Hockey JACK

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November 5th, 2001

Dr. Andrew Rawicz
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RE: *ENSC 340 Design Specification for Automated Air Hockey Player*

Dear Dr. Rawicz,

The attached document, *Hockey JACK Design Specification,* outlines the design specifications for our automated air hockey player system. The goal of our 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.

This document lists the designs of the overall system and the specifications of the various 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*

# Design Specifications for a

Hockey JACK™

## Interactive Air Hockey System

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| | |
|---|---|
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Date: November 5th, 2001

## Abstract

JACK'D Inc. is currently endeavoring to build the HockeyJACK air hockey unit. This low-cost, automated-opponent is devised of three major subsystems: a puck-sensing array, a processing unit to map the trajectory of the puck, and an actuator system to move the mallet to intercept the puck. The sensor array utilizes two lines of 20 reflective sensors that continuously scan for changes in the input light intensity interpreting inputs that break a threshold voltage as a detected puck. These sensors are time-division-multiplexed to the processing unit, which then extrapolates the trajectory of the puck using in-house developed algorithm. From this data, the target position of the mallet can be determined and an appropriate signal can be sent to the motor to actuate the mallet. The motor is placed behind the rink moving an arm that translates the angular position of the shaft to the lateral position of the mallet along the rack.

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## Glossary

| Term | Definition |
|---|---|
| Mallet | The striker piece that is used by the player to strike the puck. |
| Rink | The arena surface in which the game is played. |
| Goal | The horizontal slots on either side of the rink. |
| Centerline | The line the runs along the center of the rink.  Parallel to short-side of rink. |
| | |
| CPLD | Complex Programmable Logic Device.  A fast, configurable logic device containing flip-flops and combinatorial logic. |
| PWM | Pulse Width Modulation.  A technique enabling control of servo motors, by varying the duty cycle and pulse width of a signal. |
| | |
| Rack | The device laid across the short side of the rink to guide the HockeyJACK's mallet. |
| Arm | The device that extends from a servo motor located behind the rink to the rack in order to control the lateral position of the mallet. |
| RAMA | or Rack-Arm-Motor Apparatus™, consists of the 3 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.

The purpose of this document is to describe the design requirements of the HockeyJACK systems 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 1 illustrates the overall block diagram of the entire HockeyJACK system.

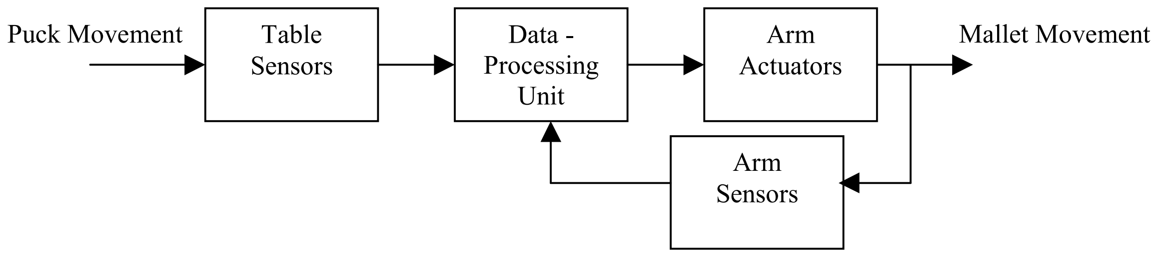



**Figure 1: System Block Overview**

The HockeyJACK system will detect an air hockey puck's movement through the use of table-mounted sensors. The data processing unit will then read the input data and activate the arm to block the puck according to a custom algorithm.

The first step is to detect the puck, using a grid of sensors. The sensing system compares a reference voltage level to that obtained from the sensors. If a puck disturbs the sensor, the data is transmitted digitally to the processing unit. The data processing unit then activates a servomechanism mounted on the custom RAMA system to move the HockeyJACK mallet blocker.

The following dimensions pertain to the Air Hockey table chosen for the project. All reaction times and design specifications are geared towards a table of these dimensions.

| | |
|---|---|
| Rink | 97cm × 47cm |
| Puck | 6.5cm diameter, < 4mm thickness |
| Goal | 20 cm wide |
| Rink wall | 1.3 cm thick, 1.3 cm above rink floor, 14 cm above table top |
| Mallet | 6.5 cm bottom diameter, 3.5 cm handle diameter |

**Figure 2: HockeyJACK Table Dimensions**

The parts list and detailed schematics for the HockeyJACK system can be found in the appendix.

# 3 Table Sensing Sub-System

The Table Sensing Sub-System detects the puck's movement and passes this information to the data processing unit.  Figure 3 illustrates the context diagram for this system.

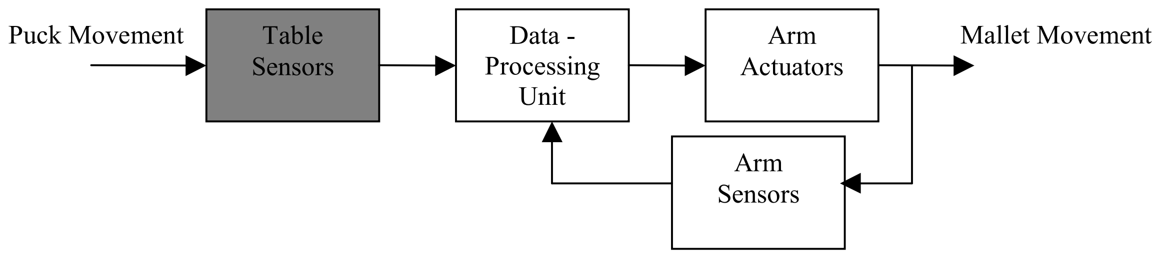



**Figure 3:  Table Sensing Sub-System Context Diagram**

## 3.1 Sensor Layout

To accurately determine the trajectory of the puck, one position vector is all the information required.  Once the position vector of the puck is known, then the trajectory line can be easily deduced from it.  Since the position vector requires a starting point and end point, two rows of sensors are implemented.  To accommodate for bounce off of the rink walls, we can use the Law of Reflection, which states that the angle of incidence equals the angle of reflection.  The position vector obtained contains the information on the angle of the incidence.  The angle of the reflection is then used to generate the second position vector.  In summary, two rows of sensors are enough to obtain the essential information of the trajectory of the puck.

In addition, a fine grid system is needed to locate where the puck is along the row.  To be able to locate the puck accurately, three or four adjacent sensors are needed to cover its area.  Because the width of the table is 47cm and the diameter of the puck is 6.5cm, a simple calculation results in twenty sensors per row.  Figure 4 shows the top view of the sensor system layout.

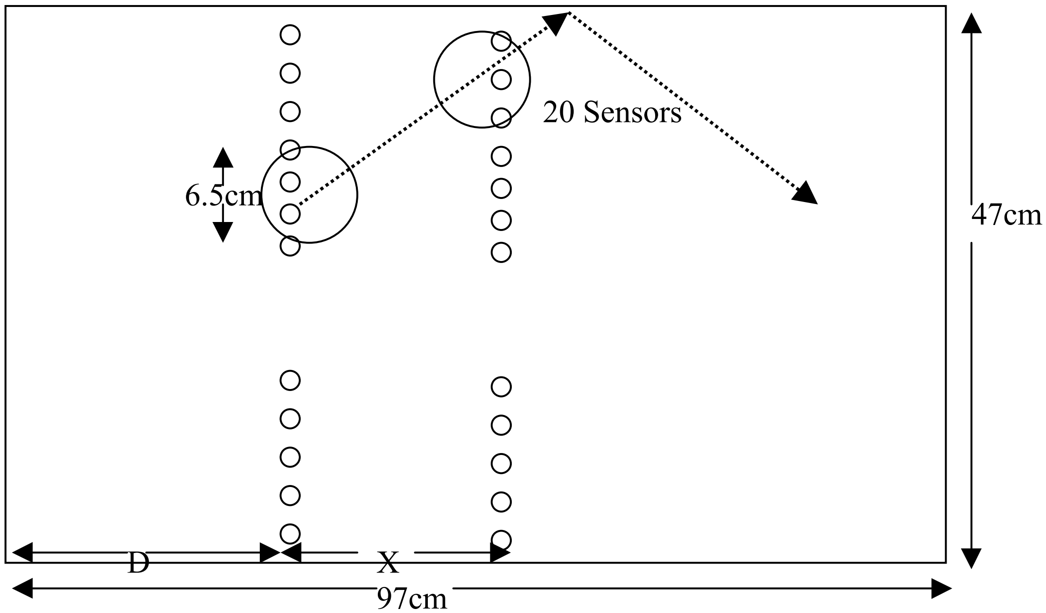



**Figure 4: Layout of the Sensors(Top View)**

The distance D and X specified in the Figure can be varied. The optimum distance for D and X will be obtained by trial and error method. A lower limit for X has to be set to ensure no bounce-off occurs in between the two rows of sensors. Otherwise, the position vector will falsely represent the trajectory of the puck.

Velocity information can be also easily obtained since the time elapsed between the two sensor readings will be known. The velocity of the puck can be obtained by dividing the distance X by the time elapsed between the readings of the two rows of sensors.

The sensors will be mounted on top of the table as shown in Figure 5.

