ProjectBot Solutions

March 26, 2021
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RE: ENSC 405W/440 Design Specification for PuckHoover™

Dear Dr. Scratchley,

The following document details the design specification for the PuckHoover™ project for ENSC 405W/440. The goal for our capstone project is to create an autonomous device which can efficiently pick up hockey pucks and stack them in an organized fashion to help save time during hockey games and training sessions.

These specifications will describe the various subsystems of the PuckHoover™. These include schematics and background theory for the hardware for the movement, lifting mechanism, and image detection. The document will also describe how these subsystems are integrated and interact with each other.

Our team would like to thank you in advance for taking the time to review our requirements specification. If you have any questions, please feel free to email me at tvt1@sfu.ca .

Sincerely,

Tina Vo Tran
CCO
ProjectBot Solutions

ProjectBot Solutions

PuckHoover™
Design Specifications

ENSC 405W
Spring 2021
Company 3
March 26, 2021

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Abstract

Hockey teams use a great number of pucks for their practices and exercises. Eventually all of these pucks must be collected by someone, however this process can be very long and tedious. We have the intention of creating an autonomous robot that can collect these pucks in a timely manner, named the PuckHoover™. This document will focus on discussing the design choices made for the proof-of-concept for the PuckHoover™ and comments will be made on the future iterations of the PuckHoover™, the engineering prototype, mass production unit, etc. The PuckHoover™ is comprised of 3 main subsystems, the lifting from the ice subsystem, the image recognition subsystem, and the autonomous movement system. This document can be used to identify the justification for the design solutions used in these subsystems and the relevant requirement specifications.

Contents

List of Figures

List of Tables

Version History

Version Number	Implemented by	Revision Date	Approved by	Approval Date	Reason
1.0	Hanaa Diab, Forbes Ng, Edwin Tam, Tina Tran, Jeffery Wael	03/26/21	Tina Tran	03/26/21	Initial Design Definition draft

Glossary

#	Number
AI	Artificial Intelligence
DC	Direct Current
Des	Design
EP	Engineering Prototype
GPIO	General-purpose Input/Output
LED	Light-emitting Diode
MCU	Micro-controller
POC	proof-of-concept
REQ	Requirement
RPM	Rotation per minute
Spec	Specification
Tech	Technical
UI	User Interface
USB	Universal Serial Bus

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1 Introduction

The PuckHoover™ is a robot that autonomously roams an ice rink using computer vision to identify hockey pucks, plan the fastest path to pick them up, and store them within the robot. At hockey training the average number of pucks scattered on the ice rink by the end of the training session is 100 pucks and Eventually, someone end up having to pick up each and every puck [1]. PuckHoover™ will helps hockey players to get rid of the time consuming and tedious process of collecting the pucks after training and allow them to maximize their training time. At ProjectBot Solution we aim to resolve this issue with our PuckHoover™ robot.

1.1 Scope of POC prototype

This document will go through the design specifications for the PuckHoover™ product. Each design specification will have its own justification for the design decision that was chosen. Each of the design specifications will also have a reference to a requirement specification that it is associated with.

The POC will cover the movement, lifting mechanism, and image detection for the prototype. The integration of these subsystems will be done for the engineering prototype as part of the AI of the robot.

1.2 Design Specification Classification

The following convention will be used to identify each design specification in this document:

Des [Section].[Subsection].[Specification Number]-[Design Stage]

In the interests of clarity, the design stages are classified as follows:
POC - proof-of-concept
EP - Engineering Prototype

1.3 System Overview

The PuckHoover™ can be broken down into several subsystems, the movement subsystem, the puck lifting subsystem, and puck detection system. The movement subsystem will be complete for the PoC using two driven wheels, one motor per wheel, allowing the robot to move forwards, backwards, left, and right. The lifting subsystem will be able to handle lifting one puck from the ice for the PoC version but for the engineering prototype, the necessary changes will made to the subsystem to be able to handle a continuous stream of pucks. As for the puck detection subsystem of the PoC, it will be able to detect a hockey puck on the ice using an image sensor and for engineering prototype. The detection system will be made more robust to be able identify the puck with other noise on the image. Such as the rink walls, line markings on the ice, and hockey nets.
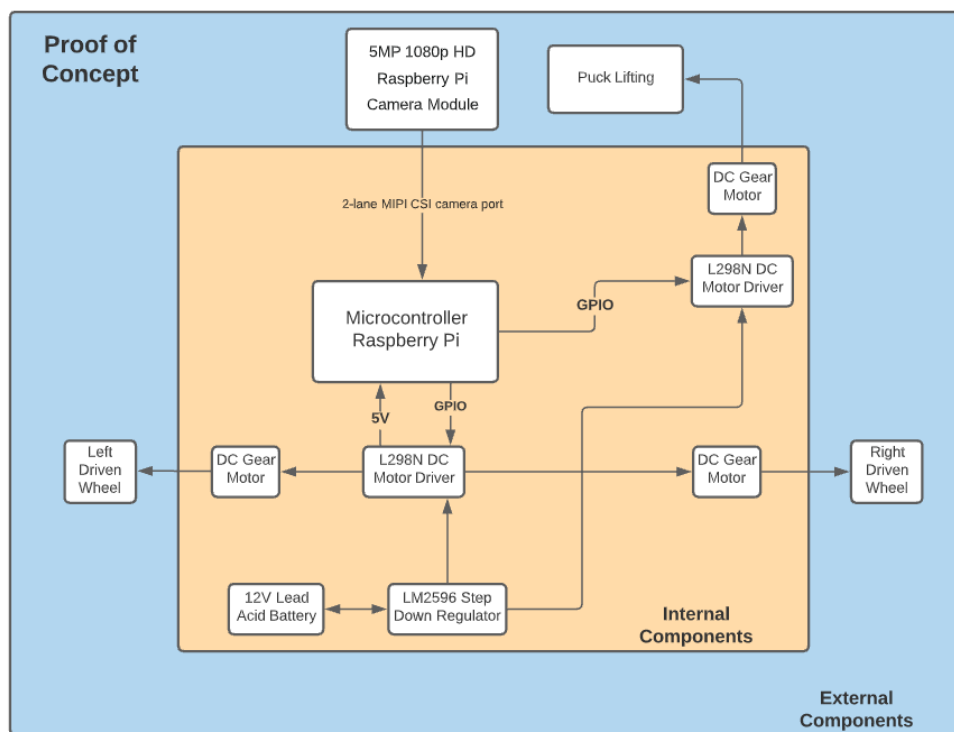
Figure 1.1: Proof-of-Concept Block Diagram
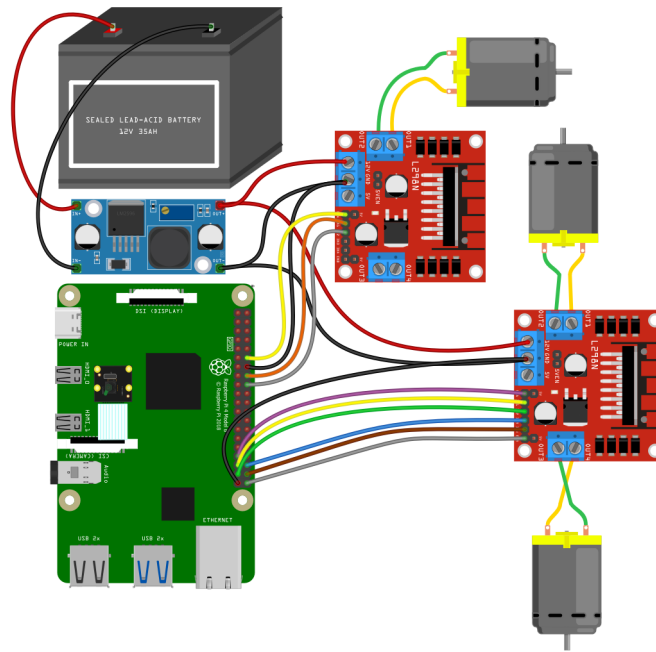
Figure 1.2: Proof-of-Concept Wiring Diagram

