



Capstone Project Proposal

Robotic Air Hockey System
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Introduction

The Capstone Project Proposal will make a case for the Robotic Air Hockey System and will provide a high-level description of how the project will work. The proposal document is intended for review by faculty members of the Electronic Systems Engineering (ESE) program at Conestoga College. The Robotic Air Hockey System will be capable of autonomously playing air hockey against a human player. This project will attempt to address the problem of a lack of public knowledge about the ESE program. This problem needs to be solved as there is limited marketing material available that showcases the technical knowledge and capabilities taught in the ESE program that can be understood by both technical and non-technical audiences. Our project will allow group members to develop industry relevant technologies while applying them to a fun and interactive game that will add value to the ESE program through public demonstrations.

Literature Review

The Robotic Air Hockey System will rely on successfully integrating several unique technologies into one holistic system. This section will review literature covering examples of air hockey playing robots, methods for tracking objects in motion, and mechanisms for high speed position control.

Existing Air Hockey Robots

This project was inspired by an open-source project built by jjrobots [1] [2]. The jjrobots design uses an Arduino to drive three stepper motors from a 3D printer to control the movements of the air hockey paddle. In the version 1 of the jjrobots design, a PC running OpenCV is used to track the positions of the puck and paddle which are sent to the Arduino with a serial connection. In version 2 of the design, an Android smartphone running a custom application was used to track the puck and paddle positions while also providing a user interface for the system. The jjrobots system implemented three distinct control strategies: defense, offense, and offense + defense. Our project would implement a simple defense strategy at first, and more advanced strategies once the core platform is stabilized. Our proposed project was inspired by the jjrobots design, but our implementation will be our own work with the detailed system design being driven by system level performance requirements.

Methods for Tracking Objects in Motion

This project will require accurate real-time position tracking of the air hockey puck in order to calculate its trajectory and velocity. There are a multitude of methods that can be used to track the position of an object. Table 1 summarizes several technologies that may be considered for this project. At this phase in the project we have not committed to any specific technical solution for this problem.

Table 1 - Technologies to Track Objects in Motion

Technology	Description	Pros	Cons
Magnets [3]	Array of sensors directed toward moving magnetic object.	<ul style="list-style-type: none"> • Low cost • Low power 	<ul style="list-style-type: none"> • Inaccurate measurements • High complexity to track small object on large surface
Computer Vision [4] [5] [6]	Camera images processed by a computer to locate specific shapes or colours.	<ul style="list-style-type: none"> • Open-source solutions available • Accurate tracking of objects in motion 	<ul style="list-style-type: none"> • Requires large amount of processing power • Susceptible to changes in lighting conditions
Ultrasonic Sensors [7]	Array of sensors directed toward moving object.	<ul style="list-style-type: none"> • Low cost • Readily available 	<ul style="list-style-type: none"> • High complexity to track small object on large surface

Mechanisms for High Speed Position Control

The air hockey paddle will need to move very quickly in order to compete with the best human players. Research into high speed linear position control mechanisms was conducted in order to prepare for the detailed design phase of the project (Table 2). System level performance targets developed in the next phase of the project will drive the design of our chosen position control mechanism.

Table 2 - Technologies for High Speed Position Control

Technology	Application Examples	Pros	Cons
Belt Drive [1] [2]	<ul style="list-style-type: none"> • Air hockey robot (jrobots) • 3D printers 	<ul style="list-style-type: none"> • Low cost • Scales to larger/smaller travel distances • Off the shelf components available 	<ul style="list-style-type: none"> • High speed rotating components • Moderate mechanical complexity • Low mass
Linear Electric Motors [8]	<ul style="list-style-type: none"> • Maglev trains • High speed pick and place machines 	<ul style="list-style-type: none"> • High speed • Few moving parts 	<ul style="list-style-type: none"> • Custom designed • High cost • High mass
Linear Actuators [9] [10] (Electromechanical, pneumatic, hydraulic)	<ul style="list-style-type: none"> • Industrial automation • Heavy equipment • Active suspension 	<ul style="list-style-type: none"> • Few moving parts • High force output 	<ul style="list-style-type: none"> • High cost • Fixed stroke lengths • High mass

Project Description

Overview

The proposed project includes the design, integration, and validation of a robotic system capable of playing air hockey against a human player. This project will serve as demonstration of the capabilities of ESE students for the general public. This project will have a positive impact on the ESE program by increasing the programs exposure within the academic community, and by providing outward visibility for potential students, employers, and industry partners. This project may also serve as a platform to allow disabled people to play air hockey, or for professional players to train against.