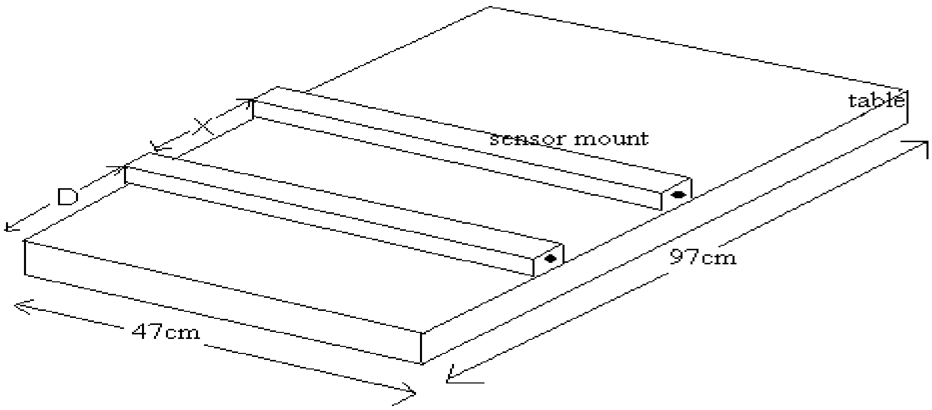



**Figure 5: Sensor Mount on the Table**

The distance between the table surface and the sensor mount will be less than 2cm so that not much ambient light disturbs the system. Also the mount will have a protection wall to protect the sensors from potential puck impact.

## 3.2 Determination of Puck's Position

Reflective object sensors are arranged in a row to determine the presence and the position of a puck. Sensor arrangement is critical to accurately determine the center of the puck for trajectory prediction. To locate the puck's center requires the sensors to be separated by less than the diameter of the puck. Calculation of the puck's center is achieved by separating sensors by 2cm in a row. Figure 6 shows a portion of the sensors arrangement.

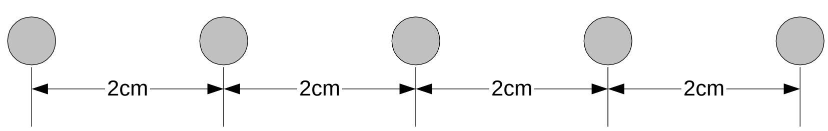



**Figure 6: Illustration of Sensors Arrangement (Portion)**

Two cases will be encountered as a puck passes through this row of sensors: three sensors turned on, or four sensors turned on. These two cases are shown pictorially in Figure 7 and Figure 8.

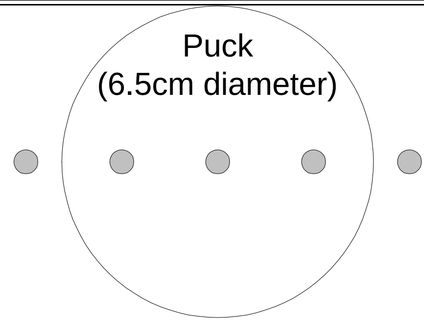



**Figure 7: Case 1 - Three Sensors On**

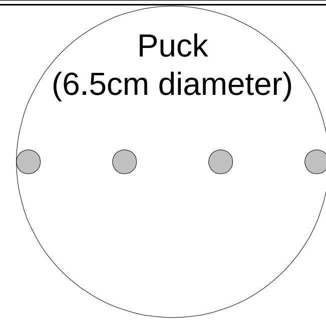



**Figure 8: Case 2 - Four Sensors On**

Case 1: The puck's center is determined to be the location of the middle sensor. Although the puck might be displaced slightly on one side, the worse case scenario gives an error of ±0.5cm (<8%) from the middle sensor's location. This error is tolerable since the mallet is wide enough to ensure contact with the puck.

Case 2: The puck's center is determined to be half the displacement between the outer two active sensors. In worst case scenario, this case gives an error of ±0.25cm (<4%) from the calculated middle point of the outer two sensors.

## 3.3 Sensor System Design

### 3.3.1 Power Supply for Sensor System

Three-terminal adjustable voltage regulators, LM317 will be used to supply appropriate voltage levels for electronic components used in the sensor system. The LM317 is capable of supplying in excess of 1.5A over a 1.2V to 32V voltage range. It guarantees one percent of the output voltage tolerances and its operating temperature is from 0°C to 125°C. Figure 9 shows the package of the regulator.

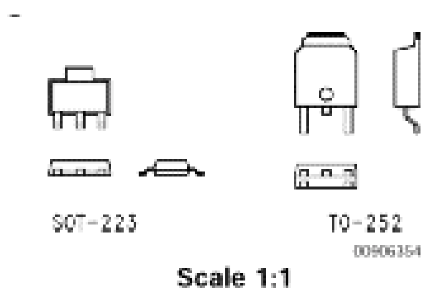



**Figure 9: Three-terminal adjustable voltage regulator, LM 317**

The LM317 will be used to supply 1V to a LED and 5V to a BJT transistor component. In addition, it will be used to supply 5V to a comparator as well as a buffer in the sensor system. Figure 10 shows how it will be configured to generate desired voltage outputs.

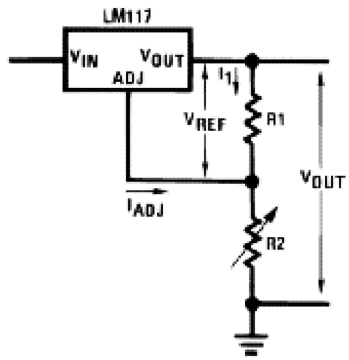



**Figure 10: The Schematic of LM317 to Generate Voltage Supply**

Although not shown in Figure 10, 0.1µF ~ 1µF bypass input and output capacitors to ground will be added to reject the rippling effects of the power supply.

The output voltage will be regulated as follows:

$$V_{out} = V_{REF}\left(1 + \frac{R_2}{R_1}\right) + I_{ADJ} R_2$$

Since the resistor $R_2$ is a potentiometer, a desired voltage level can be easily obtained in real-time.

### 3.3.2 Sensors

The layout of sensors guarantees accurate data capture to determine the trajectory of the puck thus predicting its final destination. In this section, sensor operation will be explained in details.

The QRB1113/1114 IR sensors will be used for our puck detecting system. Figure 11 shows the schematic of the QRB1113 from its design specification.

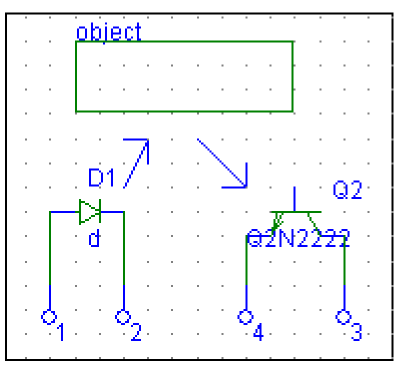



**Figure 11: The Schematic of QRB1113/1114**

As shown in the above Figure, the QRB1113/1114 consists of an infrared emitting diode and a NPN silicon phototransistor. The phototransistor responds to radiation from the emitting diode only when a reflective object passes within its field of view so that the radiation gets reflected back. Figure 12 shows the designed circuit of the sensor for the puck detection.

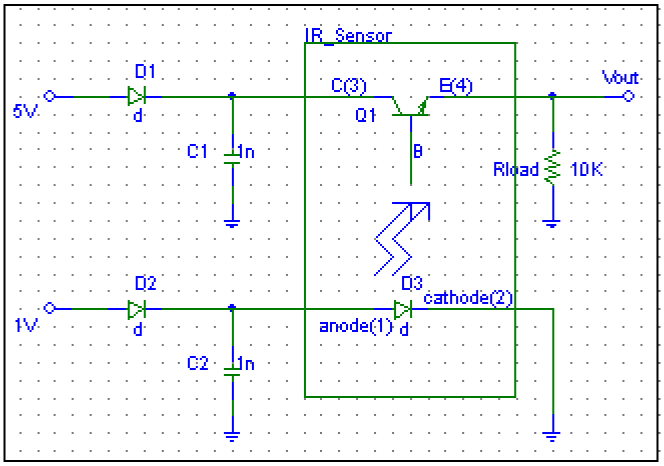



**Figure 12: The Designed Schematic of the Sensor for Puck Detection**

The LM317 voltage regulator will generate 5V and 1V voltage input for the transistor and the LED respectively. The two diodes in Figure 12, D1 and D2, protect the transistor and LEDs of the sensors from possible damages by excessive currents which might be due to possible circuit shorts. The capacitors, C1 and C2, provide a bypass for currents and eliminate noises coming from the power line.

The output signal, $V_{out}$ will be generally high when there is no reflected radiation. When the radiation generated by the diode gets reflected by the moving puck, the base of the transistor picks up the radiation and draws a current. This current will lower the emitter current hence, pulling the $V_{out}$ low. In other words, The output signal $V_{out}$ will be an active low signal.

## 3.4 Sensor Output: Analog to Digital Conversion Scheme

The analog output signal from the sensor must be converted to a digital signal so that it is compatible with the processing unit. For the analog to digital conversion, a comparator is chosen since a comparator can take two analog signals as its input and outputs either a high or low digital signal.