Figures 7.2 and 1.2 shows the PuckHoover™ PoC's block diagram and wiring diagram respectively. The diagrams shows how the two motors for the movement, the one motor for the puck lifting, and the camera for the puck detection that will be implemented in the PoC.
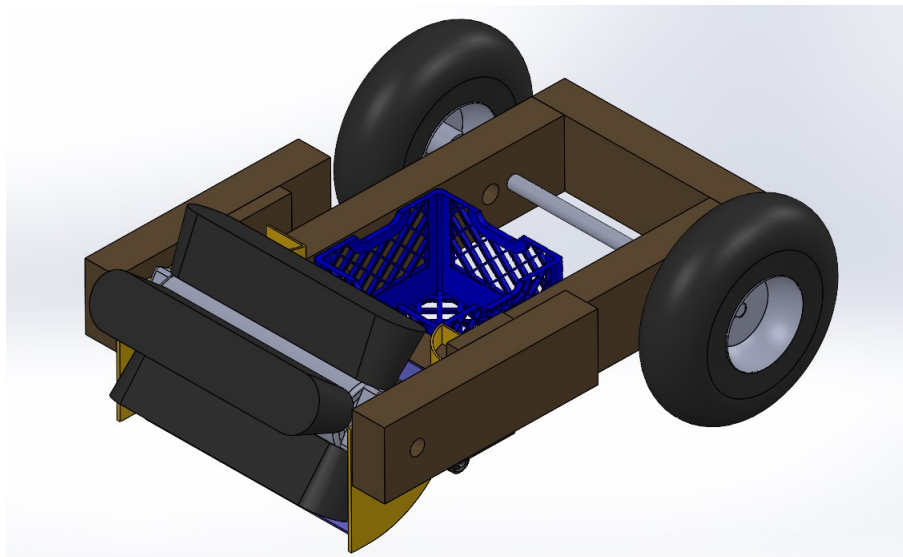
Figure 1.3: PuckHoover™ POC Hardware Design

In Figure 1.3, it shows the PuckHoover™ hardware design and its main components. It has

yellow guidance arms to guide the pucks into a brush roller that turns at the front to move the pucks up the yellow rounded ramp then into the blue basket. The chassis has two big wheels in the back and two casters in the front to add friction while ease the maneuvering of the robot.

2 Chassis Design

For the proof-of-concept, the frame of the PuckHoover™ will be manufactured out wood. This allows for a highly adaptable chassis during this period to find the best dimensions, along with having the rigidity to mount separate subsystems for testing. This option allows for a cost effective way to experiment and alter major components.

For the engineering prototype of the PuckHoover™, the findings gathered from the wooden chassis implementation will be re-implemented into a steel chassis finished with paint. Moisture and temperature is a challenge when working with wood regardless of lumbar treatment options. This is troublesome in an arena where the temperature of the storage facility and the ice rink can differ up to 15°C, which causes unpredictable coefficients of expansion in the material,and accelerates the growth of mildew and mold in extreme cases. A steel chassis with a painted finished can address the problems faced with wood, and provide a more structural rigid chassis.

Design Specification Reference	Description	Related Spec(s)
Des 2.1-POC	Material for the frame of the POC of the robot shall be wood.	Req 3.2.1.3 A The device must be built in a way that ease its modifications in the POC stage
Des 2.2-EP	Material for the frame of the EP of the robot shall be Steel.	Req 3.2.1.4 B The device must be water proof and can endure the ice rink environment

Table 2.1: Design Specifications for Chassis Design

3 Controllers

3.1 Micro-controller

For the brain of the PuckHoover™, there will be a MCU that controls all the mechanisms on the PuckHoover™, and the MCU should have to fulfill the following requirements. First of all, the MCU should have the ability of process images so that it can achieve the requirement of detecting pucks on ice, fulfilling Req. 3.2.1.3B, Req. 4.2.1B, and Req. 4.2.4F. Furthermore, multiple hardware

components will required to be controlled by multiple signals. Hence, the MCU shall have a sufficient amount of GPIO pins to support the control signals between hardware and software in the device. As the hardware on PuckHoover™ are controllable by software, MCU shall be programmable or have coding environment so that the software designers of ProjectBot Solution have the access to design and update the control as needed. Finally, the operating system and the coding environment of the MCU needs to be relatively easy to get support from the coding community which enables our software designers to request open-source libraries to implement the firmware.

Design Specification #	Description	Related Req Spec(s)
Des 3.1.1-POC	The micro-controller shall have the processing power to be able to process images.	Req 3.2.1.3 B Req 4.2.1 B
Des 3.1.2-POC	The micro-controller shall have more than 20 GPIO pins.	Req 4.2.4 F
Des 3.1.3-POC	The micro-controller shall be programmable.	Req 3.2.1.3 B Req 4.2.1 B Req 4.2.4 F
Des 3.1.4-POC	The operating system and coding environment shall be open-source and community supported.	Req 3.2.1.3 B Req 4.2.1 B Req 4.2.4 F

Table 3.1: Design Specifications of Micro-controller

Among many micro-controller options in the market, the Raspberry Pi 4 model B and Beagle-Bone Black were considered to be the micro-controller for the PuckHoover™. Both of controllers have ability to capture images, have more than 20 GPIO pins, Python compatibility, and both have community supported. However, both have different specifications that we have to decide which controller is beneficial to the device and which is not.

Part Specifications	Raspberry Pi 4 model B	BeagleBone Black
Processor	Broadcom BCM 2711 Quad-core Cortex-A72 64-bit 1.5GHz	Texas Instruments AM335X Cortex-A8 1GHz
Memory	4GB LPDDR4-3200 SDRAM	512MB DDR3 RAM
Storage	Depends on Micro-SD storage	4GB on-board flash storage
GPIO Pins	40-pin GPIO header	2x46-GPIO headers

