JACK'D Inc.
Simon Fraser University
Burnaby, BC
V5H 1S6
340-jack@sfu.ca

October 15th, 2001

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
V5A 1S6

RE: *ENSC 340 Functional Specification for Automated Air Hockey Player*

Dear Dr. Rawicz,

The attached document, *Hockey JACK Functional Specification,* outlines the requirements for our automated air hockey player system. The goal of the project is to design and build an autonomous air hockey player. It will include a sensor system to locate a puck, an electromechanical device to hit the puck, and an intelligent algorithm for strategic play.

The document lists the required functionality of the overall system and specifications of the various functional blocks of the system. The fundamental blocks include a puck-sensing apparatus, a processing-unit, an arm actuator, and an arm sensor feedback mechanism.

Should you have any questions or concerns regarding our functional specification, please contact us via email, 340-jack@sfu.ca.

Sincerely,

Judy Cha, VP External

Enclosure: *ENSC 340 Hockey JACK Functional Specifications*

Functional Specifications for a

Hockey JACK™

Interactive Air Hockey System

Submitted by: JACK'D Inc.
Dave Boen, Judy Cha, Alex Kwan, Kevin Yoon, Clarence Wong

Head Contact: Dave Boen
School of Engineering Science
dboen@sfu.ca

Group Contact: 340-jack@sfu.ca

Submitted To: Andrew Rawicz
School of Engineering Science
Simon Fraser University

Steve Whitmore
School of Engineering Science
Simon Fraser University

Date: October 15th, 2001

Executive Summary

Interactive electronic toys and games have already become part of our daily lives. Why not the same with the popular table games? JACK'D Inc. is developing a system that will enable air hockey fanatics, at reasonably low cost, to hone their skills against a mechanical opponent. This system, known as the HockeyJACK, will enable players to practice at any time of the day, anywhere, as long as they have access to an air hockey table.

HockeyJACK is a PC-based system. Optical sensors attached to an air hockey table detect puck movement and forward this information to the PC. The computer will then process the data and activate a mallet blocker according to an intelligent program designed to respond accordingly. Also included is an arm sensor feedback mechanism to ensure accurate positioning of the arm as well as provide some measure of safety for the user.

This document discusses the HockeyJACK system operation and its various stages of functionality.

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Glossary

Term	Definition
FPGA	Field Programmable Gate Array – a programmable logic chip
Puck	A plastic circular piece
Mallet	The striker piece that is used by the player to hit the puck.
Rack	The device laid across the short side of the rink to guide the HockeyJACK's mallet.
Arm	The device that extends from a motor located behind the rink to the rack in order to control the lateral position of the mallet.
RAMA	or Rack-Arm-Motor Apparatus^{TM}, consists of the three components that make up the mallet controller mechanism.

1 Introduction

What happens when a human player simply cannot find another human opponent to play? The HockeyJACK brings the comfort and excitement of automated play to the average air hockey enthusiast.

Many air hockey players practice on tables with blocked off goals, so that pucks entering a goal simply bounce off and return to the player. This method lacks excitement and force, and is of little value to the player without the calculated response of a live player that is the nature of the fast-paced air hockey game. Our project attempts to address the challenge of developing interactive, physical play with a human air hockey opponent. The HockeyJACK design is a low-cost system that will enable hobbyists to construct their own opponents. At this phase of our project, HockeyJACK is not intended to be a self-contained unit for general public use. There will be open circuit boards and exposed electrical components, as our primary goal does not include fine attention to the aesthetics of the system.

Figure 1: Air Hockey Table

The purpose of this document is to describe the functional requirements of the HockeyJACK system and the deliverables of JACK'D Inc. to its customers. This document is directed towards our project supervisors, Dr. Andrew Rawicz and Mr. Steve Whitmore, the design staff of JACK'D Inc, and external consultants and financiers.

2 System Overview

Figure 2 illustrates a basic overview of the robotic air hockey system. Sensors mounted above the table in two linear formations gather information about the puck's trajectory. The processing unit analyzes the sensory information generated on the table and sends output signals to the hockey player actuators, which control the hockey striker.