The proposed project will provide value to both the ESE program and industry by allowing group members to develop industry relevant technologies while applying them to a project that will have a positive impact on the ESE program. The project will require precise high speed position control of the air hockey paddle, technology that is highly valuable in industrial applications such as pick and place machines and 3D printing. This project will also require the ability to track the position, velocity and trajectory of the fast-moving air hockey puck. Techniques for identifying and tracking fast moving objects are highly relevant in industry for applications such as autonomous vehicles. Finally, for the robot to beat a human player it will need to be able to both intercept and strategically redirect the air hockey puck. The control strategies that will be developed for this project are highly relevant for industry applications where intercepting and redirecting an object in motion is desirable.

The proposed system will include mechanical, electrical, and software components. The development of this system will draw on the technical knowledge and skills learned in the Electronic Systems Engineering program while challenging the group members to learn new skills and techniques to successfully implement the project. The mechanical portion of the system will utilize off-the-shelf components and open-source designs as much as possible. The electrical portion of the project will use off-the-shelf components (ex: motors, microcontrollers) where possible and may reference open-source designs. The software portion of the project may leverage open-source libraries (eg: OpenCV) and may reference open-source designs [1].

The group will need to carefully consider the safety implications of implementing a high speed robotic system that will operate in close proximity to humans. It is the responsibility of the group as aspiring Engineers to consider safety in all aspects of the system design in order to reduce or eliminate the potential for injury. The group will also need to ensure that the system design is professionally documented and designed with maintenance and debugging in mind in order for the project to serve as a public demonstration after the group members have graduated from the ESE program.

Proposed Design & High Level Specifications

This project will improve upon an existing open-source design that was implemented using hardware and software from a 3D printer [1]. The proposed system may utilize the open-source computer vision library OpenCV to track the position of the puck on the playing surface and calculate its speed and trajectory. A mechanical system capable of moving an air hockey paddle in two-dimensions shall be implemented based on the performance requirements developed during the next phase of the project. The

electrical system to control the movement of the air hockey paddle may be implemented using off-the-shelf hardware. The software to control the system shall be our own. A user interface shall be implemented to allow the system to be demonstrated to both technical and non-technical audiences. Thorough documentation and a debugging interface shall be provided to enable ESE staff members to maintain and demonstrate the project after the group members have graduated.

System Overview Block Diagram

The block diagram shown in Figure 1 shows the major components in the proposed system design.

