses. For example, the microcontroller used in prior labs was not powerful enough for our application, so we had to perform our own research on other product lines and learn the new firmware interfaces required to use them. Additionally, I had to learn about PCB design and production during that phase of the project. To learn this new information, I employed many learning strategies. One of these was learning information from other public sources, such as personal projects or examples given by product manufacturers. Additionally, I attended lectures, which provided important background information which helped in the development process.

1. Discuss your ethical and professional responsibilities as they relate to this engineering design experience.

## During the development process, we kept the environmental concerns in mind. Since our project required the use of lots of materials, we chose materials that were easy to obtain and environmentally cheap when possible. For example, we used plastic only when necessary, and used lots of scrap wood when possible. Additionally, we considered the repairability of our project, implementing modular designs and easy repairability, both of which have environmental concerns for prototyping and production.Professionally, we made sure to ensure the safety of any users of the table. This includes adding ESD protection and finishing sharp edges to avoid injury. Additionally, the firmware state machine allows for a low-power standby mode, reducing the potential for an electrical issue which could result in dangerous operating conditions. The materials used are also more robust than necessary, ensuring rough operation will not damage anything or injure the user.

1. Consider what the impact of the product of this engineering design experience could have in economic, environmental, societal, and global contexts. Discuss how you would make (or did make) an informed judgement as to your product’s impact in each of these four contexts?

## This product was designed for recreational use. However, there are still many contexts that this product could impact. Economically, it is a unique product with the ability for unique gameplay and long-term reliability due to the modular design. As such, further development and production of the product could result in lower long-term operating and repair costs for end users. This also has an environmental impact, as the low-power sleep state and modular design results in lower power consumption and waste materials. The recycled materials also result in a positive environmental impact. Societally, this product allows for a new entertainment medium, especially in arcade or home uses. This is the type of activity that is increasingly rare, but a device such as our product addresses this societal need. Finally, globally, this table allows for other cultures to potentially experience air hockey for the first time. The customizability of our design is welcoming to all types of users. These judgements were made by comparing our design to similar products currently in the market. Many of these devices do not focus on the repairability and modularity in the same way we do, which is why our impact is so large relating to these aspects.

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## **(Individual Reflections Section)**

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| **Advisors** | Phil Walter |
| **Team Number** | 5  |
| **Project Title** | Smart Air Hockey Table |

| Senior Design Student Completing This Section |
| --- |
| **Name** | **Major** | **Area(s) of Expertise Utilized in Project** | **Expected Graduation Date** |
| Trevor Moorman | CompE | Software, Hardware | December 2023 |

**Individual Reflection:** Provide a brief (1-2 page) individual reflection of the design project, as outlined below:

1. Describe your personal contributions to the project.

## For hardware, I led the design of the sensor PCB. I created the sensor PCB’s electrical schematic and PCB layout. I also worked alongside other team members in researching the best hall effect sensor for the project. I provided input for the design of the master PCB through general advice, assisting in creating the electrical schematic, designing the goal detection subcircuit, and working with the team to decide on which microcontroller to use. For firmware, I primarily developed the coordinating state machine, goal detection, and external EEPROM driver. Mechanically, I worked alongside the team in the construction of the Smart Air Hockey Table’s packaging during the final assembly and produced some of the required intermediate parts.

1. Describe how your contributions to this project built on the knowledge and skills you acquired in earlier course work.

## Understanding how to read and create electrical schematics was essential for creating the sensor PCB’s electrical schematic. General knowledge of analog and digital circuit design allowed me to create the goal detection subcircuit and sensor PCB from the requirements the team determined for each. Since the firmware is completely written in C, a firm grasp of the programming language was necessary to effectively contribute to the project’s firmware. Further, the project’s firmware had significant timing constraints which required optimized code. Therefore, knowledge of common data structures, algorithms, and general optimization methods was necessary as well. Given that the firmware was developed for an STM32 microcontroller, my prior experience with STM32 microcontrollers meant I was already familiar with the microcontroller’s general functionality as well as STMicroelectronics’ surrounding documentation. The team used the STM32CubeIDE for development. My prior knowledge of the STM32CubeIDE meant that I was able to help get other team members set up, provide guidance on the team’s use of STMicroelectronics’ HAL and LL drivers, and explain the project’s file structure.