Table 3.2: Design Options of Micro-controller [2][3]
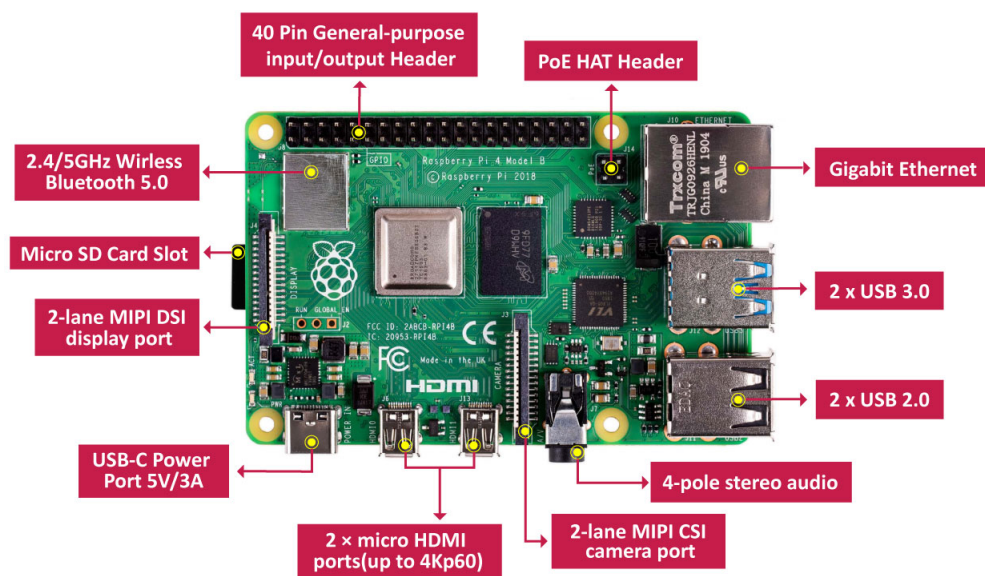
Figure 3.1: Raspberry Pi and its connection Ports [4]

Specifications

- Broadcom BCM2711, Quad core Cortex-A72 (ARM v8) 64-bit SoC @ 1.5GHz
- 2GB, 4GB or 8GB LPDDR4-3200 SDRAM (depending on model)
- 2.4 GHz and 5.0 GHz IEEE 802.11ac wireless, Bluetooth 5.0, BLE
- Gigabit Ethernet
- 2 USB 3.0 ports; 2 USB 2.0 ports.
- Raspberry Pi standard 40 pin GPIO header (fully backwards compatible with previous boards)
- 2 × micro-HDMI ports (up to 4kp60 supported)
- 2-lane MIPI DSI display port
- 2-lane MIPI CSI camera port
- 4-pole stereo audio and composite video port
- H.265 (4kp60 decode), H264 (1080p60 decode, 1080p30 encode)
- OpenGL ES 3.0 graphics
- Micro-SD card slot for loading operating system and data storage
- 5V DC via USB-C connector (minimum 3A*)
- 5V DC via GPIO header (minimum 3A*)
- Power over Ethernet (PoE) enabled (requires separate PoE HAT)
- Operating temperature: 0 – 50 degrees C ambient

* A good quality 2.5A power supply can be used if downstream USB peripherals consume less than 500mA in total.

Figure 3.2: Specs for the Raspberry Pi [4]

High processing speed and the more memory of the micro-controller would be important since this device has an image process feature. Hence, the Raspberry Pi 4 has the advantage of having faster processor and more memory than the BeagleBone Black. Furthermore, the Raspberry Pi 4 has the ability to read micro-SD cards, which can increase the system storage. However, the BeagleBone Black has 92 GPIO pins compared to only 40 pins on the Raspberry Pi. The BeagleBone Black has the advantage of connecting more signal controlled modules on a single micro-controller. Overall, the Raspberry Pi 4 model B would have a higher usability to the device than the BeagleBone Black due to its better processor, more memory, as well as micro-SD slot for expanding storage.

3.2 Motor Control Module
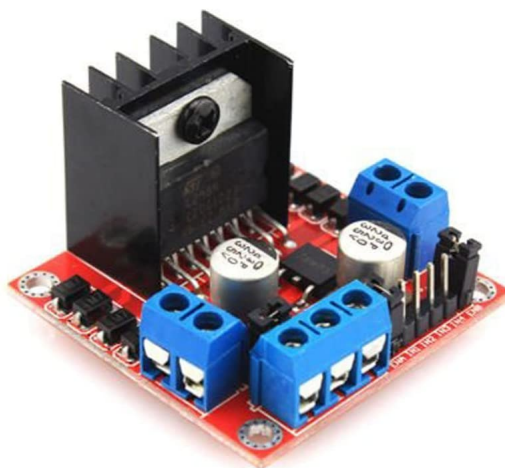
Specification -

Chip: L298N

Logic voltage: 5V

Logic current 0mA-36mA

Maximum power: 25W

Drive voltage: 5V-35V

Drive current: 2A(For each DC motor)

Dimension: 43*43*27mm/ 1.69*1.69*1.06 inch

Operating mode: Dual H-bridge driver (can drive 2 DC motors)

Figure 3.3: L298N Dual H Bridge Motor Driver Controller Board Module Source [5]

To allow the Raspberry Pi to interface with the dc motors, an L298N Dual H Bridge Motor Driver Controller Board Module is used. This module is able to control 2 dc motors at a time or one stepper motor. DC and stepper motors were considered and tested for the PoC so the L298N module was ideal for our purposes. This module may still be used for the the engineering prototype but be changed for the mass production model.

Design Specification #	Description	Tech Spec	Related Req Spec(s)
Des 3.2.1-POC	The control module shall have the ability to be powered by various voltage rating	Operating mode: Dual H-bridge driver (can drive 2 DC motors)	-
Des 3.2.2-POC	The control module shall be able to output sufficient power to the motors	Maximum power: 25W	Req 4.1.1.1 A

Table 3.3: Design Specifications of Motor Control Module

For the specifications of L298N control module, this module can be supplied up to 46 Volts, which will be useful for powering different types of motor at various power range. Despite of having two Amps maximum on the output supply current, this module can power and control the DC motors and the stepper motor of the PuckHoover™. Moreover, the L298N is compatible with Python and Raspberry Pi. The rotational speed and direction can be controlled by Python script via using the micro-controller. [6]

4 Lifting Mechanism System

ProjectBot Solutions has designed the hockey puck lifting mechanism to insure fast and reliable operation. In this section the hardware and software of the mechanism will be discussed.