### 3.4.1 Reference Signal

One of the two inputs to the comparator is the sensor output signal and the other input is the reference signal that will be compared to the sensor output signal. This reference signal will be a dc voltage that can be adjusted by using a variable resistor. The advantage of having a variable resistor is that a quick manual calibration of the reference signal can be easily done. Figure 13 shows a simple voltage divider circuit with the variable resistor to calibrate the reference input signal.

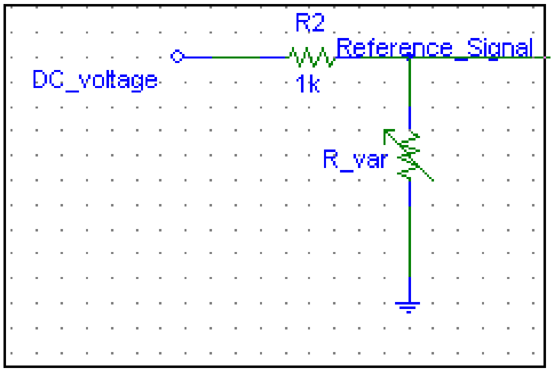



**Figure 13: A Voltage Divider for Reference Signal**

### 3.4.2 Comparator

The reference signal and the sensor output signal can now be inputted to the comparator. The LM339 **(**a Low Power, Low Offset Voltage, Quad Comparator) is chosen for the system. This has four comparators in a single chip. Table 1 summarizes important parameter values for the LM339.

| | |
|---|---|
| Number of Channels | 4 |
| Response Time, typ (us) | .50 |
| Supply Voltage, min (Volt) | 3 |
| Supply Voltage, max (Volt) | 36 |
| Supply Current per Channel, typ (mA) | .20 |
| Input Range | Vcm to V- |
| Output Type | Open Drain |
| Output Current, typ (mA) | 16 |
| Vos, Room max (mV) | 2,5 |
| Input Bias Current, max (nA) | 400 |

**Table 1: Parametric Table for LM339**

The LM317 voltage regulator again will generate the supply voltage for the comparator. Figure 14 shows the schematic diagram of the comparator including the voltage divider circuit for the reference signal.

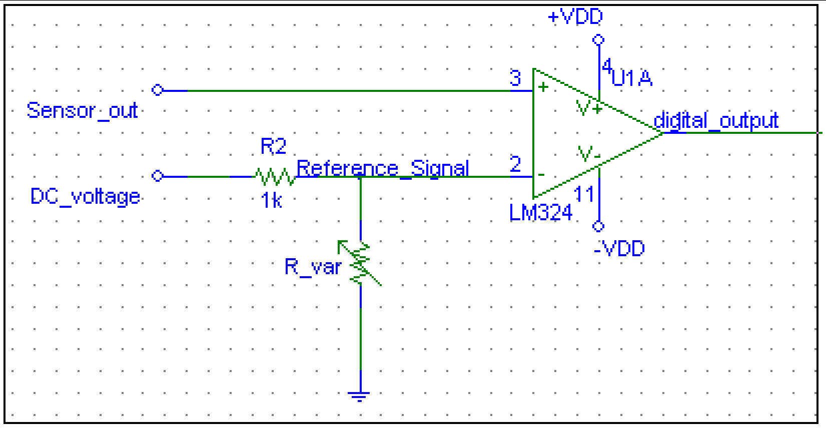



**Figure 14 : Schematic Diagram for the Comparator**

Since the sensor output signal is active low, the sensor output signal is normally high. Hence, the reference signal is a dc voltage 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. Figure 15 describes the normal state of the sensor without the presence of the puck.

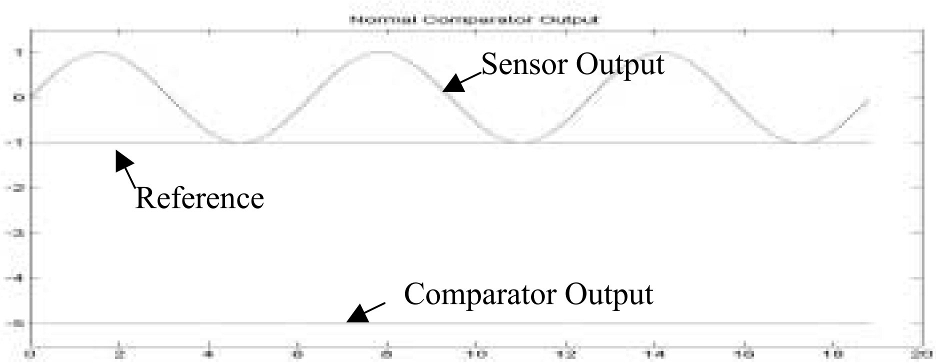



**Figure 15 : Normal State of the Comparator Output**

When the sensor detects the puck, the output signal is lowered past the reference signal. Then, the output of the comparator toggles 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. The output signal of the sensor with the presence of the puck is described in Figure 16.

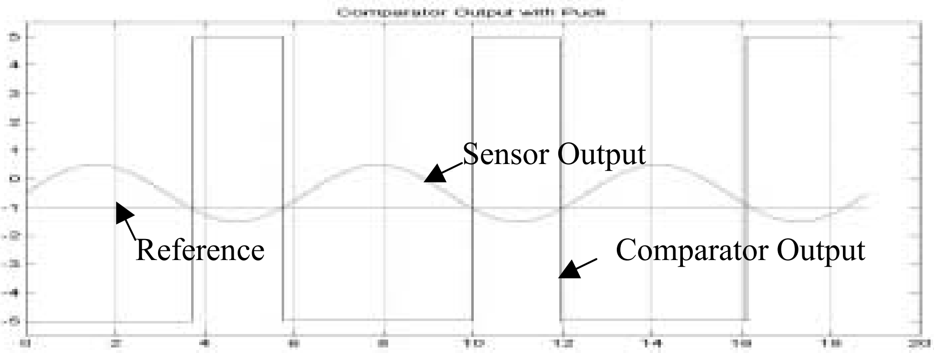



**Figure 16 : Output of Sensor and Comparator with Puck Present**

### 3.4.3 Buffer

Since more circuitry is connected to the output of the comparator, a buffer is used to isolate the output signal of the comparator. The output of the comparator then is not affected by the following stages of circuitry. The LM324, the Low Power Quad Operational Amplifier is used in a unity gain inverting amplifier configuration to be used as a buffer. Table 2 summarizes important parameter values for the LM324.

| | |
|---|---|
| Channels (Channels) | 4 |
| Input Output Type | Vcm to V-,Not R-R Out |
| Bandwidth, typ (MHz) | 1 |
| Slew Rate, typ (Volts/usec) | .50 |
| Supply Current per Channel, typ (mA) | .18 |
| Minimum Supply Voltage (Volt) | 3 |
| Maximum Supply Voltage (Volt) | 32 |
| Offset Voltage, Max (mV) | 3,7 |
| Input Bias Current, Temp Max (nA) | 200,500 |
| Output Current, typ (mA) | 20 |
| Voltage Noise, typ (nV/Hz) | 40 |
| Shut down | No |

**Table 2 : Parametric Table for LM324**

### 3.4.4 Rectifier

A rectifier will be used to maintain a dc high-level output in the presence of the puck. The circuit design is shown in the Figure 17.

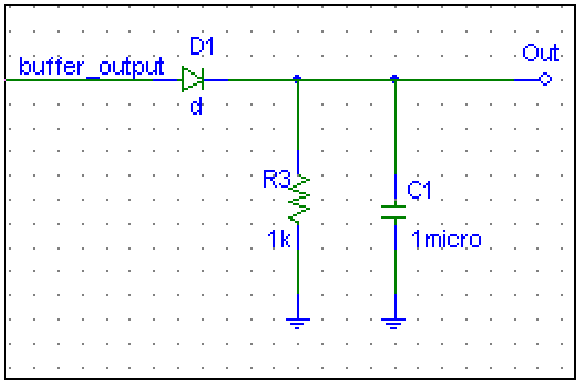



**Figure 17 : Schematic Diagram of the Rectifier**

The output of the rectifier is shown in Figure 18. The output of the rectifier will pass through an interface system to the processing unit and will then be processed.