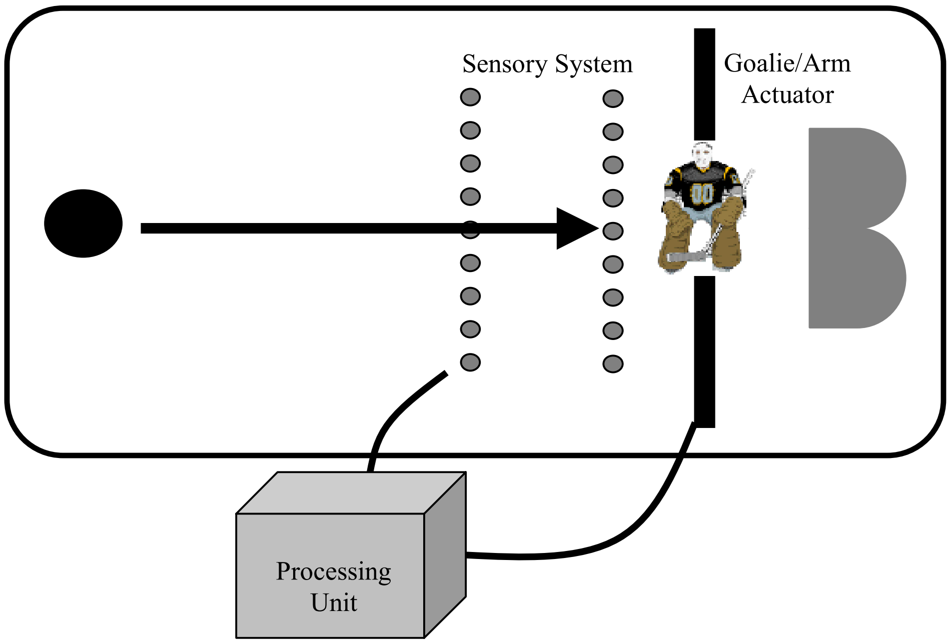

Figure 2: Air Hockey System Overview

The processing unit executes preprogrammed instructions in response to the puck's trajectory and striker's position, or possibly manually entered motion commands from a terminal.

Figure 3 illustrates the basic block diagram of the air hockey system. The details of each block will be discussed in the following sections.

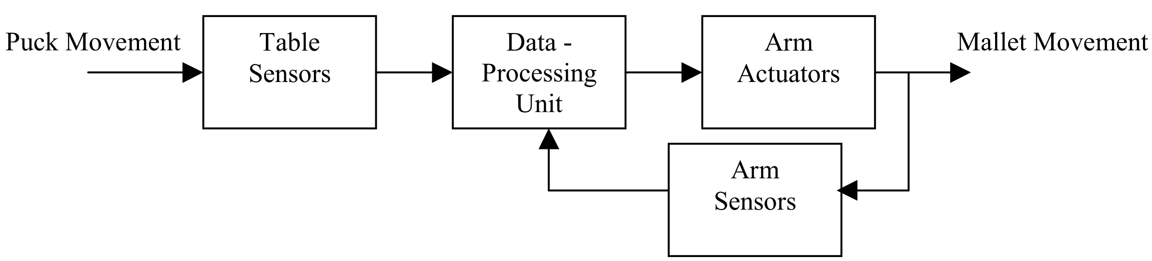

Figure 3: System Block Overview

The Hockey Jack System Shall:

- have response time of less than 5 ms
- utilize IR reflective sensors to detect the puck movement and trajectory
- utilize a servo-mechanical system for mallet movement
- have a programmable interface to the arm actuator and sensory system
- utilize separate power supplies for each functional block, to isolate sensitive electronics from power intensive motors

3 Table Sensing Sub-System

The Table Sensing Sub-System shall detect the puck's movement and pass this information to the data processing unit. Figure 4 illustrates the context diagram for this system.

