Functional Specification

Year: 2023 Semester: Fall Team: 5 Project: Smart Air Hockey Table

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1.0 Functional Description

The Smart Air Hockey Table (SAHT) is a sophisticated iteration of the traditional arcade game, integrating advanced technological enhancements. Central to its design is a grid of RGB LEDs, which dynamically represent the puck’s movements and game events, enabled by a meticulously positioned array of hall effect sensors beneath the translucent playing surface. These sensors detect changes in magnetic fields caused by the magnet-equipped puck, providing unparalleled accuracy in puck tracking.

This sensor arrangement facilitates precise real-time tracking, ensuring the LEDs accurately reflect the puck’s location and movement. Furthermore, an OLED display provides score updates, complemented by a photoresistor and LED combination at each goal for accurate goal detection.

Overall, the SAHT offers a harmonious blend of traditional gameplay and contemporary technological advancements, ensuring precision and enhanced player engagement. It is powered via a standard 120 VAC outlet, with an AC/DC regulator ensuring a stable 5VDC. A buck converter then steps down this output to 3.3VDC for the main PCB, while the regulator directly powers the RGB LEDs and hall effect sensor boards. A detailed functional block diagram can be found in Appendix 1.

2.0 Theory of Operation

The expected way two players will interact with the Smart Air Hockey Table will be the same as a traditional air hockey game as listed here [1]. The additional systems the team will add are the systems that react to the game state. These are the aforementioned network of sensors, the game state tracking system, the graphics drawing system and the light-up display that is present under the playing system.

The network of sensors can be split into two systems: the puck tracking system and the goal detecting system. The puck tracking system can be summarized as such:

$P = Position(Sensor Data, Calibration Data)$

As for the goal tracking system, a modified version of the equation above can also be used for goal detection:

$G = GoalDetected(Sensor Data, Calibration Data)$

The game state tracking system, referred to as the game state machine in the functional block diagram in Appendix 1, will be implemented as a basic finite state machine that tracks the game status. This will make sure that the game logic is robust and not prone to major bugs. The following is the function that determines the next game state:

$S= GameStateMachine(P, G, Past State)$

The graphics drawing system will rely on the current game state, puck position and past image.

$Image=GraphicDrawing(S,P, Past Image)$

Finally, the light-up display will be reliant on the usage of individually addressable LEDs. The common communication standard for addressable LEDs that can be chained is non-return-to-zero (NRZ); a brief explanation on this encoding can be found at [2].

3.0 Expected Usage Case

The Smart Air Hockey Table will be used recreationally in a residential setting. Thus, the Smart Air Hockey Table will not meet all of the US Air Hockey Association’s standards to be a sanctioned table for competitions [3]. Furthermore, the product will not be built to withstand the harsher conditions of a commercial setting, such as an arcade.

Similar to other air hockey tables, the consumer is expected to have a dedicated area for the table that provides enough space around the table for use. This dedicated space should have a wall outlet to power the Smart Air Hockey Table directly, with an extension cord, or with a power strip. The consumer may decide to move the Smart Air Hockey Table while it is not in use, however the air hockey table should only be moved small distances and will require assistance.

Like regular air hockey, two users will use the Smart Air Hockey Table simultaneously, with each playing on the opposing sides of the table. These users will be adults and adolescents with adult supervision. Spectators may be present as well. The players and spectators are expected to be tall enough to see the playing field. Users are expected to be familiar with the rules of air hockey. If any rules are modified, then these changes will be described in the user manual. Similarly, instructions for using the Smart Air Hockey Table’s new features will be described in the user manual.

4.0 Design Constraints

In this section, we will explore key categories of design constraints that are particularly relevant to our project.

4.1 Computational Constraints

The primary computational functions of the project include:

* Reading in Hall effect and LDR sensor data
* Deriving the absolute position of the puck given Hall effect sensor data
* Determining LED color/intensity given current puck location data
* Driving fully addressable LED rows while simultaneously running main application

In terms of memory considerations, all sensor data processing will be done in real time, and not stored for any considerable duration. Significant RAM resources could be required to contain all relevant sensor data in a given moment. Hall effect sensor data will be compressed and aggregated to ensure that all relevant sensor data is within the capabilities of the available computing hardware.

A timing constraint that will be important to consider for the sake of user experience is LED matrix latency. Since the LED matrix is ultimately driven from data produced by the Hall effect sensors as a result of ongoing gameplay, end-to-end latency between data acquisition, intermediate derivations, and LED display update must be minimized.

4.2 Electronics Constraints

For this project, Team 5 will be using a large number of hall effect sensors and LEDs to accurately track the air hockey puck position and display lighting effects on the table. Because of the number of components and size of the table, a grid of PCBs will be connected together containing all of the components. The digital hall effect sensors will be compressed with AND gates into rows and columns. This data will then be sent to the microcontroller,, where this data can be used to calculate the approximate position of the puck.

 The individually-addressable LEDs will be connected to the master microcontroller, where they will be controlled using a custom serial interface defined by the LED controller itself. Other peripherals will be connected to the master such as an OLED controlled with SPI will be used to show score and digitized LDR to detect a puck entering a goal (raw digital signal).