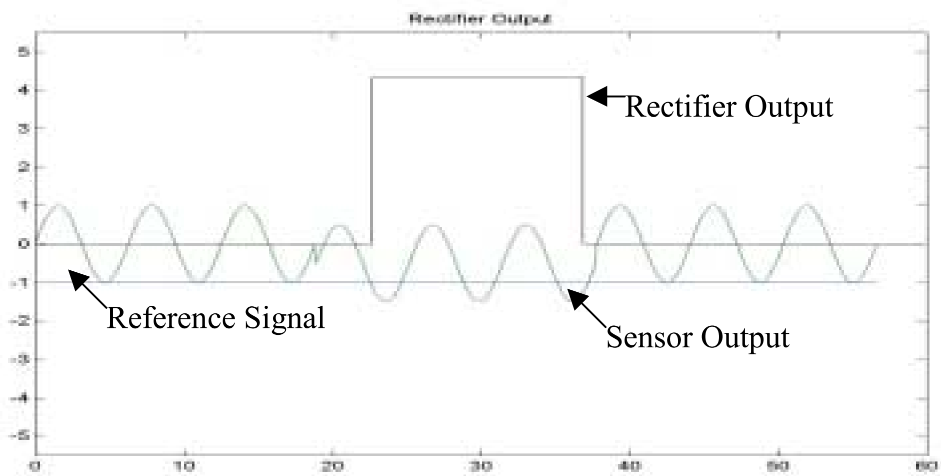



**Figure 18 : Output of the Rectifier**

## 3.5 Time Multiplexing Sensor Signals

To minimize the I/O pin usage on the processing unit for sensor data acquisition, the time multiplexing scheme is utilized. The implementation of this scheme requires the use of the MC14512B 8-Channel Data Selector. This data selector is selected for its low power rating and its fast switching capabilities. Table 3 summarizes the important operating parameters for the MC14512B 8-Channel Data Selector.

| Symbol | Parameter | Value | Unit |
|---|---|---|---|
| $V_{DD}$ | DC Supply Voltage Range | -0.5 to +18.0 | V |
| $V_{in}$, $V_{out}$ | Input or Output Voltage Range | -0.5 to $V_{DD}$+0.5 | V |
| $I_{in}$, $I_{out}$ | Input or Output Current | ±10 | MA |
| $P_D$ | Power Dissipation | 500 | MW |
| $t_{TLH}$, $t_{THL}$ | Output Rise and Fall Time | Typ. 100 | Ns |

**Table 3: Important Parameter Values for the MC14512B 8-Channel Data Selector**

Sensors are divided into groups of eight, and the sensor outputs from each group are connected to the eight channels on the MC14512B. The processing unit then switches the select signals (A, B, and C) for the data selector with respect to the system clock. The relationship between the select signals and data selector output is described in the truth table in Table 4. The eight inputs of this data selector is represented by X0, X1, X2, …, X7.

| Select C | Select B | Select A | Inhibit | Disable | Output Y |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | X0 |
| 0 | 0 | 1 | 0 | 0 | X1 |
| 0 | 1 | 0 | 0 | 0 | X2 |
| 0 | 1 | 1 | 0 | 0 | X3 |
| 1 | 0 | 0 | 0 | 0 | X4 |
| 1 | 0 | 1 | 0 | 0 | X5 |
| 1 | 1 | 0 | 0 | 0 | X6 |
| 1 | 1 | 1 | 0 | 0 | X7 |
| X | X | X | 1 | 0 | 0 |
| X | X | X | X | 1 | High Impedence |

**Table 4: Truth Table for MC14512B**

In doing so, the sensor outputs are time-multiplexed and are sampled at a rate of 1/8 of the system clock frequency (when all 8-channels on MC14512B are used). The minimum requirement for the sensors sampling rate is 1kHz, and therefore the minimum system clock requirement is 8kHz.

From Section 3.2, the puck simultaneously turns on multiple adjacent sensors. To maximize the efficiency and minimize the time lag of the data acquisition process, every fifth sensor output is connected to the same data selector. This idea is illustrated in Figure 19 with four data selector being used.

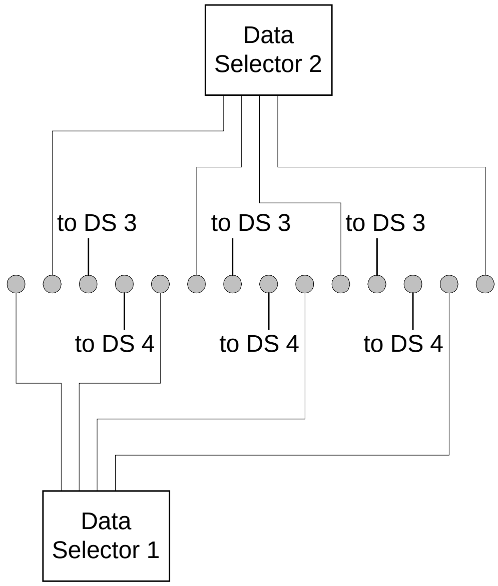



**Figure 19: Sensor Outputs Connection to Data Selectors**

Using the scheme depicted in Figure 19, the processing unit will poll all data selector outputs continuously. Since only 5 channels of the MC14512B are used, the sensor outputs are sampled at a rate of 1/5 of the system clock. The minimum requirement for the sensors sampling rate is 1kHz, and therefore the minimum system clock requirement is 5kHz.

# 4 Processing Unit Sub-System

The processing unit takes information gathered by the table sensing sub-system and formulates the decision to move the mallet arm. Figure 20 illustrates the role of this sub-system in the overall hierarchy.

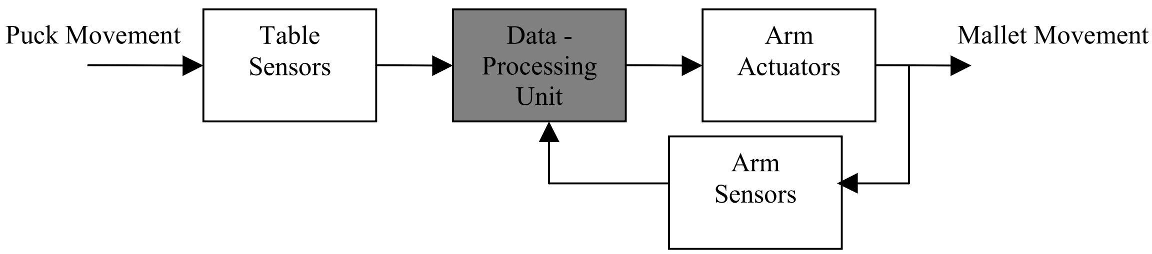



**Figure 20: Processing Unit Sub-System Context Diagram**

## 4.1 Hardware Selection

A number of 8 and 16 bit microprocessors were considered for use in the HockeyJACK processing system. Among those were the

- Microchip PIC
- Atmel Mega103
- Motorola HC11 and HC12

However, the PIC and HC chips lack the ability to handle large amounts of memory and programming the Mega103 requires additional hardware.

The PC was chosen as a controller unit for the following reasons:

- Widespread availability of inexpensive parts and software
- Scalability in processing power
- Easily programmed
- Freely available real-time operating systems such as QNX
- Familiarity with the system
- Easily user interfaced through the use of keyboard and GUI displays

A primary disadvantage of the basic PC is a lack of I/O ports to interface external hardware. The largest data path is through the Parallel Port, which consists of a number of control signals and an 8-bit, bi-directional data bus. Therefore, additional hardware will be required to overcome the I/O limitation. An external CPLD will act as a combination multiplexer/PWM interface through which the computer will interact with the table sensing and arm actuation subsystems.

The PC is also very bulky in its original form. However, an integrated PC with an on board video chip was chosen to enable the computer to be uncased and hidden within the table structure.

### 4.1.1 Parallel Port Interfacing

A number of choices are available to connect external devices to the PC. An ISA bus interface would enable the computer to interact with the system at high speeds, but was rejected due to time constraints.

Another option is a connection through the PC's parallel port. While slower in throughput (limited to around 200 KB/s), the parallel port will allow users to connect their own computers to the sensor interface without the need of a dedicated computer. It will enable even non-technically savvy users to plug into the system and use it. For the purposes of this project, a stripped down Pentium class computer will be embedded into the system.

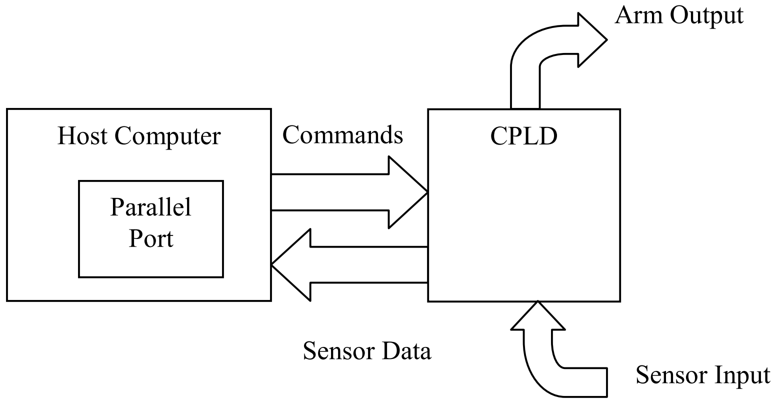



**Figure 21: Processing Unit Functional Diagram**

A modern, bi-directional interface is obviously required, to exchange data and communications. This precludes the use of Standard (SPP) Parallel Port communications, which basically only has output pins. Communications will utilize the Enhanced (EPP) Parallel Port communications standard to exchange data. An EPP interface will require 16 pins on the CPLD device. Figure 22 illustrates the type of connector used on the parallel port.