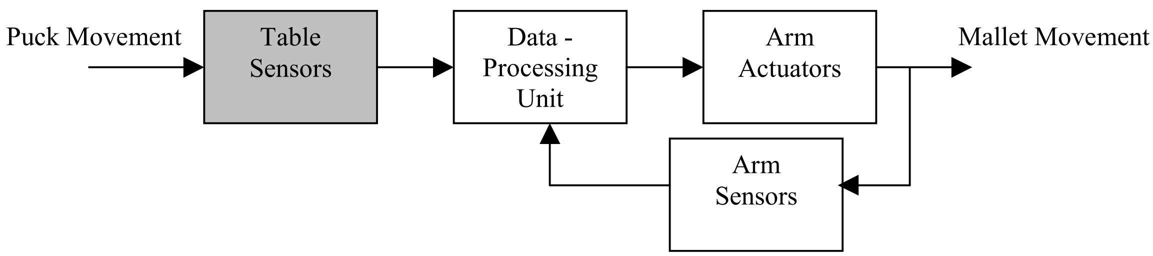

Figure 4: Table Sensing Sub-System Context Diagram

Figure 5 illustrates the functional blocks comprising the table sensing system.

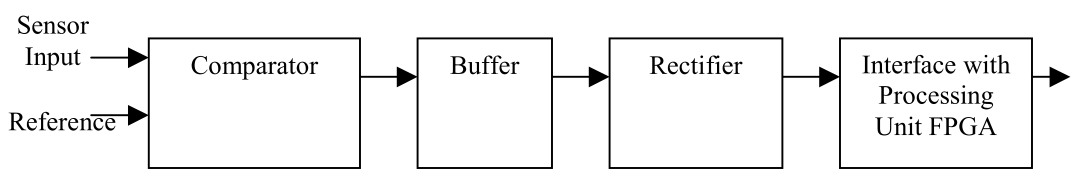

Figure 5: Table Sensing Sub-System Functional Diagram

Infrared reflective sensors will trace the location of the puck. These sensors will be hung across the width of the table to allow detection between the sensors and the tabletop. The arrangement of these sensors will be in two linear rows. The actual number of sensors per row is determined by the relative sizes of the rink and the puck. These two rows of sensors will be separated at an optimum distance to detect any collision motion, which is, bouncing off the wall.

The sensor system shall

- sample at least 1000 times per second
- compare analog sensor signals to a threshold reference and convert to digital format
- buffer the digital conversion system from the downstream blocks
- rectify the signal to produce a signal compatible with logic systems
- tolerate significant noise and disturbance
- withstand possible high speed impact of the puck

3.1 Infrared Object Reflective Sensors

Each infrared object reflective sensor is composed of an infrared emitting diode and a matching phototransistor. The chosen object reflective sensors would produce different signals depending on the distance between the sensor and the detecting object. In our application, the sensors are placed at a constant distance from the tabletop; thus, generating a constant reference signal. As soon as the puck moves across the table, the distance between the sensor and the reflective object is decreased. This, in turn, would generate a signal corresponding to the presence of puck. By comparing these two signals, the sensing system can determine where the puck is located.

3.2 Comparator

The comparator shall convert an analog output signal of the IR sensor to a digital signal so that the processing unit can process it. A reference signal will be needed to determine threshold level. The sensor signal is normally high and when the puck passes under a sensor, the signal will be lowered. Hence, the reference signal will be a dc signal whose voltage level is right below the lowest point of the output signal of the sensor. The output of the comparator then is normally a negative power supply. The normal state of the sensor, without the presence of the puck, is shown in Figure 6.