1. Describe how you acquired and applied new knowledge as needed to contribute to this project. What learning strategies did you employ to do so?

## By watching a team member create the first revision of the master PCB’s layout and a lecture on PCB layout design considerations, I was able to learn enough about PCB layout design to create the sensor PCB’s layout. As I worked on the sensor PCB’s, I showed my progress and discussed my design decisions with trusted peers and mentors, such as team members and my professor, to avoid design flaws and to ensure that I created the best design possible for the project. As a side effect, my experience deepened my understanding of KiCad’s features as I had only previously utilized it for creating electrical schematics. Additionally, I learned about standard electrical component packages. Through individual research and practice, I learned how to solder although this skill ended up not being necessary for the team as another team member had greater expertise. I was exposed to engineers of different majors as I used university facilities to produce parts required for the project’s packaging. These experiences and relationships helped me better understand how other engineering disciplines and their expertise can improve a primarily electrical project. Similar interactions while determining the mechanical design of the project furthered my understanding of fundamental mechanical engineering concepts, including aerodynamics.

1. Discuss your ethical and professional responsibilities as they relate to this engineering design experience.

## Throughout prototyping the project, all members of the team needed to individually consider potential hazards to those working on the project, the end user, and the project itself. As the project progressed, hazards were temporarily introduced which the team needed to handle with proper precaution. For example, the final assembly of the project required applying expanding foam to seal potential air leaks in the project’s air chamber. Labels on the expanding foam’s packaging warned that it is a fire hazard while being applied and is an irritant to humans. Therefore, before applying the foam, the team protected ourselves and those nearby by ensuring that there were no open flames nearby and a fire extinguisher was available for the duration of the application and setting process. To protect the project, while assembling and handling the PCBs, team members were grounded by an anti-static wrist strap to prevent electrostatic discharge from harming any electrical components. Throughout the electrical and mechanical design process, design considerations were made to ensure that the final prototype would not be hazardous to an end user.

1. Consider what the impact of the product of this engineering design experience could have in economic, environmental, societal, and global contexts. Discuss how you would make (or did make) an informed judgement as to your product’s impact in each of these four contexts?

## Despite there currently being no plans to continue the project’s development into a commercial product, design decisions were reasonably made to best allow for such development in the future. The Smart Air Hockey Table is designed to be used recreationally in a residential setting. However, this consideration was difficult given the large amount of unknown variables, such as the potential economy of scale, inability to estimate required labor for manufacture, and unknown target markup. Economically, the project is intended to be only somewhat more expensive than the currently available “standard” air hockey table intended for residential use. Environmentally, the current prototype primarily utilizes wood for its packaging, which is a renewable and sustainable material when sourced ethically. However, the electronics required by the project contain environmentally hazardous materials as well as use such materials to be manufactured. Depending on where the project is operated, the source of electricity required to power the product will have a varying impact on the environment. In addition, some countries may have unreliable or unavailable power grids which would restrict the project’s potential use in those markets. Since the team is completely composed of US citizens, our design implicitly relies on typical US cultural knowledge, such as general knowledge on “standard” air hockey. If the project were to be commercialized and offered in other countries, then the project’s design would need to be evaluated with that country’s cultural view in mind first.

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| **Advisors** | Phil Walter |
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| Senior Design Student Completing This Section |
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| **Name** | **Major** | **Area(s) of Expertise Utilized in Project** | **Expected Graduation Date** |
| William Dobert | CompE | Firmware, Hardware | May 2024 |