4.1 Hardware Design

After going through multiple hardware mock-up designs we decided to use a tube of the same width of our robot frame to cover the largest area possible and be able to reduce the possibility of our system getting jammed by the pucks. The mechanism will consist of a brush roller that would spin in order to push the pucks up a rounded ramp into a basket that lies at the top of the ramp. Areas that are not covered by the brush roller will contain a guiding arm to guide the puck into the roller, as shown in Figure 4.1.
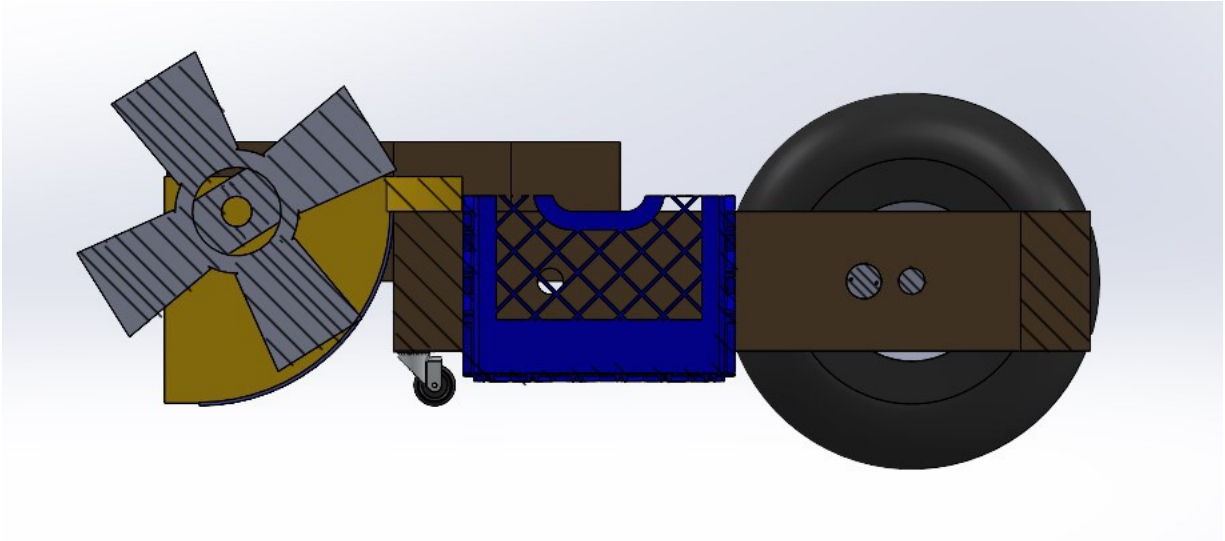
Figure 4.1: Cross sectional view of the PuckHoover™

This method creates a robot of about 50cm and small width of 40cm that would allow us to turn in the hockey goal (Req 4.1.2.3 A: A Device must be under 120 cm (4 feet) in width to fit through goal post) and go through the doorways and player entrances (Req 4.1.2.2 A: A Device must be under 60 cm (2 feet) in width to fit through doorways and player entrance gate). Meanwhile covering the whole width of the robot would also allow us to better achieve Req 3.2.1.1 B (Device should be able to collect and carry 25 to 50 (approx. 4.25 - 8.5kg) pucks).
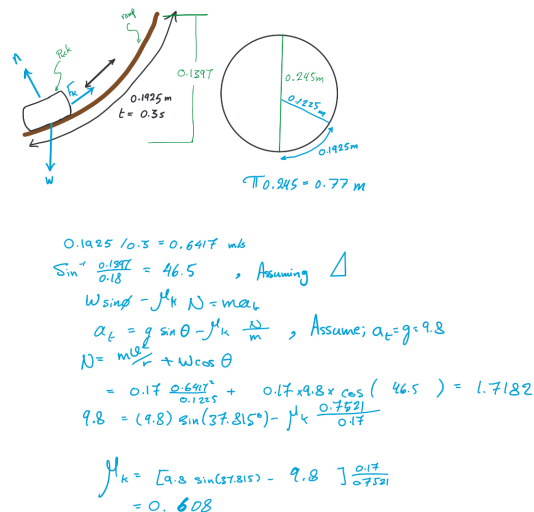
Figure 4.2: Calculating the puck ramp friction coefficient

4.1.1 Motor Specifications

To choose the motor for the lifting mechanism we needed to get the ice-puck friction and the puck-ramp friction to measure the required force needed in order to push the puck from the ice rink into the top of the ramp. To reduce the brush roller friction against the handle bearings will be used which allowed to neglect the friction in the following calculations.

The estimated friction coefficient for a puck on ice is 0.1 [7] (which allowed us to ignore it for these calculations), and the estimated friction coefficient is 0.608 as shown calculated in Figure 4.2. As the tube turn it would face some air drag force which is considered in a simple case of a tube with no brushes. In -20C the air density is 1.3943 [8]. The tube has a circular shape with drag coefficient of 0.47 [10]. Using the calculations shown in Figure 4.3 we get the torque required to push one puck up the ramp to be 0.456 N.m. Finally, the worse case scenario torque to push multiple pucks into the basket where found to be 2.41 N.m, as shown in Figure 4.4.
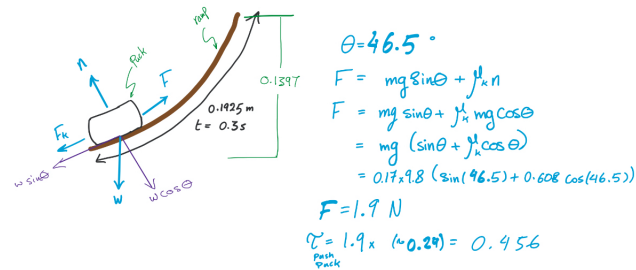
Figure 4.3: Calculating the puck up the ramp required torque

Going into the ramp calculations:

$$\Sigma F_x = 0$$
$$F_{ramp} + f_k = F_{tube}\sin\theta$$
$$F_{tube}\cos\theta + n = m\vec{g}$$
$$F_{ramp} + f_k\, mg - F_{tube}\sin\theta$$
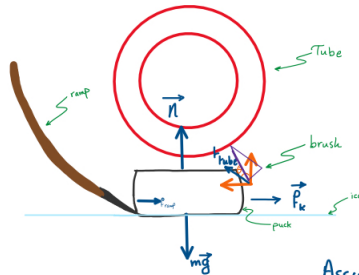
Assume ramp **Force** to be max of the Force needed to push the puck up.

$$F_{tube}\sin\theta = 1.9 + 0.1 \times 0.17 \times 9.8$$
$$F_{tube}\sin\theta = 2.0666$$

@ $\theta = 90°$ $F_{tube} = 2.0466\,N$ ⟵ Take the max

@ $\theta = 60°$ $F_{tube} = 1.7897\,N$

From these calculations we can get the motor torque needed for the lifting mechanism:

The cylindrical mount of brushes measurement:

$m_{cyl} \approx 2kg$, $r \approx 0.12\,m$, As we don't want high speed assume ($s = 1\,rps = 60\,rpm = 2\pi\,rad/s$)

As the robot won't collect pucks right away we can give acceleration time of 5s

Acceleration phase:

$$\tau = I_a$$
$$I = \tfrac{1}{2}mr^2 = 0.0144\,kg.m^2$$
$$a = \frac{2\pi}{5} = 1.2566\,m/s^2$$

∴ Acceleration torque : $\tau = 0.0181\,Nm$

Accounting for air drag

$$F_D = \tfrac{1}{2}C_d\,\rho v^2\,A \quad , \quad v = 2\pi rs = 2\pi(0.12)(1) = 0.24\pi \quad m/s$$
$$\rho_{20°C} = 1.3943\,kg/m^3 \;\; [wiki] \quad , \quad C_d = 0.47 \quad [wiki]$$
$$F_D = 0.22\,N \quad \leadsto \tau_D = \tfrac{2}{3}(0.3)(0.22) = 0.044\,Nm$$

# of pucks max on the ramp $\approx$ 9 pucks ⟶ 3 going into the ramp
                                     ⟶ 6 going up the ramp into the basket

$$F_{\Sigma Puck} = (3 \times 1.7897) + (6 \times 1.9) = 16.7691\,N$$

The Puck max Torque can then be: $\tau = Fr = 16.7691 \times (0.12 + 0.02) = 2.34767\,Nm$

∴ Max torque = 2.41 Nm

Figure 4.4: Calculating the collecting required torque

Giving the previous calculations to meet the requirements the required motor specifications are:

Des Spec #	Description
Des 4.1.1.1-POC	The motor will have a torque of at least 2.5 N.m
Des 4.1.1.2-POC	The motor will have a speed of at least 60RPM
Des 4.1.1.3-POC	The motor will have a maximum height of 8.89 cm (3.5 in) to fit on the frame hand
Des 4.1.1.4-POC	The motor will have a maximum of 12V to match our battery max
Des 4.1.1.5-POC	The motor will have a maximum of 3A to match our control module max
Des 4.1.1.6-POC	The motor will be able to function in the cold 20° temperature of the ice rink

Table 4.1: Design Options of the motor for the lifting mechanism system

In order to choose our motor, two different methods were searched, a brushed DC motor and a Stepper motor. The comparison is shown in the Table 4.2.