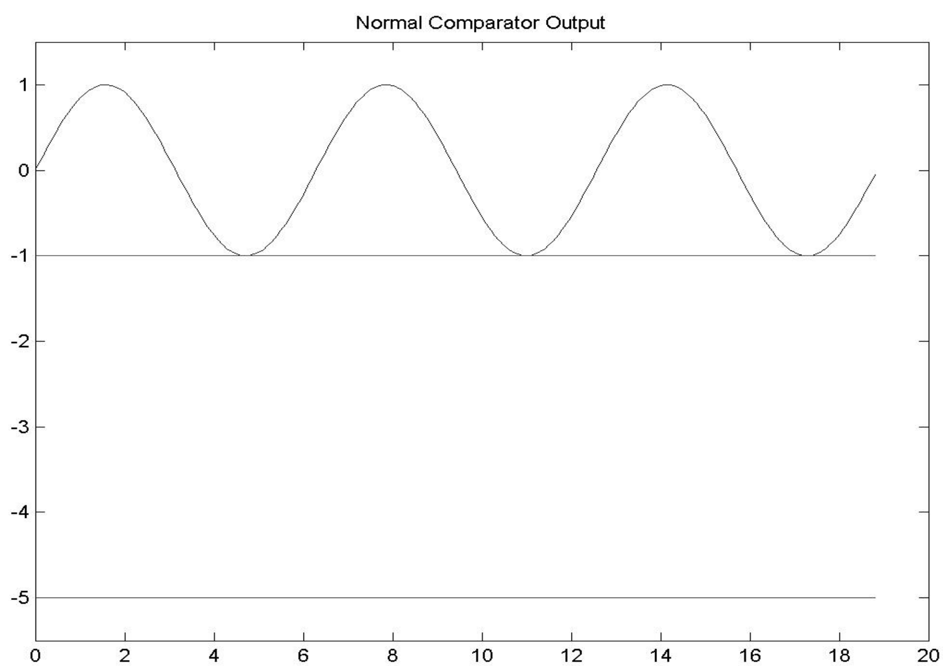

Figure 6: Normal State of the Sensor and Comparator

When the puck passes under the sensor, the output signal of the sensor will be lowered and hence, the reference signal will sit between the sensor output signal swing. Then, the output of the comparator will toggle between the positive power supply when the output signal of the sensor is lower than the reference signal and the negative power supply when the output signal of the sensor is higher than the reference signal. A digital signal will result at the comparator output. The output when puck is present is shown in Figure 7.

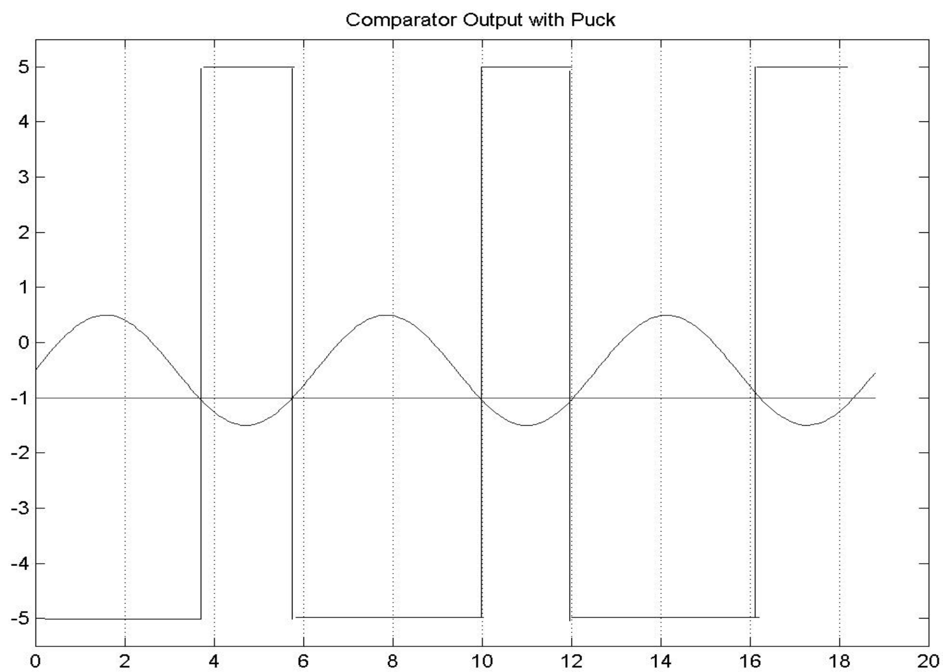

Figure 7: Output of Sensor and Comparator with Puck Present

3.3 Buffer

Since more circuitry is connected to the output of the comparator, a buffer is used to buffer the output signal of the comparator. The output of the comparator then is not affected by the circuitry that is connected after the comparator.