**Individual Reflection:** Provide a brief (1-2 page) individual reflection of the design project, as outlined below:

1. Describe your personal contributions to the project.

## In terms of writing firmware, I was responsible for setting up our microcontroller’s firmware toolchain. To accomplish this, I worked to gain familiarity with *STM32CubeIDE* and the suite of tools it offers. The microcontroller’s peripherals can be configured with a graphical interface, so I spent considerable time setting up and exhaustively checking that these configurations followed our intended design. Many of the firmware drivers that our main application software uses to interface with hardware were my responsibility to develop. Each driver presented its own unique challenges and design considerations, so very little work could be duplicated between them. The team decided to transition to a microcontroller in a different product line than our then-current choice. Throughout this transition, I managed rewriting our codebase to be compatible with the new microcontroller. Several of the peripheral devices we rely on were modified in how they operate, so I rewrote portions of the drivers from scratch to accommodate. Over the course of our table’s construction, I contributed on numerous occasions to carpentry and assembly-related tasks. I collaborated with the team to review and revise submissions to our codebase throughout the duration of the project. The goal chutes at either end of the table were my responsibility to design and model, aided by feedback from the team.

1. Describe how your contributions to this project built on the knowledge and skills you acquired in earlier course work.

## My previous coursework with C programming informed much of my knowledge of the language as I developed code for the project. Algorithms, data structures, and other “tools of the trade” that I learned about in the past were all useful in the course of contributing to our codebase. As I worked to implement all the features contained in our project, I filled in gaps in my knowledge and broadened my understanding of programming. I especially enjoyed the opportunity to build on my previous coursework with microcontrollers and digital communication. Knowing how to approach a problem while being conscious of the limited resources that a microcontroller possesses was a valuable skill that I continued to build upon while developing this project. Somewhat unexpectedly, my prior knowledge of hardware design was an asset when it came to designing our main application, as the core of our software is represented by a state machine.

1. Describe how you acquired and applied new knowledge as needed to contribute to this project. What learning strategies did you employ to do so?

## To make important contributions to a project of this scope, I worked to acquire new knowledge throughout the duration of the project. Having a team with such varied knowledge was a great asset in this process, as I was able to draw on their unique experience, collaborate on solving technical problems, and accomplish more than we could’ve individually. The lectures provided as part of this course provided a solid base of knowledge to draw from as well. I regularly attended these and applied their lessons as I continued developing the project. I found it necessary at times to seek out instances of other individuals developing solutions for similar problems that I was facing. For example, much of my knowledge regarding our toolchain was bolstered by reading online advice and forum posts.

1. Discuss your ethical and professional responsibilities as they relate to this engineering design experience.

## I personally see my ethical and professional responsibilities as having vital importance throughout the development of the project. Keeping in mind the end user and potential hazards imposed by components of our design had an influence on how I contributed to the overall design. Unavoidable hazards were introduced as a consequence of ongoing development, but the team took proper precautions to mitigate and eventually eliminate many of these hazards. For instance, the later stages of project assembly required dispensing sealing foam along key joints to seal any air leaks in the table’s inner chamber. Prior to using the foam, the team ensured that there were no open flames nearby and that a fire extinguisher was on hand in order to protect ourselves and those in the vicinity. To preserve electrical components while assembly was ongoing, we made use of grounding anti-static wrist bands to prevent electrostatic discharge.

1. Consider what the impact of the product of this engineering design experience could have in economic, environmental, societal, and global contexts. Discuss how you would make (or did make) an informed judgement as to your product’s impact in each of these four contexts?

## Throughout our initial research, the team did not identify any existing products on the market or in DIY communities that achieves what our project aims to. This fact alone amplifies the impact that the project has in all aspects. Although it is designed as a recreational device, our project has impacts in several key areas. In terms of economic impact, this project could be fully developed into a marketable product and sold in retail locations. The compelling nature of the product would serve to drive sales and increase the overall relevance of the home recreation market. When it comes to environmental impacts, our project is designed to be sturdy and repairable. This will reduce waste and encourage re-use instead of using more resources. Additionally, the project is designed to enter a low-power mode when not in use to save energy. When thinking of societal impacts, it is easy to imagine our project bringing together friends, families, teams, and more to enjoy an engaging competitive recreation experience. In the context of global impact, our product may enable those across the world who haven’t had experiences with air hockey to experience a renewed take on the concept. Depending on the culture that our project is localized for, aspects may be modified to better accommodate or attract potential customers in those markets.