Part Specification	Geared DC motor	Stepper motor
Control	Easy to control and move both directions	Easy precise speed control using raspberry pi directly
Efficiency	70-80%	70%
Torque versus Speed	High torque art low speed	Excellent torque at low speed
Limitations	High noise, easily worn out and heat up due to brush heating	Some noise, consume constant max current and become hot, and may skip steps in high loads

Table 4.2: Comparing motors to choose the motor for the lifting mechanism system

Studying the Table 4.2, the stepper motor was chosen for our design as it has better control over speed and can be controlled via the Raspberry Pi. It also requires less maintenance and the design is not affected with the motor skipping steps at heavy loads as rotation precision is not required.

The stepper motor chosen to meet the motor requirement has the following dimensions shown in Figure 4.5 specification sheet shown in the Figure 4.6. The DC motor torque (0.314 N.m) does not reach the calculated required torque (2.41 N.m) and gear ratio of 1:9 will be applied to ensure

it can go above the calculated torque to account for calculations assumptions and life imperfections (2.82 N.m).

Dimension

Wiring Diagram

Figure 4.5: Stepper Motor Dimensions. Adapted from [9]

Item	Specifications
Step Angle	1.8°
Step Angle Accuracy	±5% (full step, no load)
Resistance Accuracy	±10%
Inductance Accuracy	±20%
Temperatru Rise	80°CMax. (rated current,2 phase on)
Ambient Temperatuar	−20°C~+50°C
Insulation Resistance	100M?Min.,500VDC
Dielectric Strength	500VAC/ for one minute
Shaft Radial Play	0.02Max. (450 g−load)
Shaft Axial Play	0.08Max. (450 g−load)
Max. radial force	28N (20mm foom the flange)
Max.axial force	10N

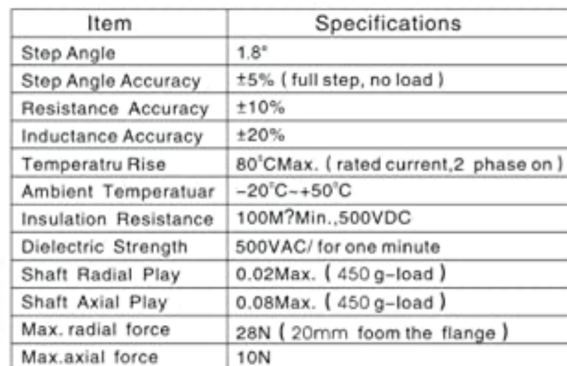| Model No	Rated Voltage	Current /phase	Resistance /phase	Inductance /phase	Holding Torque	#of Leads	Moment of intertia	Weinght	Orientation Torque	Length
	V	A	Ω	mH	Kg-cm		g-cm²	kg	g-cm	mm
SL42STH38-1684A	2.8	1.65	1.68	3.2	3.2	4	54	0.26	150	38

Figure 4.6: Stepper Motor Specification Sheet. Adapted from [9]

4.2   Software Design

The L298N module is used to take the instructions from the Raspberry Pi to control the motor attached to the brush roller. Since the brush roller spins constantly in the same direction, the motor will only need to be notified when it needs to be turned on and off.

4.3 Summary

Des Spec #	Description	Tech Spec	Corresponding Req
Des 4.1.1.1-POC	The motor will have a torque of 2.82 N.m	Holding Torque: 3.2Kgcm (0.3138 N.m) + Gear ratio of 9:1	Req 3.2.1.1 B Device should be able to carry 25 to 50 (approx. 4.25 - 8.5kg) pucks
Des 4.1.1.2-POC	The motor will have a speed of 60RPM in maximum load	Step Angle of 1.8°	Req 3.2.1.1 B Device should be able to carry 25 to 50 (approx. 4.25 - 8.5kg) pucks
Des 4.1.1.3-POC	The motor have a height of 3.8 cm (1.5 in) and will fit on the frame hand	Dimensions show the length to be 38mm	Req 3.2.3.1 B Device must be waterproof and shockproof for durability purposes (e.g. lifting the device out of the rink and collecting pucks with a lot of ice), and Req 4.1.2.2 A Device must be under 60 cm (2 feet) in width to fit through doorways and player entrance gate
Des 4.1.1.4-POC	The motor will have a maximum of 12V to match our battery max	Rated voltage = 2.8V	–
Des 4.1.1.5-POC	The motor will have a maximum of 3A to match our control module max	Current = 1.65	–
Des 4.1.1.6-POC	The motor will be able to function in the cold 20° temperature of the ice rink	Ambient Tempreture = -20°C +50°C	Req 4.1.1.3 A Device must be operational in low temperatures to handle the coldness of the rink

Table 4.3: Comparing motors to choose the motor for the lifting mechanism system

5   Image Recognition System

5.1   Software Design

The computer vision method that is used for the puck detection system is the blob detector from the Open CV library. Since a hockey puck is a solid black cylindrical disk, identifying a puck can be broken down into identifying black blobs in the image followed by further identifying if any of the existing black blobs are hockey pucks. For the PoC, the vision system will focus on identifying the black blobs then for the engineering prototype it will classify these black blobs as pucks, complying with the beta phase requirement Req 4.2.1 B that states the "Software must be able to find a puck on the ice in an image, 1 to 2 m (3 to 6 ft) in front of the robot". Open CV works for our purposes because it has a tune-able blob detector built into the library. Additionally it is python library that can be easily downloaded and used on the Raspberry Pi.