3.4 Rectifier

A rectifier will be used to generate a dc high-level output when the puck passes under the sensor. The rectifier shall convert the duration of the puck into a digital signal that toggles between positive and negative power supply. Its output is shown in Figure 8.

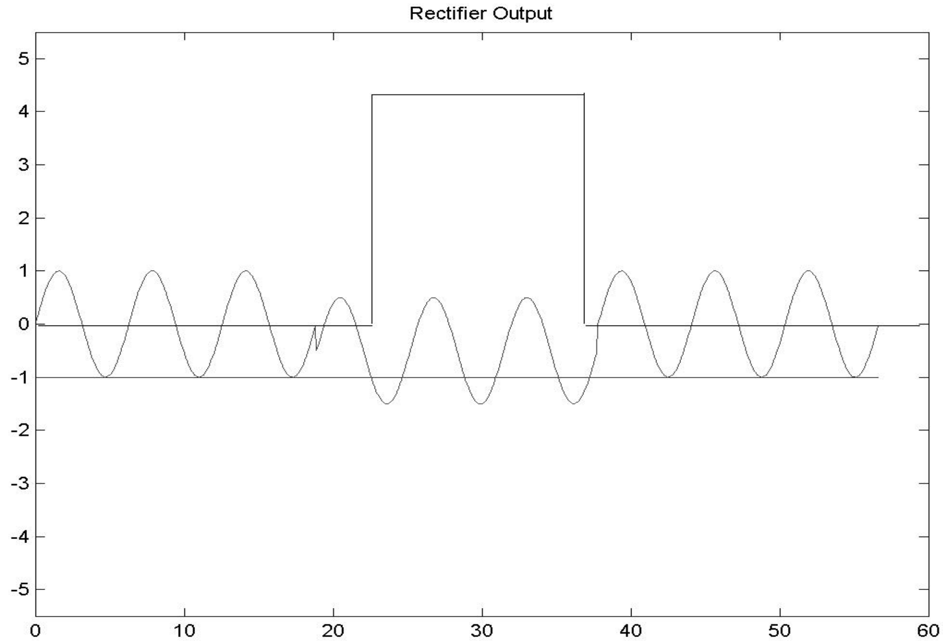

Figure 8: Output of the Rectifier

The output of the rectifier will pass through an interface system to the processing unit and will then be processed.

3.5 Multiplexing Sensor Signals

Our table sensing system consists of many sensors. As a result, dozens of sensor signals need to be fed to the processing unit. The simplest interface would be directly connecting the digitized output to the processing unit. However, it would require ridiculously large amount of processing unit's IO pins being allocated for the sensors. To resolve this large amount of pin assignments, the sensor outputs shall be multiplexed with 8-to-1 digital multiplexers. The select signals of these multiplexers are controlled by the processing unit in such a way that the processor will switch to a different select signal at every clock cycle. In other words, the sensor outputs are time-multiplexed by the processing unit. Because the time-multiplexing scheme is used for polling the sensor outputs, this puts additional timing requirement on the processing unit to maintain the sensor sampling rate of at least 1 kHz.

4 Processing Unit Sub-System

The processing unit shall take information gathered by the table sensing sub-system and formulate the decision to move the mallet arm. Figure 9 illustrates the role of this sub-system in the overall hierarchy.

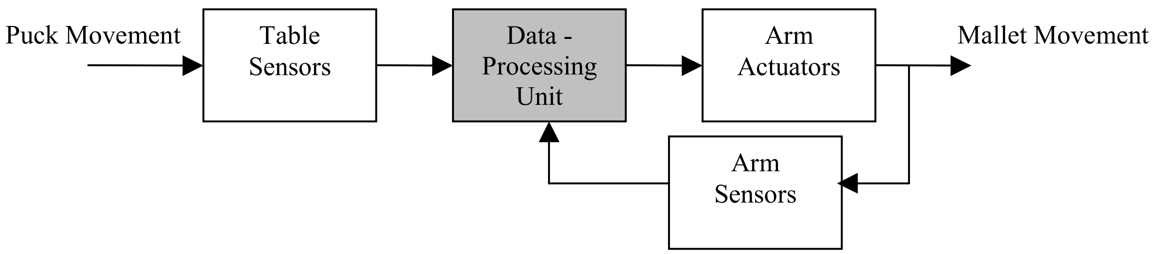

Figure 9: Processing Unit Sub-System Context Diagram

Figure 10 illustrates the functional block diagram of the processing unit.

