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 is a modernized air hockey table designed to elevate player interaction. It will consist of a network of sensors that will continuously track the elements of the game and send this information to a centralized device which will track game state as the game is played. The two elements of the game the network of sensors will need to track are the puck position and goals scored. The device will then generate and display a graphic that corresponds to concurrent game events on a dynamic display underneath the playing surface consisting of individually addressable LEDs. 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:

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

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:

The graphics drawing system will rely on the current game state, puck position and 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 infrared 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
* Communicating between row master microcontrollers and synchronizing processing (SPI between multiple microcontrollers in parallel)

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. Additionally, sensor data processing will be distributed across several row master microprocessors, thereby alleviating the concern of ingesting a full matrix of sensor data all at once.

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, LEDs, and microcontrollers 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. In a given row, the analog hall effect sensors will likely communicate with various microcontrollers, which will convert the analog signal into a digital value to represent the strength of the magnet for each sensor. This data will then be sent to each row’s “row master” microcontroller, which holds the data to present to the “master” microcontroller, likely over SPI, where this data can be combined with data from other rows to generate a whole-table map of all sensors. 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 LCD to show score (likely connected over I2C) and IR sensors to detect a puck entering a goal (raw digital signal).

One major constraint of the project is the sheer number of SPI lanes required to communicate with each row master. The current design calls for either 8 or 16 rows of PCBs, which is much more than the number of SPI lanes available on most microcontrollers. Thus, Team 5 will be forced to multiplex the SPI data lines or encode/decode the SPI chip select lines in order to exceed the onboard limit. This requires fast microcontrollers and fast multiplexers to handle the multi-megabit SPI connection speeds anticipated.

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 ROM 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. We plan to employ a commercial battery or separate wall outlet to power the blower system. 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