Design Specification #	Description	Tech Spec	Related Req Spec(s)
Des 5.1-POC	Vision system is capable of identifying black blobs in an image from the camera feed	-	Req 4.2.1 B
Des 5.2-POC	The vision system software is compatible with the Raspberry Pi 4	-	Req 4.2.1 B
Des 5.3-EP	The vision system is capable of classifying a black blob as a puck or not a puck	-	Req 4.2.1 B

Table 5.1: Image Recognition System - Software Design

5.2   Image Sensor
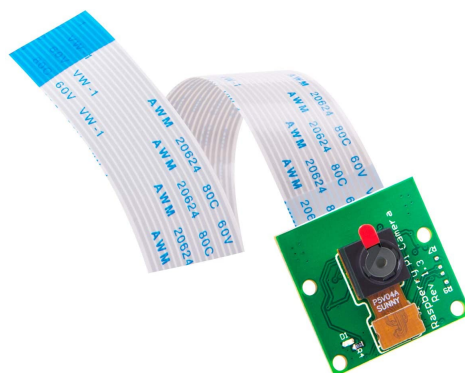
Specifications:

Manufacturer: AuviPal
Model: Pi-CAM-5MP
Sensor: 5 Megapixels Omnivision OV5647
Interface: CSI
Still picture resolution: 2592 x 1944
Video Resolution: 1080p@30fps, 720p@60fps, 480p@90fps
Focus Mode: fixed-focus
Output Pins: 15Pin
Output Signal: YCBCR4:2:2,RGB565,RAWRGB
Optical Configuation: 4G+IR650
Module Size: 25*24*9mm
Ribbon Length: 6 inch

Figure 5.1: Raspberry Pi Camera Module with OV5647 Sensor [11]

The image sensor used is the 5MP 1080p HD Raspberry Pi Camera Module with OV5647 Sensor, as seen in figure 5.1. This image sensor connects to the Raspberry Pi via the 2-lane MIPI CSI camera port which is a proprietary camera port on the Raspberry Pi that ensures maximized performance and minimum latency for the sensor which helps fulfill requirement Req 4.2.2 B which states the "Image processing must be fast enough to process updated images of the robot as it moves". This image sensor has a still picture resolution of 2592 x 1944 but has a max video resolution of 1080p which is what will be used for the PuckHoover™ . For the image detection, the image sensor should have a high enough resolution to allow the software to accurately detect the puck.

Design Specification #	Description	Tech Spec	Related Req Spec(s)
Des 5.2.1-POC	Compatible with the Raspberry Pi 4	Interface: CSI	Req 4.2.1 B
Des 5.2.2-POC	Capable of resolutions high enough to identify the features of a hockey puck	Video Resolution: 1080p@30fps, 720p@60fps, 480p@90fps	Req 4.2.1 B

Table 5.2: Image Recognition System - Image Sensor Design Specifications

6 Driving System

6.1 Hardware Design

For the alpha phase, we chose to use an economical high torque DC motor which has workable performance characteristics to what we want to achieve with the final prototype.

Figure 6.1: 12V 200RPM DC Motor - 0.832 N· m Peak Torque [12]

The motors and wheels are currently connected via a gear system that has a gear ratio of 3:1. The same tires will be used for both the POC and prototype, which is a rubber pneumatic wheels that is derive from a hand trolley.

6.1.1 POC Torque and Speed Rating

$$GearRatio = \frac{DrivenGearTeeth}{DrivingGearTeeth} = \frac{45}{15} = 3$$

$$WheelTorque = 2 \cdot GearRatio \cdot MotorTorque = 2 \cdot 3 \cdot 0.832N \cdot m = 5N \cdot m$$

$$Wheelspeed = \frac{MaxMotorRPM}{GearRatio} = 200/3 = 66.667RPM$$

$$WheelCircumference = 2 \cdot \pi \cdot 5" = 31.416in = 0.798m$$

$$TheoreticalRobotSpeed = \frac{WheelRPM \cdot WheelCircumference}{60seconds} = 0.887m/s$$

Currently, the theoretical top speed of the robot is 0.887 m/s with a max torque rating of 5 N·m. These specifications are adequate for POC phase testing before we acquire the finalized motor in EP phase.

6.1.2 Prototype Torque and Speed Rating

To gain the best understanding of the motor specification needed for the final PuckHoover™ prototype, the finalized testing from the POC can derive how well the wheels can find traction on the ice. Depending on the traction solution resulting from testing, it will be directly related to rolling resistance the motors will need to overcome[13].

Des Spec #	Description	Tech Spec	Corresponding Req
Des 6.2.1-POC	The wheels will be outfitted with small spikes to maintain traction in all scenarios	-	Req 3.2.2.1 B
Des 6.2.2-EP	The driven motors should provide enough torque to overcome rolling resistance and the weight of the robot	-	Req 3.2.2.2 B

Table 6.1: Driving System - Driving System Design Specifications

6.2 Software Design

The movement of the PuckHoover™ 's POC be will be controlled remotely using a gaming controller which will allow for manual control. The movement of the POC will be made manual to run unit tests such as, moving under load, moving in and around the hockey net, etc. The movement of the PuckHoover™ will then be converted to autonomous controls for the engineering prototype. This software is the logic that will translate the user/autonomous control to the appropriate signals for the driving motors, which relates to requirement Req 4.1.1.2 A Which states that the "Device must use motors to move around the hockey ice rink".

Design Specification #	Description	Related Req Spec(s)
Des 6.2.1-POC	The movement of the PuckHoover™ is controlled using move forward, move backwards, turn left, and turn right commands	Req 4.1.1.2 A
Des 6.2.2-POC	The movement of the of PuckHoover™ is controlled remotely	Req 4.1.1.2 A
Des 6.2.3-EP	The movement of the PuckHoover™ is controlled autonomously	Req 4.1.1.2 A

Table 6.2: Driving System - Software Design Specifications

7 Power Supply

For the power source of the PuckHoover™ , two 12V 7Ah sealed lead acid batteries connected in parallel are chosen for their affordability, robustness in cold environments and charge stability. Lithium polymer cells were also considered for their high energy density, packaging, light weight, and faster charging rate. However, to match the same power capacity, a lithium polymer system would cost three times more compared to a similar lead acid system due to more expensive Battery Management Systems (BMS), and cell prices. Currently, the charge time for the lead acid system takes 3-4 hours from empty to full. Although this is a relatively long charging time, this fits the use case of the product provided that it is only deployed once at the end of a practice session. The system monitors the battery voltage for charge, and is capable of alerting the user before the batteries reach an low voltage which may be damaging for the batteries.

Figure 7.1: 12V 7Ah Sealed Lead Acid Battery

Two DC-DC voltage step down buck converter is used to regulate the output of the battery

in order to protect the internal components. When lead acid batteries are fully charged, they can exhibit a max voltage of up to 14V, which can damage sensitive control modules. Currently, one buck converter is set to 12V for the L298 H-bridge modules to drive the motors, and the other is set to 5V for the Raspberry Pi.

Description

Features/Specification
Car regulator , solar photovoltaic, wind power and other applications of voltage instability .
Technical parameters
Model Specification:Automatic Buck module
Module Properties:Non- isolated boost (BOOST)
Rectification:Non- Synchronous Rectification
Input Range:3.8V- 32V
Output Range:1.25V-35V
Input Current:3A (max),no-load 18mA (5V input , 8V output, no-load is less than 18mA. Higher the voltage , the greater the load current ,)
Conversion efficiency:<94% (greater the pressure, the lower the efficiency)
Switching frequency:400KHz
Output Ripple:50mV (the higher the voltage , the greater the current , the greater the ripple)
Load Regulation:± 0.5%
Voltage Regulation:± 0.5%
Operating Temperature:-40 →+85
Dimensions:48mm * 25mm * 14mm (L * W * H)

Character:	Boost
Input Voltage:	5V - 32V
Output Voltage:	1.25V - 40V
Output Current	4A(MAX)
Conversion efficiency:	<94%
Switching Frequency:	50mV
Output Ripple:	+0.5%/-0.5%
Voltage Regulation Factor:	+0.5%/-0.5%
Working Temperature:	~ -45C - +85C
Size:	48.1 x 24.9 x 1.40mm (LxWxH)
Weight:	~17.4g

Figure 7.2: DC-DC Voltage Step-Down Buck Converter [14]

A 6A automotive style fuse is connected from the 12V battery to the buck converters to protect the internal components from excessive current draws. The fuse can act as a fail-safe in the event of a high current draw (eg. The pick-up mechanism jamming/snagging on non-puck objects.