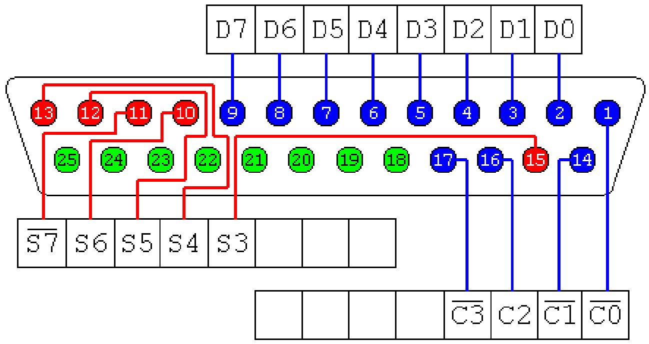



**Figure 22: D-Sub 25 Parallel Port Connector**

The D7-0 pins correspond to the bi-directional data bus, while S7-3 and C3-0 correspond to status register (IN) and control register (OUT) pins. The base address of the parallel port on the PC is 0x378. All data reads and writes will occur using this base address.

The EPP data register, uses additional control signals to ensure data is transferred properly. This register is located at address base + 4 and can be read from or written to. Table 5 describes the modified EPP and control signals from the PC to the CPLD.

| Pin | Name | Direction | Purpose |
|---|---|---|---|
| 1 | Nstrobe | Out | A low on this line indicates a Write, High indicates a Read |
| 2-9 | D 0-7 | In-Out | Data Bus. Bi-directional |
| 10 | Nack | In | Interrupt Line. Interrupt occurs on Positive (Rising) Edge. |
| 11 | Nwait | In | Used for handshaking. An EPP cycle can be started when low, and finished when high. |
| 12 | Tsensor | In | Indicates incoming Table Sensor Data |
| 13 | Asensor | In | Indicates incoming Arm Sensor Data |
| 14 | NdataStrobe | Out | When Low, indicates Data transfer |
| 15 | Error / Fault | In | Spare |
| 16 | Reset | Out | Reset - Active Low |
| 17 | Ncommand | Out | When low, indicates PC Command sent |
| 18-25 | Ground | GND | Ground |

**Table 5: Parallel Port - CPLD Interface Pinout**

### 4.1.2 CPLD Interface

An Altera CPLD, the EPM7128SLC84-6, operates as the main link between the PC, sensing and arm subsystems. Since it is electrically programmable, the CPLD retains its program in the absence of power, without additional circuitry. The 7128SLC84-6 is packaged in an 84-pin Plastic Lead Chip Carrier (PLCC) format, containing 60 general-purpose I/O pins. With the sensing system I/O pin requirements at 11 pins and 1 PWM control pin to service the servo, additional pins can be devoted to pushbuttons and LEDs for manual user control and debugging purposes.

Eleven I/O pins dedicated to the sensor system provide an 8-bit input path into the CPLD and 3 multiplexor control pins (A, B, C) to control sensor data reads.

The CPLD also contains 128 flip-flops, which will be utilized in counters and FIFO buffering applications.

A 1 MHz clock controls the sampling rate and data communications. The sensing system requires a sustained sampling rate of at least 1 KHz, necessitating an actual read rate of 8 KHz, due to the forty sensors being read byte-wise at a time, five times in succession. Ideally, the CPLD would capture sensor data at a much higher rate, as close to instantaneously as possible. The use of this higher clock rate will also allow the CPLD to clear the Parallel Port of data transfers as quickly as possible to allow the computer to send commands.

### 4.1.3 Interface Board External Interfacing

The Interface Board contains,

- Two 26-pin shrouded header, with 13 usable pins, to allow communications between the CPLD, sensor and arm subsystems.
- Two pushbuttons (Omron type B3F switch type) to allow manual user control without the computer present.

### 4.1.4 Verilog Substructure

The following subsystems in Figure 23 will be implemented in the CPLD using the Verilog Hardware Description Language.

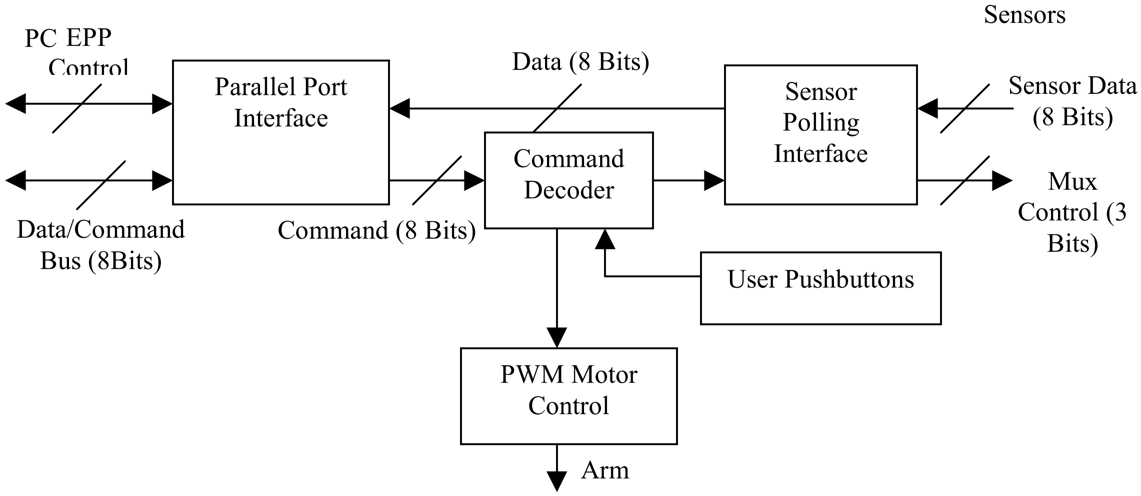



**Figure 23: CPLD Verilog File Hierarchy**

### 4.1.4.1 Parallel Port Interface

The Parallel Port Interface block decodes and encodes the EPP control signals to receive commands and send data respectively. The Interface utilizes the EPP Data Read and Data Write cycles to receive commands and send data respectively on the combined Data/Command Bus.

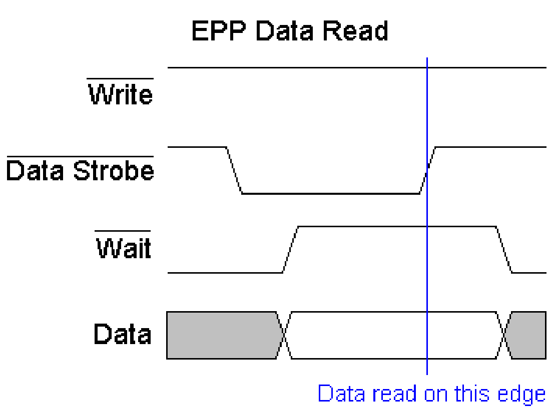



**Figure 24: Sensor Read Cycle**

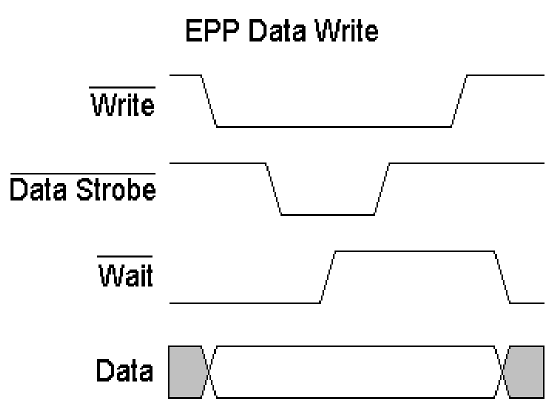



**Figure 25: Command Write Cycle**

The command decoder will decode received commands and actuate a new command for the PWM motor interface or request a read from the sensor interface. The MSB of the command will indicate whether to initiate a sensor update or issue a PWM change.

| Command (Binary) | Description |
|---|---|
| 0XXX XXXX | Initiate Sensor Update |

| | |
|---|---|
| 1000 0000 | PWM Duty Cycle 0 |
| 1000 0001 | PWM Duty Cycle 1 |
| … | … |
| 1110 0011 | PWM Duty Cycle 99 |

**Figure 26: Command Set Definition**

The command decoder interprets inputs from the two onboard push-buttons, to allow arm left or arm right commands from the user for manual testing purposes.

#### 4.1.4.2 Sensor Interface

The Sensor Interface responds to a PC request for a sensor update, a '0' in the MSB of the command byte, and initiates a burst sample of the forty sensors, eight at a time in successive clock cycles. Forty of the CPLD's onboard flip-flops form a FIFO buffer necessary to capture the five consecutive byte read cycles until sensor update request.

#### 4.1.4.3 Servo Motor Interface

The servo motor interface reads the lower seven bits of the command byte upon detecting a '1' in the MSB. Since the period of the PWM signal is 15 ms and the clock runs at a rate of 1 MHz, a 14 bit counter is required to control the period. The motor interface interprets the 7 bit value as an offset value, to control duty cycle period in the range of 1-2 ms.

## 4.2 Software Interface

PC programming will be done using the QNX 6 Real Time Operating System (RTOS). While the hardware requirements are higher to support the overhead of this operating system, relative to DOS, QNX offers a number of important features such as multi-process capability, interrupt handling and timers.

A C process will be developed (sensor_update) to automatically send the command to poll the sensors at regular intervals. The results of the sample will be placed in QNX shared memory and be available to the control algorithm.