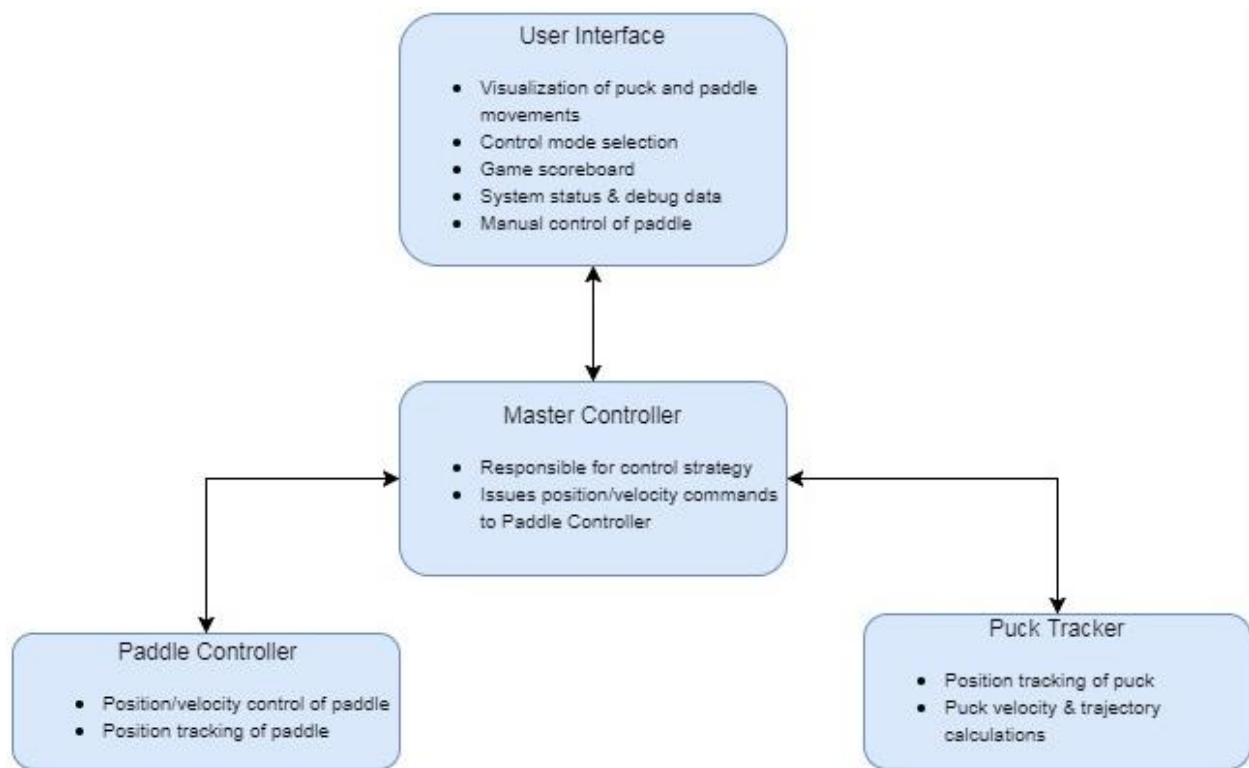


Figure 1 - System Overview Block Diagram

High Level Schedule

Figure 2 shows our intended development schedule and alignment with the ESE capstone project roadmap. Appendix A outlines several project milestones that will be further defined during the specification and planning phase of the project.

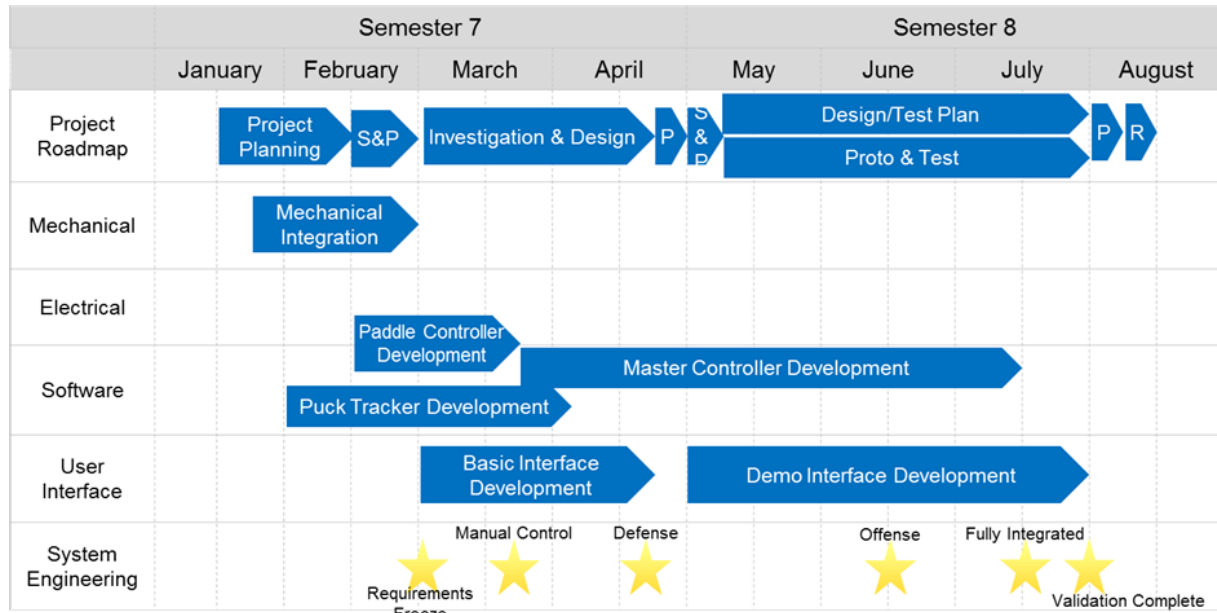


Figure 2 - High Level Schedule

Project Feasibility

Expertise

This project will draw upon the skills and knowledge learned in the ESE program including embedded system design, software engineering, control theory, operating systems, and electromechanical systems. This project will require acquiring knowledge in the areas of autonomous control strategies, object tracking methods, and mechanical design. The ESE faculty and online references will provide technical expertise to help complete this project.