Another major constraint is related to the STM32 itself. Because we are storing the data of hundreds of sensors, our microcontroller will require lots of RAM to store this data. If we do not store these values efficiently or our microcontroller is not capable, we would not be able to track the position of the puck with high reliability. Furthermore, because we have to program in logic to keep track of score and lighting effects, we need lots of storage to store this code.

The last main electronics constraint is primarily related to space. Since we need to fit these PCBs between the top playing surface and the bottom of the table, the PCBs and components need to take up little vertical room. This limits our component selection to almost exclusively SMD parts. Additionally, the moving magnet close to the electronics may affect our analog signal integrity and needs to also be considered. Other factors caused by the electronics, such as heat dissipation of densely populated components, are considered in the following section.

4.3 Thermal/Power Constraints

The thermal and power constraints of the entire system are ultimately dictated by the power draw available from a single US standard wall outlet. Assuming 15A 120V, we must not exceed a total draw of 1800W at any point. However, even during peak load, we do not expect to approach this limit. A commercial power supply will be contained within the table to provide regulated power to the computing hardware, LED lighting, and other small peripheral devices. The blower providing pressure and airflow to the table will be run via a separate power source from all other powered components. Distributing the power system across two independent supplies will serve to simplify the overall design and increase isolation between the blower and more sensitive components.

The most relevant thermal constraint for our design is to ensure that the playing surface does not approach 44°C, as this is the temperature at which first degree burns start [4]. Given that the project’s powered hardware consists primarily of microcontrollers, LED lighting, and a blower motor, we do not expect significant efforts to be necessary to maintain safe thermal conditions. Provided that these components are powered and used within standard operational limits, there is not a major thermal source present. This is also assisted by the fact that the majority of the table’s computing hardware will be contained under the table surface, surrounded by constant cooling airflow.

4.4 Mechanical Constraints

Our provisional dimensional constraints for the playing surface are 800 mm x 1600 mm. This playing surface will be either rectangular or rounded, and will be level to the ground. The overall table should remain below 1000 mm x 2000 mm. The external LCD may stick out past the edge of the table, but should not exceed an additional 250 mm in width (1250 mm total maximum width). Given that the product is designed to be stationary, weight is not a real constraint for this project, as long as it is heavy enough to stay stationary during typical gameplay. In order to ensure maximum play quality, the table will be airtight around the edges and bottom, so air will only exit through the holes drilled in the playing surface.

To ensure safety while playing, the outer edges of the table will be rounded or padded in some way to prevent injury to players. This includes both corners and other edges. Additionally, the table must be able to endure typical playing conditions, including weight being applied to the table surface and paddles hitting the table with moderate force. Unreasonable forces (entire bodyweight or deliberate hitting of the table) are not expected to be survivable for the table over the long-term. Since this is a consumer product, not industrial or professional, durability constraints are lower than such products.

4.5 Economic Constraints

Given the Smart Air Hockey Table’s innovative features not yet present in the market, consumers are expected to be willing to pay a premium compared to existing air hockey tables. However, the price of current air hockey tables on the market provides a baseline for the minimum the Smart Air Hockey Table will retail at. As described previously in section 4.4, the Smart Air Hockey Table’s playing surface will be 1600 mm long, which places the product between five feet and six feet long. Existing five-foot and six-foot air hockey tables intended for residential use retail between $550 and $700. Thus, the Smart Air Hockey Table will retail between $800 and $1000 [5][6]. The Smart Air Hockey Table’s prototype will cost more than the manufactured product given the economy of scale. However, the prototype will require refinement before being ready for manufacture and a markup will need to be applied in order to profit. Therefore, the prototype could cost between $1000 and $1200 to build before being concerned with its economic viability. The team currently estimates that the project will cost $680, which leaves plenty of leeway for unexpected expenses.

5.0 Sources Cited:

[1] US Air Hockey Association. Fundamentals. Available: <https://airhockeypros.com/fundamentals.html>

[2] Gorry Fairhurst (2006). Non Return to Zero Encoding: <https://erg.abdn.ac.uk/users/gorry/course/phy-pages/nrz.html>

[3] US Air Hockey Association (2020). Air Hockey Rules of Play. Available:

 <https://airhockeypros.com/assets/pdfs/USAA-Air-Hockey-Rules.pdf>

[4] Pencle FJ, Mowery ML, Zulfiqar H. First Degree Burn. (2023). In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2023 Jan-. Available:

<https://www.ncbi.nlm.nih.gov/books/NBK442021/>

[5] “Hathaway Warrior 5’ Air Hockey table,” Game World Planet, <https://www.gameworldplanet.com/products/hathaway-warrior-5-air-hockey-table> (accessed Sep. 2, 2023).

[6] “Hathaway Midtown 6’ air hockey family game table,” Amazon, <https://www.amazon.com/Hathaway-BG1009H-P/dp/B0746WP95C> (accessed Sep. 3, 2023).

Appendix 1