# 5 Arm Actuation and Arm Sensors

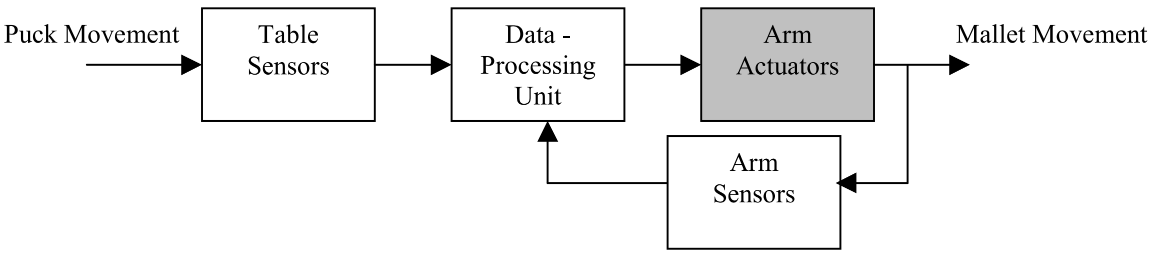



**Figure 27: Arm Actuator Unit Sub-System Context Diagram**

## 5.1 Motor Selection

### 5.1.1 DC Motor

In an effort to minimize cost of the arm controller setup, the use of a simple DC motor was explored. Some experimentation was conducted with a geared-down Pittman 24V DC motor and a LMD18201 H-bridge by National Semiconductor in the setup shown in Figure 28.

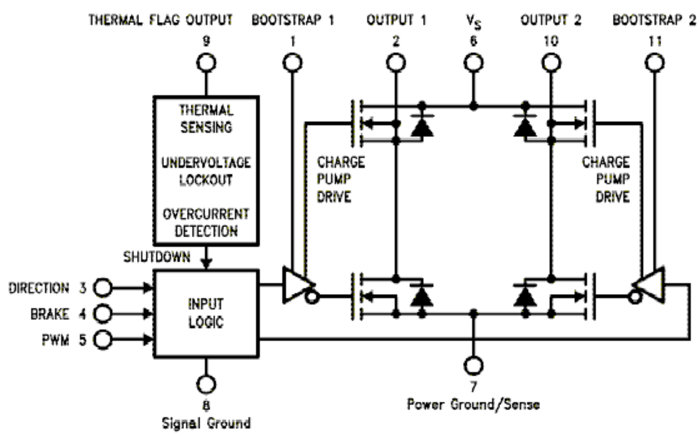



**Figure 28 - H-bridge block diagram for DC motor control**

The DC motor was attached to the two outputs of the H-bridge. Three digital inputs (brake, direction, PWM) were also utilized. The function of the brake and direction inputs is obvious. The PWM signal defines the velocity of the shaft.

It was discovered that it was too difficult to achieve precision positioning of the motor without an attached inertial arm let alone with one. The torque of the motor also increased with velocity, which was not a desired dependency. While quick braking and reliable direction control were much desired features that the H-bridge provided, it was still difficult to map a given step input length to a certain angle of rotation, especially when an inertial and frictional torque is applied. Even if the optical encoder built into the Pittman motor was utilized, it would still be difficult to determine how much voltage to apply in order to correct an offset position. The DC motor also appeared to exhibit limits beyond which it did not behave according to the expected characteristics.

A motor with more discrete settings or internal closed-loop control was required. A high-torque RC servo would serve well for this application.

### 5.1.2 RC Servo Motor

The Hitec HS-805BB is one of the lower-priced, high-torque RC servos available. With a heavy duty nylon gear train it can put out some considerable force. Table 6 outlines the main characteristics of the motor.

| **Bearing Type** | Dual Ball Bearing | |
|---|---|---|
| Operating Voltage | 4.8V | 6.0V |
| Torque | 19.8 kg/cm | 24.7 kg/cm |
| Speed @ 60 degrees | 0.19 s | 0.15 |
| Size (L × W × H) | 66 × 30 × 58 mm | |

**Table 6- Hitec HS-805BB RC Servo Specifications**

This servo has three inputs: a positive supply, a ground, and a pulse-width-modulated (PWM) control signal. The PWM signal is a square-wave of varying duty cycle which determines the angular position of the servo shaft. From the test plan described in Section 7.4, a 15ms signal with a duty cycle varying between 1.2 and 2.1ms gives us a range of more than 90 degrees on the servo shaft. This range is more than the 60 degrees that is required, giving us a decent buffer for configuration. (Sixty degrees is an arbitrary range chosen on the basis that a wider angle would call for more speed and torque on the motor while a smaller angle would require much greater precision from the motor.) Some fine-tuning may be done at later stages to find the frequency that yields the highest angular resolution for our application.

This single-input control is much more advantageous over the DC motor setup since the torque is relatively constant and no limits exist beyond which the motor behaves strangely, as the DC motor did. Also because of the internal feedback of RC servos, little error is present in position. Precision can be increased by reducing the frequency of the input clock, albeit at the cost of angular range.

## 5.2 Mechanical Setup

While the choice of the motor is crucial to the design of the RAMA system, the overall mechanical setup has to complement the decision. Our goal in design and assembly is threefold: simple, inexpensive, and low load for the motor. And the overall design can also be divided into four parts, which are the motor, the rack, the arm, and the mallet holder. The next figure shows a top view of our final design.

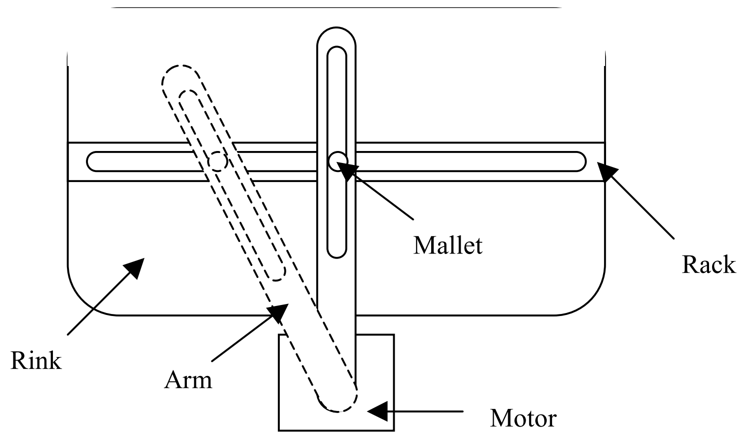



**Figure 29: Top View of Mechanical Setup**

Basically, the motor is the controlling centre. All motion of the RAMA system originates from this anchoring point. The motor provides angular motion of approximately 60 degrees. On top of the motor is where the arm is mounted. The arm is an extension of the spinning motor gear. The rack is a fixed piece upon which the arm slides on. The combination of arm and rack translates the angular motion into lateral motion. Attached to the arm-rack hinge point is the mallet holder. The mallet holder hangs from the rack on one end, and secures the mallet piece on the other end.

When in operation, the data processing unit will send a signal to the motor. The motor will interpret the signal and move to the commanded angular position. This will cause the arm to slide to a certain position on the rack. When the arm moves, the attached mallet holder will move accordingly. As a result, the RAMA system has the ability to intercept the incoming puck.

The description above is a brief introduction to the RAMA system. The following sections will provide a more detailed discussion on the specific parts of this system.

### 5.2.1 Rack

The rack is the piece of material on which the arm slides. In addition, the mallet holder hangs from the rack. Therefore, the rack must be stiff since it supports most of the weight of the RAMA system. Another major factor is friction. Since the arm moves on the rack, it must provide a sliding mechanism that minimizes the motor load.

Our choice is the lightweight KrisTrack pocket doorframe kit. The kit includes one rigid metal rail, and two wheeled sliders. They are shown in the following figures.

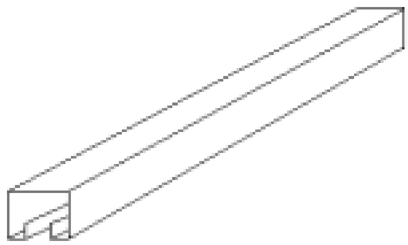


Figure 30: Simplified Isometric View of KrisTrack Rail

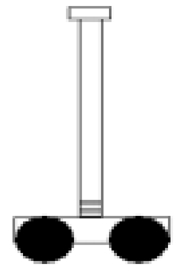


Figure 31: Side View of Modified KrisTrack Sliding Unit

While this domestic piece of equipment is not designed for our purpose, it satisfies many of our selection criteria. Here are the dimensions of the KrisTrack pocket doorframe kit.

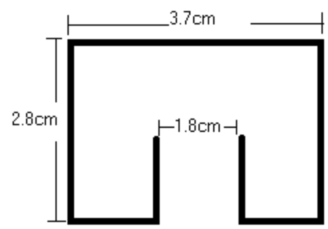



Figure 32 - Cross-sectional view of KrisTrack Rail

There are many advantages for using the KrisTrack kit. The rail is designed to be lightweight yet very rigid. The sliding unit has two wheels on each side. As a result, movement is nearly frictional and very straight. The total of four wheels also permits a large amount of weight to be suspended over the sliding unit.

The sliding unit is modified for our design, mainly for the purpose of connection to the mallet holder and the arm. This includes substituting the short spring-loaded screw in the original parts to the 10cm long steel screw. The head of the screw is attached to the mallet holder while the body of the screw provides means for attachment to the arm.