Resources

Successful completion of this project will require regular access to the ESE lab space. This project may also rely on other Conestoga College resources such as 3D printing and machine shop facilities. This project may utilize open source software libraries. This project may utilize mechanical components based on open source designs. The estimated budget for this project is \$1000 CAD. The Air Hockey table will be donated by one of the group members' families. Where possible the group will use hardware that has already been purchased (ex: Semester 4 robot controllers). This project may be sponsored by the ESE program as it will have a positive impact on the program.

Risk Analysis

Based on the risks we have evaluated in the table below, we have determined that the overall risk for this project is low.

Risk (Priority Highest to Lowest)	Category	Impact on Project Objectives	Potential Risk Reduction
1. Mechanical design/integration problems	Technical	Unable to control robot motion	-Start mechanical prototyping early -Leverage group members Mechanical Engineering experience
2. Real-time object tracking problems	Technical	Unable to automate robot motion	-Start object tracking prototyping early -Leverage proven open-source object tracking solutions
3. Security of project in shared classroom	External	Lack of lab workspace availability. Potential damage to project hardware.	-Utilize dedicated ESE lab space -Advocate for continued support of ESE dedicated lab space
4. Catastrophic loss of data	Organizational, external, technical	Schedule delays.	-Utilize source control for all project materials -Manually back up all data once per week
5. Managing scope creep	Organizational, project management	Schedule delays. Lack of focus on core features.	-Strictly define scope of project during planning phase -Additional features shall only be implemented after 100% completion of core project features
6. System sizing incorrect	Technical, performance	Lower than desired system performance.	-Use system level performance requirements to drive component design -Define system level performance requirements based on real-world data
7. Inexperience with HMI design & implementation	Technical	Less relatable demonstration. Worse user experience. Difficult to debug.	-Define user interface features early (see: Managing scope creep) -Start HMI prototyping early -Utilize popular GUI implementation solutions

References

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Appendix A – Project Milestones

I. System Design Freeze

- Functional requirements documented for complete system
- Technical requirements documented for each module/component
- API documented for all digital communication interfaces
- Proof of concept demonstrated for key technologies
 - Vision based puck tracking
 - Mechanism for controlling paddle position

II. Paddle Controller Feature Complete

- Electromechanical system capable of controlling paddle position & velocity in 2-dimensions
- Position tracking & reporting of the air hockey paddle
- Communication with Master Controller Implemented

III. Manual Control of Paddle

- Manual control of paddle using proposed architecture (commands sent to Paddle Controller via Master Controller)
- User input from keyboard or gamepad

IV. Puck Tracker Feature Complete

- Puck Tracker capable of tracking puck position in real time
- Puck Tracker capable of calculating puck velocity and trajectory in real time
- Communication with Master Controller implemented

V. System Integration Milestone I

- Functional robotic air hockey system implemented
- Basic “defensive” control strategy implemented
 - Robot only tries to stop human player from scoring
- Basic user interface implemented
 - Manual control of paddle position
 - Display of system debug data (eg: puck position, module states)

VI. User Interface Mockup Complete

- Proof of concept for user interface implementation
- Demonstration of technologies to be used for visualization of puck and paddle position and trajectory
- No communication with Master Controller

VII. System Integration Milestone II

- “Offensive” control strategy implemented

- Robot will strategically add energy to the puck in order to try and score goals against the human player
- User interface mostly implemented
 - Ability to switch between defensive/offensive control modes
 - Visualization of puck and paddle position and trajectory

VIII. System Integration Milestone III

- Fully integrated, feature complete system
- Robust hardware, software, user interface, diagnostics, etc

IX. System Validation Complete

- Requirements driven test plans written and executed

X. Simulator Feature Complete (Aspirational)

- Simulated playing environment to enable testing of alternative control strategies or training a neural network
- Dynamics of Paddle Controller modelled based on real-world data
- Visualization of simulated playing environment

XI. Machine Learning Control Strategy Demonstration (Aspirational)

- Demonstration of a neural network trained to control paddle position/velocity in order to maximize points differential against the opponent in a simulated environment