## Electric Motor Types and Applications

Electric motors may be used in this project to control the movements of the air hockey paddle. There are several different types of electric motors, each with their own characteristics that make them suitable for specific applications. Literature discussing the pros and cons of brushed and brushless DC motors, stepper motors, and linear motors was reviewed and is summarized below [1][2].

**Brushed DC Motors**

Brushed DC motors are very popular and are used in a wide range of applications. These motors are affordable, simple to control, and output high torque at low speed. Brushed DC motors may not be suitable for all applications as the brushes wear out over time, can generate electromagnetic noise, and have limited speed due to brush heating.

**Brushless DC Motors**

Brushless DC motors are becoming more popular as cheap microcontrollers have made it possible to control them in a wide range of applications. These motors are more efficient and reliable than brushed DC motors, and can achieve higher speeds. Brushless DC motors are more difficult to control than Brushed DC motors.

**Stepper Motors**

Stepper motors are commonly used for position control as they do not require an encoder which makes them very simple to use. Stepper motors are highly commoditized and are very reliable as they do not use brushes. Stepper motors are limited in top speed due to small stepping distances and may miss steps under high loads resulting in incorrect position measurements.

**Linear Motors**

Linear motors eliminate the need to have a mechanical device convert rotational motion to linear motion resulting in low friction and therefore higher speeds. Linear motors only have one moving part so they are very reliable and simple to maintain. Linear motors are very expensive as they are usually purpose built for each application and require custom controllers.

## Air Hockey Robots

The Air Hockey Robot project was inspired by an open source project built by jjrobots [3][4]. The jjrobots design used an Arduino to drive stepper motors from a 3D printer which controlled the movements of the air hockey paddle. A PC running OpenCV was used to track the positions of the puck and paddle which were sent to the Arduino with a serial connection. In version 2 of the jjrobots design, the PC was replaced with an Android smartphone running a custom application that performed position tracking of the puck and paddle while also providing a user interface for the game.

## Object Tracking Methods

An object tracking method will be required in this project to track the position and speed of the air hockey puck. There are many ways to track the position of an object, and the literature review below summarizes the pros and cons of several common methods.

**Magnets**

Using magnetic sensors for tracking position and orientation of a magnetic object has become a popular area of testing and study in the medical field due to its non-invasive nature [5]. This method of object tracking requires an array of sensors directed towards the moving magnetic object. Magnets are inexpensive and low-power, but unstable and inaccurate readings make it difficult to achieve precise velocity calculations for an object in constant motion.

**Vision**

Object tracking using vision systems has improved drastically in the last decades [6][7]. Open source solutions have simplified the process to level suitable for academic purposes. A well implemented vision system can be accurate and consistent, providing sufficient data for determining the position and speed of the object in motion. Vision systems are relatively expensive due to the requirement for large amounts of processing power.

**Ultrasonic Sensors**

Another method of object tracking is ultrasonic sensors, which use sound waves reflected off the target to measure distance to the target [8][9]. While ultrasonic sensors can measure very quickly and are cost effective, it would be difficult to design an array of sensors to cover a large surface with a small target object.

## Human Machine Interface Design & Implementation Options

* + - Building a Good HMI (<https://www.automation.com/pdf_articles/opto_22/2061_High_Performance_HMI_white_paper.pdf>)
    - Qt (<http://www.embeddeduse.com/2014/04/19/why-use-qt-for-embedded-systems/>)
    - PyQt and Rpi (<https://www.baldengineer.com/raspberry-pi-gui-tutorial.html>)
    - Website (<https://www.embeddedarm.com/blog/creating-a-human-machine-interface-hmi-web-application/>)
    - Smartphone (<https://www.controleng.com/single-article/an-iphone-as-your-next-hmi/ee2900d7d9c4382803be2b547c767c87.html)>

The project will include a Human Machine Interface (HMI) in order to satisfy the requirement of having a user interface that allows the system to be demonstrated to both technical and non-technical audiences, as well as a debug interface for system troubleshooting. A few options for HMI implementation are discussed below with pros and cons listed for each suggestion.

**QT**

A cross-platform application framework that is a popular choice as an HMI. Familiarity by a group member would lead to quick development of features.

**Python**

A command line interface using Python is simple and takes little time to develop. A less comfortable user experience for non-technical users, however as the debug interface for technical users it would be optimal.