### 5.2.2 Arm

The arm is the connection between the rotating motor and the sliding unit on the rack. For this piece, many unique adjustments are needed on top of a normal rectangular metal piece. It must be lightweight to reduce the load on the motor. Its length must be able to vary for at least 10cm to accommodate for its swinging motion. Finally, it must have sufficient means to connect to the motor and the sliding unit.

Our choice is a modified version of the Accuride Model 2009-14 Variable Height Keyboard Slide. The original application is for sliding computer keyboards and pencil drawers, but its variable sliding length adjustment fits well with our design. A simplified diagram is shown below,

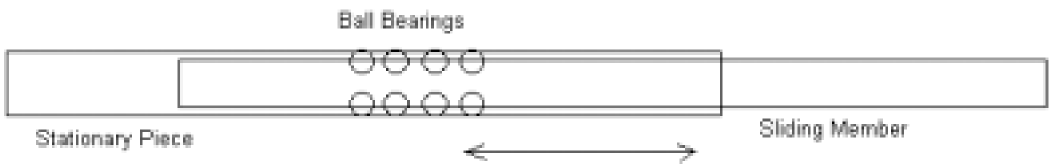



**Figure 33: Top View of Arm**

Here are some of its specifications,

| | |
|---|---|
| Length of Stationary Piece | 35.56cm (14.00") |
| Length of Slide Member | 26.67cm (10.50") |
| Maximum Load | 34.09kg (75lb) |
| Movement | Steel ball bearings |

**Table 7: Specification for Accuride Model 2009-14**

The Accuride slide is made of cold rolled steel and weights about 2lbs. However, its sliding member utilizes carburized steel ball bearings, which provide smooth operation. This quality is very advantageous since friction is assumed to attribute to most of the load on the motor.

Slight modifications will be needed to connect the arm piece to the motor and the sliding unit. This will involve drilling holes in the metal piece.

### 5.2.3 Mallet Holder

The mallet holder keeps the mallet in place, and moves according to the sliding unit of the rack. Our design consists of a metal angle and a plastic pipe fixer piece. The following figure shows the arrangement,

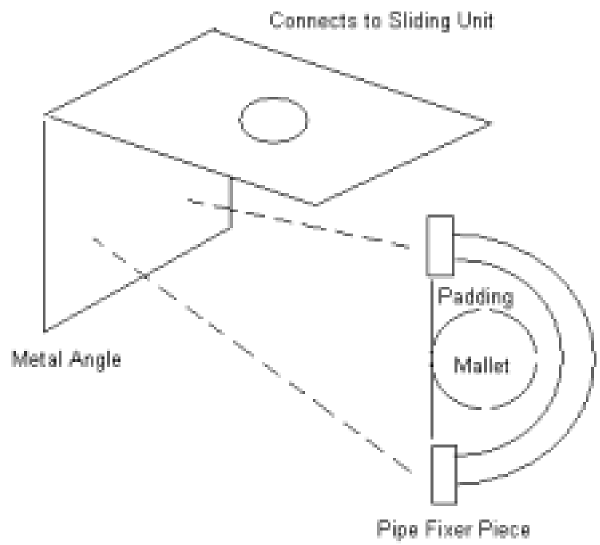



**Figure 34: Simplified Diagram of Mallet Holder**

Basically, the pipe fixer unit is used to hold the knob of the mallet holder to the metal angle. The fixer unit is large by intention, allowing possible use of spring for reacting action or padding for shock absorption. The metal angle piece has a hole in the top, which connects to the modified long rod that protrudes from the sliding unit.

### 5.2.4 Mounting Apparatus

In order to reduce software and hardware calibration effort, the hardware setup must be rigid placing all of the components of the RAMA within constant dimensions, thereby ensuring accuracy of mallet positioning during operation. A simple mounting apparatus is shown in Figure 35.

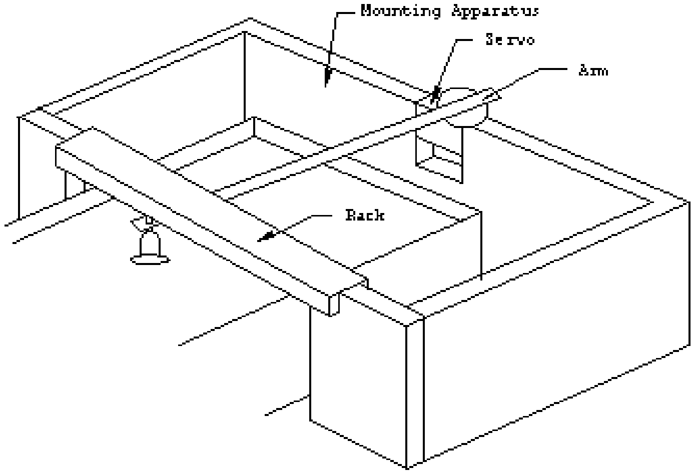
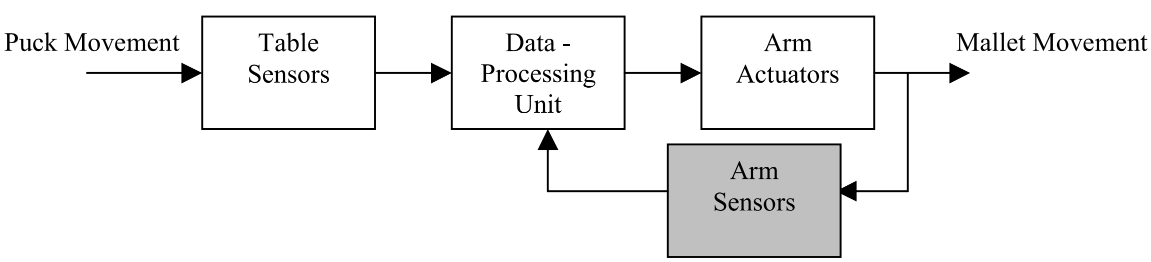



**Figure 35 - Mounting Apparatus**

It will be constructed mainly of wood and functions to secure the servo in a fixed position with respect to the rack. To increase tolerable puck speeds, we can set the entire apparatus back so that the mallet has more time to move before the puck crosses the rack line. The rack will rest above the rink bottom by approximately 10cm giving some clearance space for the mallet-holding mechanism.

The servo will be placed at a distance of approximately 30cm to 40cm from the center of the rack set in the middle of the mounting apparatus. From this position we utilize 60 degrees of the servo rotational range to cover the 47cm of distance along the length of the rack. With a zero-load velocity of about 60 degrees/0.2 seconds, we can achieve fairly good reaction times, given that, theoretically, no opposing torque is present on the arm since the rack slider is frictionless.

## 5.3 Arm Sensors




Sensors will be used as a feedback mechanism for the RAMA system. The sensors used will be the Fairchild QRB1113/1114 IR sensors, which is of the same type as the sensors used for puck detection. Three sensors will be used to track the motion of the arm. Their schematics and operation are very similar to the puck detection scheme.

Of the three sensors, one will be placed in the far-left end of the rack, to detect for the leftmost limit position for the arm. One will be placed in the far-right end of the rack, to detect for the rightmost limit position for the arm. When the arm is moving beneath either sensor, they are activated, and the signal is sent as feedback to the processing unit. Knowing that the arm is moving approaching the limiting position, the processing unit will halt all arm motion.

Another arm sensor will be placed in the centre on the rack. This sensor provides a safeguard mechanism for RC servo accuracy. After every motion, the arm is returned to its central position, as commanded by the control algorithm in the processing unit, which will be checked and calibrated by this sensor.

## 6 Control Algorithm

The mission of the control algorithm is to intercept the puck from entering the goal. The processing unit generates appropriate motor signals to react with any puck movements towards the goal. Figure 36 shows the high-level flow chart for the control algorithm.

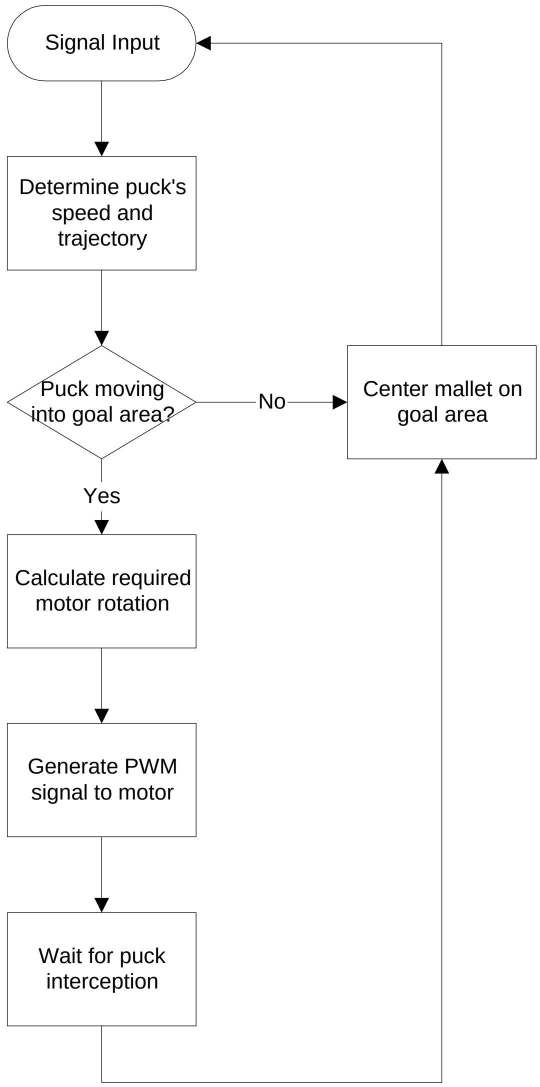



**Figure 36: Control Algorithm Flow Chart**

# 7 Testing

## 7.1 Table Sensors

### 7.1.1 Reference Level Calibration

1) After powering up the sensor units.
2) On the sensor unit, adjust the reference level potentiometer to a level where the "Calibration Required" LED just turns off.