8   Conclusion

The progress on the driving and puck lifting subsystems are the main focus for the PoC for the PuckHoover™ . For the PoC the puck lifting subsystem will be able to collect one puck at a time using brushes on a cylindrical roller to move the puck up the ramp and into the robot. As for the driving subsystem, it will be able to handle the load of the robot which include the circuitry, battery, frame and puck lifter. Now that the design specifications for the PoC have been determined, it will streamline the process of transitioning the PuckHoover™ from the proof-of-concept to the engineering prototype.

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A   Appendix A: User interface design

A.1   Introduction

ProjectBot Solutions is designing PuckHoover™ , a robot that would automatically move around the ice rink and collect hockey pucks after hockey training sessions. This would save the hockey players time and remove the tedious process of collecting the pucks off the ice. The hardware design of this robot would focus on functionality, ease of use, and safety of the user.

A.1.1   Purpose

This appendix will illustrate the user interface and appearance design of the PuckHoover™ . It will provide an overview of the design decisions and components for the proof-of-concept and prototype hardware design.

A.1.2   Scope

This appendix will discuss, graphical presentation, user analysis, technical analysis, engineering standards, analytical usability and empirical usability testings. The technical analysis of the Puck-Hoover™ will use the "Seven Elements of UI Interaction" as a reference for evaluation.

A.2   Graphical Presentation

In order to operate the PuckHoover™ to collect pucks from ice rink, the user will interact with the PuckHoover™ via the buttons on device body. The figures below illustrate the location of the buttons as well as the handle location and the orientation. The feature of each buttons is explained in Section 4 - Technical Analysis.

The main buttons for the normal routine are shown in Figure 2.1. With the buttons located at the back of the device, user will be able to access to buttons without risking the robot collides to the user. In case of an emergency, the user can cease the operation via the power button, or user can press the emergency button to stop the device before it causes personal injury. Moreover, the handle mounted on the body, shown in Figure 2.2, gives access to the user to move the Puck-Hoover™ manually. Finally, Figure 2.3 illustrates the remote control of the PuckHoover™ , and the buttons on the control are color-coded and labelled such that user will be able to turn on or off the device as well as to start or pause the PuckHoover™ operation.
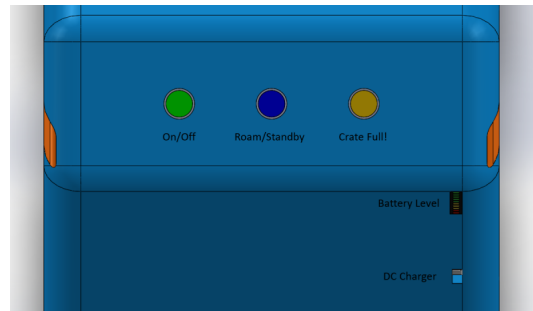
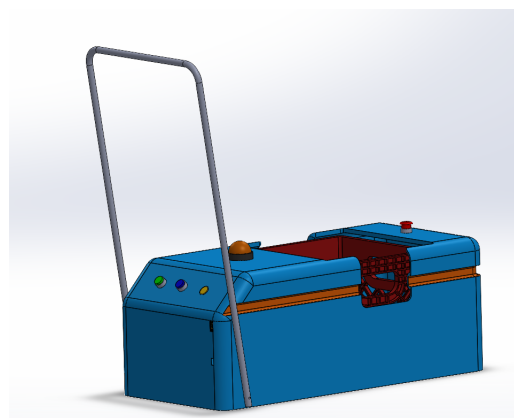Figure A.1: Back of the PuckHoover™ showing the buttons

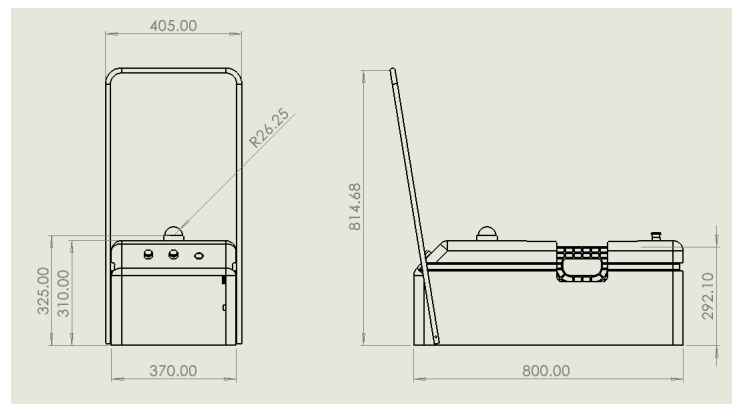

Figure A.2: Back of the PuckHoover™

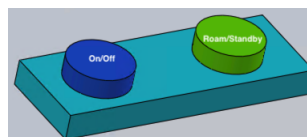Figure A.3: PuckHoover™ Dimensions (in mm)

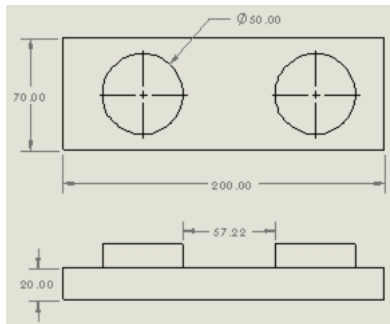Figure A.4: PuckHoover™ Remote Control

Figure A.5: PuckHoover™ Remote Control Dimensions (in mm)

A.3   User Analysis

The main users of the PuckHoover™ are the Hockey players from different age and experiences. We are aiming for the user to be at least 16 years old to be able to run the device alone. The user need to be able to lift a mass of at least 15kg to ensure no physical harm upon themselves. The user also needs to be aware to not unload/load the puck storage or remove/put the PuckHoover™ into the ice rink while wearing ice skates to ensure their safety and ease of usability. The user should not need much background knowledge of robotic devices to be able to learn and control the device. Functioning the device should be relatively similar to other robotic devices such as iRobot's Roomba.

A.4   Technical Analysis

The "Seven Elements of UI Interaction" stated in the book "The Design of EveryDay Things" will be used as the basis for the technical analysis of the user interface and appearance. The seven elements of UI interaction are the following: discovery, feedback, conceptual models, affordance, signifiers, mappings, and constraints.

Discoverability
The discoverability is the extent to which the user can tell what can be done with the PuckHoover™
. There are three buttons on top of the robot, "Power On/Off", "Roam/Stand-by", and "Emergency Stop" buttons are clearly labeled and easily visible.

Feedback
The feedback is the signals that the PuckHoover™ will output given the inputs from the user or events that occur.The power on/off and roam/standby buttons on the remote controller will have LEDs that will light up to indicate that the buttons has been pressed. The PuckHoover™ will have 5 lights of various sizes to provide visual feedback and they intuitively display the status of the robot. Below are details for each of the lights on the PuckHoover™ :

- Power On/Off LED

    – The color of the LED will depend on the power status of the PuckHoover™ . This LED

will be green when the PuckHoover™ is on and it will be off when the PuckHoover™ is off.