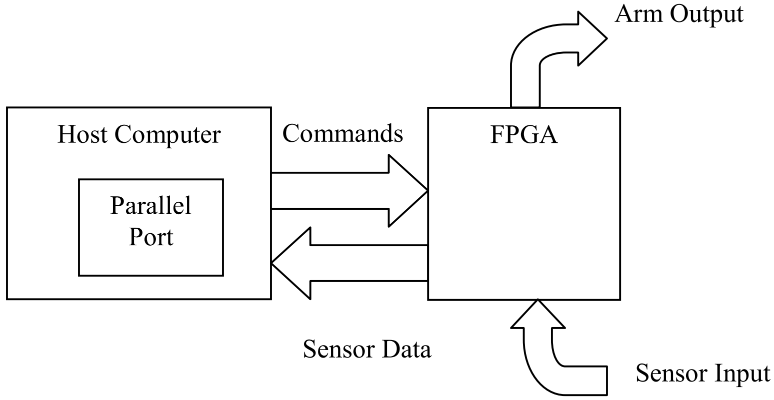

Figure 10: Processing Unit Functional Diagram

The processing unit shall be implemented using a combination PC – FPGA system. In order to fulfill the needs of the table sensors and arm actuator, the processing unit shall have the following features.

4.1 Overall System

- A response time of no more than 5 ms, dictated by maximum puck velocity
- A parallel port interface between PC and FPGA

4.2 FPGA

- A simple LED system of two red status LEDS and a green power LED
- A simple two pushbutton system for manual arm control
- A separate 9V power supply, regulated to 5 V, with reset switch and on/off switch for ease of use.
- A minimum of twenty input pins for the table and motor sensors
- A minimum of ten output pins for the arm actuators
- Ability to buffer two samples of sensor data for processing

4.3 Software

- A high level language such as C for algorithm design
- Ability to perform complex math, such as trigonometric or exponential math functions
- Real-time processing power
- A programmable command set for interfacing with the table and arm actuators through the FPGA

5 Arm Actuation and Arm Sensors

5.1 Arm Actuation

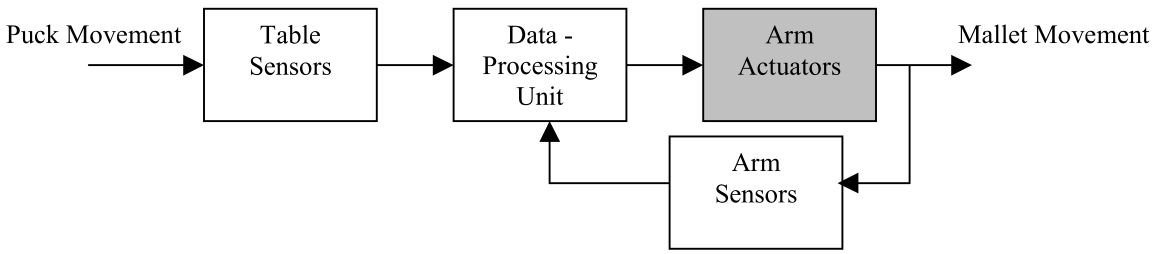

Figure 11: Arm Actuation Sub-System Context Diagram

The arm is a critical component of the HockeyJACK system. It is responsible for the whole mechanical mechanism that strikes the puck. It shall,

- Hold the mallet in place and withstand the impact of the incoming puck
- Contain at least three degrees-of-freedom
- Utilize about 60 degrees of rotational space
- Have response time in the order of hundred milliseconds
- Have lateral precision of at least five centimeters
- Have a fixed position with respect to the rink
- Move with minimal frictional resistance

The mallet holder will be mounted onto a sliding rack mechanism that is placed across the width of the rink above of the side-walls of the rink. Because a single arm is driving the motion of the mallet across this rack, and because it needs to do so as fast as possible in order to intercept a puck incoming at high velocities, a motor with large torque and precision characteristics is required. Located just behind the rink, the motor will utilize rotational space that will be translated into lateral motion of the mallet. Figure 12 provides a mechanical overview of the RAMA.