NOTE: At the first use of equipment, please adjust the potentiometer such that the "Calibration Required" LED is turned on and then perform step 2.

### 7.1.2 Sensors Operation

1) Calibrate the reference level as described in 7.1.1.
2) Manually pass the puck under each sensor and observe the corresponding sensor test LED. The sensor test LED should turn on as the puck is present under that sensor.

## 7.2 Control Algorithm

### 7.2.1 Directed Straight Line Detection

1) Line up two test rails on the air hockey table so that the path is perpendicular to the short side of the table.
2) Place a puck between the two test rails and hit it towards the RAMA side.
3) Observe if the corresponding sensor test LEDs turn on.
4) Observe if the RAMA moves into the path to attempt a block.
5) Observe if the central arm feedback sensor is turned on when the RAMA retracts.
6) Repeat steps 1 to 5 with different test rails locations.

### 7.2.2 Directed Straight Line Detection (Angled)

1) Line up two test rails on the air hockey table so that an angled path forms from one end of the table to another end.
2) Place a puck between the two test rails and hit it towards the RAMA side.
3) Observe if the corresponding sensor test LEDs turn on.
4) Observe if the RAMA moves into the path to attempt a block.
5) Repeat steps 1 to 4 with different test rails locations and angles.

### 7.2.3 Directed Reflected Angle Detection

1) Line up two test rails on the air hockey table so that it directs the puck to the side of the table.
2) Place a puck between the two test rails and hit it towards the side of the table. The puck should hit the table side and get reflected out at the same incident angle towards the RAMA side.
3) Observe if the corresponding sensor test LEDs turn on.

4) Observe if the RAMA moves into the path to attempt a block.
5) Repeat steps 1 to 4 with different test rails locations and angles.

## 7.3 Processing Unit

### 7.3.1 Visual Inspection and Power Tests

1) Visually inspect the interface board and verify component presence on the board.
2) Manually probe power connections and verify a proper voltage is maintained at the regulator output
3) Verify the presence of a 1 MHz clock output at the test point provided.

### 7.3.2 Manual Arm Control

1) Depress the pushbuttons on the interface board to verify arm output controllability.

### 7.3.3 PC Connectivity Test

1) Verify that all ribbon cables and power cables connecting the various PC components are properly in place before powering the system.
2) Issue a send command and receive a data command to test the PC connectivity with the interface board.

## 7.4 RAMA System

The RAMA system will be tested in the following methods to ensure proper operation.

### 7.4.1 Motor Operation Test

1) Apply regulated 5V and ground to the power lines. Generate the PWM signal with a function generator, using the square wave settings and set the period to 15ms. Set the signal amplitude to 5V and set DC offset to 2.5V. Adjust the duty cycle so the pulse width is about 1.5ms. Apply PWM signal to the input line of the motor. The motor should be at its central position.
2) Adjust the duty cycle to change the pulse width to 1ms. The motor should be at its leftmost position, approximately 45 degrees counter-clockwise from its central position.
3) Adjust the duty cycle to change the pulse width to 2ms. The motor should be at its rightmost position, approximately 45 degrees clockwise from its central position.
4) Listen to the motor for extraneous noises to ensure the limits of motion are not exceeded.

### 7.4.2 Motor Precision Test

1) Using the same setup as the operation test, apply 1.500ms pulse to reset the motor.
2) Apply a 1.550ms pulse. The motor should have moved 5 degrees counter-clockwise.
3) Apply a 1.600ms pulse. The motor should have moved another 5 degrees counter-clockwise.
4) Apply a 1.500ms pulse. The motor should return to its original central position.

### 7.4.3 System Integrity Test

1) Detach the arm from the rack mechanism.
2) Slide the mallet holder on the rack by applying a small force. Observe the smooth sliding motion and ensure a clear path.
3) Fix the mallet holder by holding the holder-rack hinge. Simulate the force of an incoming puck on the mallet holder and inspect the mallet is secured by the holder.
4) Reattach the arm to the rack mechanism.
5) Apply a PWM signal, using the setup from motor operation test, to rotate the arm. Observe the arm sliding on the rack. Inspect for any unexpected movements from the fixed rack and motor.
6) Simulate the force of an incoming puck on the mallet holder. Inspect for any unexpected movements from the fixed rack and motor.

# 8 Appendix

## 8.1 Parts List

| Item | Manufacturer | Part Number | Quantity |
|---|---|---|---|
| Sensor System | | | |
| Quad Comparator | National Semiconductor | LM317 | 8 |
| Voltage Regulator | National Semiconductor | LM339 | 2 |
| Quad Operational Amplifier | National Semiconductor | LM324 | 8 |
| IR Sensors | Fairchild Semiconductor | QRB1113/1114 | 40 |
| 8-Channel Data Selector | | MC14512B | 5 |
| Diode | | | 40 |
| Capacitor | | | |
| Resistor | | | |
| Potentiometer | | | 3 |
| Processing Unit | | | |
| Adaptor, AC-DC, 9 V | Mindflight Technologies | | 1 |
| Capacitor, aluminum electrolytic | | 470 nF | 1 |
| Capacitor, aluminum electrolytic | | 22 nF | 1 |
| Capacitor, aluminum electrolytic | | 100 nF | 1 |
| Capacitor, mono-ceramic | | 220 uF | 8 |
| Connector, 10 pin, shrouded | Assmann Electronics | | 1 |
| Connector, 26 pin, shrouded | | | 2 |
| Connector, DC Power | Mode Electronics | | 1 |
| D-Sub Connector, right angled, 25 pin | Assmann Electronics | | 1 |
| LED, green | Mode Electronics | | 1 |
| LED, red | Mode Electronics | | 2 |
| PLCC IC Socket, 84- | Assmann | | 1 |

| | | | |
|---|---|---|---|
| pin | Electronics | | |
| Pushbutton | Omron, Inc. | B3F | 3 |
| Resistor, 0.25 W, 1 % | | 2.2 kΩ | 6 |
| Resistor, 0.25 W, 1 % | | 1 kΩ | 4 |

## 8.2 Schematics

### 8.2.1 Table Sensor Schematic

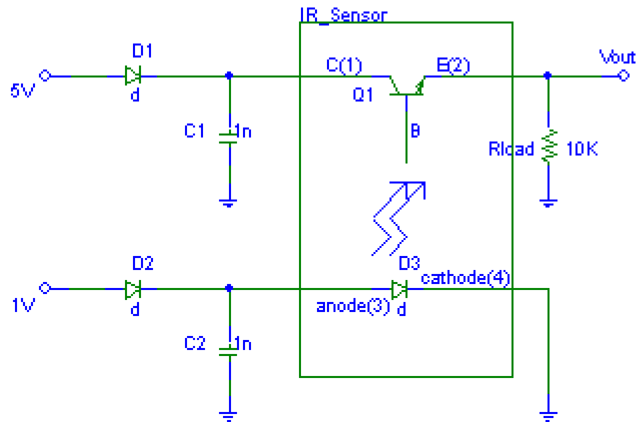



**Figure 37 : The Sensor Schematic Diagram**

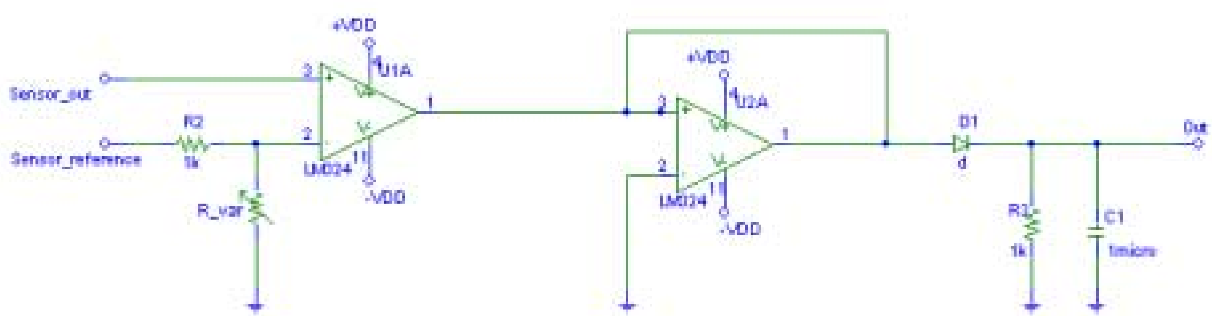



**Figure 38 : Analog to Digital Conversion Schematic Diagram**

### 8.2.2 Processing Unit Schematic