**Mobile Application**

Using a mobile application as an HMI provides portability to the system. The portability would be especially useful for demonstrations and showcasing. Limited application development experience by the group may bring this out of scope for the project.

**Website**

A website running locally on the master controller would provide the necessary HMI for the system, both user and debug interface. The groups expertise in website development from Semester 7 would allow for a clean, versatile solution.

## Air hockey strategy

All points about air hockey strategy (<http://www.bubbleairhockey.com/air-hockey.html)>

In order to understand the game, the project software will include different aspects of air hockey rules. To make project challenging and entertaining for players with different skills, the system will have to utilize fundamental strategies for offense, defense, tips, trick shots, etc. To fulfill the above plan, the air hockey paddle will have to interfere with a puck in 2D motion. The above points are discussed below with some comments.

**Rules**

<https://www.libertygames.co.uk/blog/air-hockey-the-rules/>

First player to reach 7 points wins the game. Point is counted when the puck breaks the horizontal plane inside the opponent’s goal. Once the puck is on a certain player’s side of the center line, he/she has 7 seconds to hit the puck back across the center line. Any fouls or score (e.g. “topping”, puck leaves the table, etc) can be informed via HMI.

**Tips and Strategies**

In offense puck should never need to bank off more than one wall before it goes in your opponent's goal, as it slows down after hitting each wall. Also the system has to watch out for ricochets after its’ own shots, so the paddle needs to be moved in a defense position right after each attack.  
Gaming algorithms will need to vary shots, and keep track of decisions that happened to be successful in the game (e.g. use different walls for bank shots, use trick shots, change interval between each shot).

**Offense**

Shooting zone (shown on Figure 1) is an invisible semicircle behind the centerline on your side of the table that has the highest percentage to score from. A rule of thumb by professional players is to take 90% of the shots form the zone. In order to do that the paddle mechanism will need to be able to stop and drift puck quickly to the shooting zone.

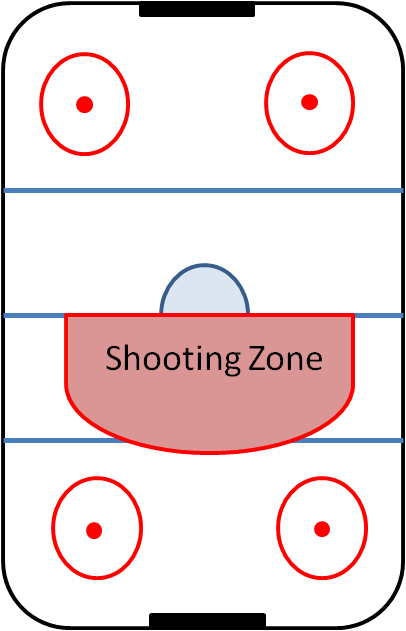


Figure 1 – Air Hockey Shooting Zone

Straight shot only used when your opponent is leaving a gap in their goal open on defense directly across from the position of the puck on your side of the table. Angle shot are two most popular and effective shots, as they are more deceptive and hard to read.

**Defense**

The puck has to be constantly followed. Paddle in the moment of an opponent’s shot needs to be moved to the area around your goal. The triangle style defense is probably the most common method to playing the game.

**Machine Learning**

Air hockey AI tutorial in Unity <https://www.youtube.com/watch?v=ZlAMVEVHkuI&list=PLB6lc7nQ1n4hLTDIPJiUD6OlBSNvtp7YP>

<https://blog.openai.com/dota-2/>

<https://www.techemergence.com/machine-learning-in-gaming-building-ais-to-conquer-virtual-worlds/>

In air hockey each player adapts to the opponent’s gaming style. Machine learning would also allow our system to readjust and counteract unusual techniques demonstrated by new players, and make each move unique. Nowadays, Artificial Intelligence is widely and successfully used in gaming industry, even in more complicated games than air hockey (e.g. Dota 2, StarCraft, Chess, etc). Though, no past machine learning experience among group members might bring this out of scope for the project.

## Communication Methods in Distributed Embedded Systems

The project will include multiple number of major components (Puck Tracker, Paddle Controller, Master Controller, User Interface) that will need to communicate between each other. There are many protocols for network design available on the market today. Some wired and wireless protocols will be discussed below with pros and cons listed for each suggestion.