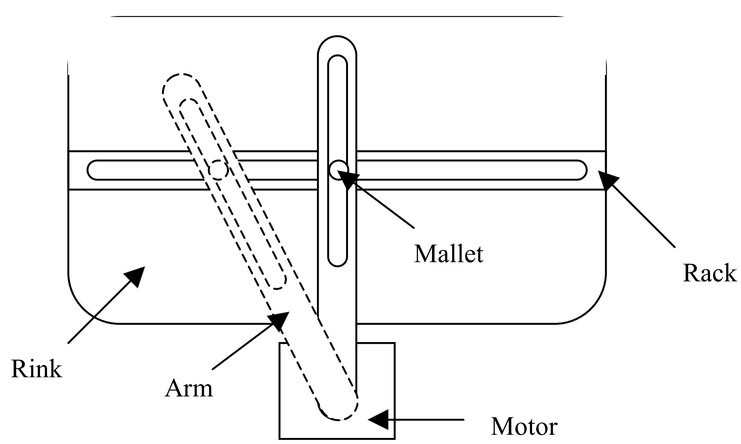

Figure 12 - RAMA Design Concept

Whether we are utilizing an RC servo or a DC motor, a pulse-width-modulated (PWM) signal will be required in order to achieve the degree of positioning accuracy that is required of the arm. The motor, given the length of the arm itself and the mass that it must displace at a high speed, must also supply a significant torque. The amount of torque can be regulated through the supply voltage and the gear-down ratio. Gearing down, however, increases torque at the expense of speed and must be taken into consideration when designing for reaction times necessary.

5.2 Arm Sensors

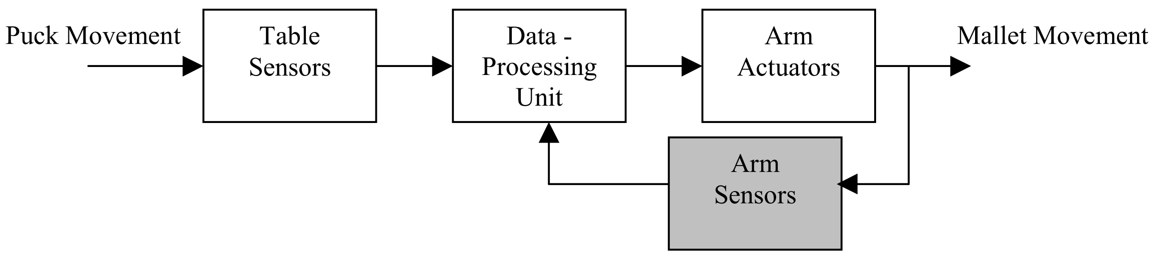

Figure 13: Arm Sensor Sub-System Context Diagram

In the case of a DC motor, a feedback system is imperative. An optical encoder would suit our purposes well in maintain precision monitoring of the arm position. An RC servo, on the other hand, is a reliable open loop mechanism that delivers a precise output position for a given PWM input, thus requiring no data to be fed back to processing unit in terms of position.

6 Requirements

6.1 Physical Requirements

6.1.1 Sensors

1. The sensors shall be protected from possible physical impact.
2. The sensors shall be secured firmly on top of the table.
3. The sensors shall be affected minimally from physical vibration produced by human player and mechanical parts.
4. The sensors shall possess adjustable distances between the sensors and tabletop.
5. The sensors shall have adjustable spacing between the two rows of sensors.
6. The sensor lenses shall be kept clean by the user.