**CAN (wired)**

<https://www.slideshare.net/EmertxeSlides/communication-protocols-31945098>

Controlled Area Network (CAN) is the most used network protocol in vehicles today. It’s serial, asynchronous, half duplex, multi master/slave, low cost, and may connect multiple nodes together. The maximum speed rate is 1Mbps, which might be not fast enough for real-time video transmission. Due to previous ESE project experience CAN should be an easy to utilize networking solution.

**USB (wired)**

<https://www.slideshare.net/EmertxeSlides/communication-protocols-31945098>

<http://www.computer-solutions.co.uk/info/Embedded_tutorials/usb_tutorial.htm>

Universal Serial Bus (USB) is often used by embedded systems to communicate with PC (i.e. Linux box). USB is asynchronous, half duplex, master/slave, low cost, and may connect multiple devices together. The max speed rates are 1.5Mbps (low speed cable), 12Mbps (full speed cable), 480Mbps (high speed cable), which will be enough for real-time video transmission. But unlike CAN this interface will not be as simple to implement, especially due to no previous expertise in the team.

**Ethernet (wired)**

<http://engr.uconn.edu/~song/classes/nes/slides/nes-intro.pdf>

[https://en.wikipedia.org/wiki/Ethernet - cite\_note-1](https://en.wikipedia.org/wiki/Ethernet#cite_note-1)

Ethernet is commonly used for a connection of PCs and equipment in local areas (LANs). Ethernet speeds vary from 10Mbps to 100Gbps. Ethernet should be a good fit for our project, if we decide to use market single board computers (with included Ethernet ports) instead of custom embedded PCBs (e.g. Raspberry Pi).

**Wi-Fi (wireless)**

[https://www.forbes.com/sites/gordonkelly/2014/12/30/802-11ac-vs-802-11n-wifi-whats-the-difference/ - 1ce3b9f03957](https://www.forbes.com/sites/gordonkelly/2014/12/30/802-11ac-vs-802-11n-wifi-whats-the-difference/#1ce3b9f03957)

<https://www.webopedia.com/TERM/W/Wi_Fi.html>

Wi-Fi is a technology for wireless LAN (WLAN). Wi-Fi compatible devices can connect to the WLAN via a wireless access point (hotspot). Therefore in order to use Wi-Fi in this project we will need to setup a constant hotspot (i.e. router). New standards of Wi-Fi, for example 802.11n, can reach 450Mbps. In the past, our team has dealt with Wi-Fi communication, so wireless integration shouldn’t take too much time. The greatest advantage of it will be wireless communication for HMI, that will be useful for air hockey table showcasing.

**Bluetooth (wireless)**

<https://learn.sparkfun.com/tutorials/bluetooth-basics>

Bluetooth is a standardized protocol for sending and receiving data via a 2.4GHz wireless link. It’s a secure protocol, and it’s perfect for short-range, low-power, low-cost, wireless transmissions between electronic devices. There are different speeds available for Bluetooth, like 2Mbps (v2.1) or 24Mbps (v3.0). Bluetooth is considered to be a perfect replacement for serial communication interfaces (USB, I2C, SPI, CAN) - it can wirelessly transmit relatively small amounts of data over a short range (<100m). On the other hand, none of the team members have worked with this technology before.

Mechanisms for High Speed Position Control

This project will require accurate high-speed control of the air hockey paddle position in two dimensions. A summary of several possible position control mechanisms is included below.

* **Mechanisms for high speed linear position/velocity control (Thomas)**
  + Types of linear actuators: <https://en.wikipedia.org/wiki/Linear_actuator>
    - Electromechanical
    - Hydraulic
    - Pneumatic
    - Piezoelectric
  + Belt driven carriage
    - <https://www.jjrobots.com/the-open-source-air-hockey-robot/>
  + Ball screw mechanism
    - Multiple designs – load mounted on sliding carriage or load mounted directly to end of screw rod
    - <http://www.orientalmotor.com/applications/linear-positioning.html>
  + Pneumatic linear actuator
    - <http://blog.parker.com/know-your-pneumatics-hints-tips-for-specifying-linear-actuators>
  + Hydraulic linear actuator
    - High force, difficult to control
  + Piezoelectreic actuators
    - Small range of motion, high precision, low accuracy (due to hysterises)