6.1.2 Arm Actuator

1. The arm actuator shall be robust enough to endure strain of high-speed motion.
2. The arm actuator shall have frictionless contact points to allow for high-speed motion.
3. The arm actuator shall possess a mechanical buffering system to prevent arm from rotating outside of rink.
4. The arm actuator shall have a response time of no greater than five hundred milliseconds.

6.1.3 Arm sensor

1. The arms sensors shall have sufficient number of windows in the optical encoder to decode approximately 60° of motion with a minimum precision of a few centimeters.

6.2 Environmental Requirements

6.2.1 Sensors

1. The sensors shall be placed to avoid strong surrounding light source that would disrupt the sensor's sensitivity.
2. The sensors shall operate optimally at room temperature.
3. The user shall attempt to minimize ambient light disturbance.
4. The user shall avoid the use of varying light sources during the operation of the system

6.3 Electrical Requirements

6.3.1 Sensors

1. The sensor system shall sustain a sampling rate of at least 1kHz
2. The sensor system shall provide an adjustable reference signal level to cope with various lighting conditions
3. The sensor system shall distinguish the puck presence signal with the reference signal correctly.
4. The sensor system shall attempt to minimize ambient light disturbance in sensor signals
5. The sensor system shall digitize the analog sensor signals for processing by the processing unit.

6. The sensor system shall time-multiplex the large amount of sensor output to the processing unit.

6.3.2 Processing Unit

1. The processing unit shall operate at a clock rate of at least 20kHz for polling the sensor outputs correctly.
2. The processing unit shall operate with a parallel port throughput of up to 1.5Mbps with the host computer.
3. The processing unit shall utilize a separate power supply to protect against power spikes, interruptions from arm usage.
4. The processing unit FPGA interface shall draw no more than 1A of current at 5V.

6.4 Safety Requirements

6.4.1 Sensors

1. The sensor electronics shall be enclosed to avoid electrical shocks to the user.
2. The sensor usage of mechanical, user-adjustable joints shall be fully documented.
3. All mechanical safety hazards shall be documented
4. The sensor lenses shall be unbreakable, up to a subjected force of 2500N.
5. The cabling shall be secured and hidden from the user as much as possible.

6.4.2 Arm Actuator

1. The arm shall be designed so as not to cause injury in the event that the user is accidentally struck. That is, the arm shall contain no sharp edges, and it shall brake if arm motion is hindered by obstacles.

6.5 Reliability Requirements

6.5.1 Sensors

1. The sensors shall be thoroughly impact tested.
2. The sensors shall be easily replaceable by the user in case they fail to operate

6.5.2 Arm Actuator

3. The arm shall be thoroughly impact tested.
4. The arm shall be able to position itself correctly for the duration of the game

6.6 Standards

1. The processing unit, sensor system and arm electronics shall conform to UL, CSA, and CE electrical standards.

7 System Design Limitations

The current HockeyJACK design is a simplified version of earlier proposals. There is indeed much room for improvement of the system, but given the development team's time and resources, many optional features were reserved for future improvement plans.

In terms of game play, the main limitation is the ability of the mallet to return the puck. There is no striking mechanism as such, but rather the return velocity is determined by the elasticity of the mallet connection to the sliding mechanism of the rack. Given the course precision of mallet movement in certain areas of the rack, the return trajectory of the puck is also under limited control.

The overall response time of the system is also restricted not only by electrical latching and signal propagation, but also by the moving components of the system. The arm itself requires the most time of all the stages required to execute a single motion. Factors like friction, inertia, and acceleration/deceleration time all hinder the rapid response of the arm that would be ideal. The key then is to minimize each of these characteristics to minimize the overall response time of the system.

The placement of the puck sensors is another limitation that reduces the play-space of the human player. If, however, the design is optimized enough for rapid response time, the sensors could be moved forward onto the opposite side of the rink giving the human player full play-space according to standard air hockey regulations.

8 Conclusion

We have now discussed the functional specifications of our HockeyJACK system. With each of these parameters in mind we can begin to develop detailed designs of every individual component of our system. In doing so, we aim to prove our ability to construct a prototype of a fully-functioning automated air-hockey opponent unit, using low-cost components and providing high speed play.