- Roaming / Stand-by LED

    - The color of this LED will depend on the current working state of the PuckHoover™ This LED will be solid blue when it is roaming the ice looking for a puck and it will be flashing blue when it is at a standby state.

- Battery LED

    - The indicator has an array of 10 LEDs, 5 are green, 3 yellow, and 2 red. The 10 LEDs each represent the 10% of the battery level (i.e. when the battery is at 90% capacity, 4 green, 3 yellow, and 2 red will be on). When the battery is charging, the highest level LED will be flashing until the battery is fully charged.

- Puck Storage

    - This LED will be yellow when the puck storage container is full, otherwise, this LED will be off.

- Warning / Safety Light

    - A bigger orange light will be on top of the PuckHoover™ rotating the shined light in a 360 radius around the robot to ensure that users are aware of it when it is on the ice.

Conceptual Models

Conceptual Models are concepts that relate to leveraging prior knowledge of a system to create a more intuitive experience for the user. The PuckHoover™ will behave and operate like an autonomous vacuum cleaner that is now found in many households, thus allowing the user to interface with the PuckHoover™ in a familiar way by letting it autonomously to collect.

Affordances

The affordances are the designs implemented to allow certain actions to be possible. The puck storage container of the PuckeHoover will be removable and it will have handles on the container to ensure that it is easily carry-able. Handles on one end of the PuckHoover™ will be used to allow lifting and pulling the robot on two of the wheels. The emergency stop button will be placed on the top and near the front of the robot to allow the user to turn it off before the robot collides with the user.

Signifiers

The signifiers are used to emphasize the implemented discoverability and feedback aspects of the PuckHoover™ . Symbols above their respective LEDs provide more details about the information that the LED is conveying. The power symbol will be above the on/off LED, the text "Status" will be above the roaming/standby LED, the battery will a lightning bolt will be above the battery LEDs, and a symbol of stacked pucks will be on puck storage LED.

Mappings

The mapping of designs involves the relationship between the interfaces on the PuckHoover™ and their functions. The mentioned LED signifier symbols are placed immediately beside their respective LEDs to ensure clarity and the LEDs are the back lights for their respective buttons, power

on/of and roam/standby.

Constraints

The constraints are the limitations of the PuckHoover™ that the user abides by and is limited to. The PuckHoover™ will not be able to enter the state in which it roams for puck if the puck storage container is full of pucks. The PuckHoover™ 's battery must be charged to the minimum operation threshold to maintain the lifetime of the battery.

A.5 Engineering Standards

A.5.1 Robotic Standards

Standard	Description
1872-2015	IEEE Standard Ontologies for Robotics and Automation [15]
1012-2016	IEEE Standard for System, Software, and Hardware Verification and Validation [16]

Table A.1: Robotic Standards

A.5.2 Electrical Standards

Standard	Description
CSA C22.1:21	Canadian Electrical Code, Part I (25th Edition), Safety Standard for Electrical Installations [17]
CSA C22.2 NO. 0.23:15	General requirements for battery-powered appliances [18]

Table A.2: Electrical Standard

A.5.3 Safety Standard

Standard	Description
CAN/CSA-IEC 31010:20	Risk management - Risk assessment techniques (Adopted IEC 31010:2019, second edition, 2019-06) [19]

Table A.3: Safety Standard

A.5.4 Software Standards

Standard	Description
P2755.2/D2, Sept 2020	IEEE Approved Draft Recommended Practice for Implementation and Management Methodology for Software Based Intelligent Process Automation (SBIPA) [20]
1633-2016	IEEE Recommended Practice on Software Reliability [21]

Table A.4: Software Standards

A.6 Analytical Usability Testing

Before presenting the device to users, a series of usability tests should be undergone by the engineers from ProjectBot Solutions. The user interfaces will be tested to make sure all the functionalities of the device are functional as planned before users use the PuckHoover™.

A.6.1 Designer Testing

1. Connect PuckHoover™ to charger

2. Pause at anytime for user to unload PuckHoover™

3. Emergency stop is accessible to all users in urgent situations

4. PuckHoover™ goes into standby mode after being idle for 5 minutes

5. Battery of the PuckHoover™ charges to maximum capacity after each use

A.6.2 Heuristic Evaluation

We will analyse the problems that might occur while using the PuckHoover™ . Our team will run these to ensure no major issues would occur when the user interact with the PuckHoover™ .

A.6.2.1 proof-of-concept:

1. PuckHoover™ moves and turns on the ice using two driven motors

2. The pickup mechanism is robust and repeatable in picking up pucks in various ice conditions

3. Pucks collected are stored efficiently in the puck storage.

A.6.2.2 Prototype:

1. PuckHoover™ detects pucks against the ice via it's vision system

2. PuckHoover™ stops if it detects obstruction or persons

3. The device is capable at alerting the user when the crate is full

4. PuckHoover™ can identify the goalpost and navigate outside and inside to pick up pucks

A.7 Empirical Usability Testing

To get the customer point of view, ProjectBot Solution will ask people with no prior knowledge of the PuckHoover™ to operate the it in some scenarios. The scenarios will consist of running the device, unloading and loading the puck basket, and pausing the robot in case of an emergency. After the test run, the participants will be given a UI form and will be asked for a feedback about the device interfaces as shown in the figures below.

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Figure A.6: User interface form

A.8   Conclusion

The PuckHoover™ is a robot operated by a hockey player that can be from 16 to 40 years old giving the user interface design a significant importance. Having a good user interface design would ease the device usage which would increase the probability of consistent usage and more recommendations for others. In this appendix the main components of the user interface design are discussed to ensure the ease and comfortable experience for all users. For the POC we aim to have part of the control panel, remote control interface, ease of loading and unloading the puck storage, handle, and emergency stop button. For the prototype version we will make sure to meet the rest of the UI requirements to ensure the ease of use and convenience of our product.

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B   Appendix B: Supporting Test Plans

Test Conductor: Date:

Lifting Mechanism System

Design Specification Reference	Test Plan	Result	Comment
Des 4.1.1.1-POC	A load will be applied to the motor to see if it will have a torque of at least 2.5 N.m	Pass / Fail	
Des 4.1.1.2-POC	The motor will be powered up to see if it has a speed of at least 60RPM	Pass / Fail	
Des 4.1.1.4-POC	The motor will be measured to ensure it as has a maximum of 12V to match our battery max	Pass / Fail	
Des 4.1.1.5-POC	The motor will be measured to ensured it has a maximum of 3A to match our control module max	Pass / Fail	
Des 4.1.1.6-POC	The motor will be powered up in a 20° temperature environment to ensure that it is capable of functioning at the cold temperatures of the ice rink	Pass / Fail	

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Test Conductor: Date:

Image Recognition System

Design Specification Reference	Test Plan	Result	Comment
Des 5.1-POC	The vision system will be given images of pucks to ensure that it is capable of identifying black blobs in an image from the camera feed	Pass / Fail	
Des 5.3-EP	The vision system will be given varying images of pucks and other different black objects to ensure it is capable of classifying a black blob as a puck or not a puck	Pass / Fail	

Test Conductor: Date:

Driving System

Design Specification Reference	Test Plan	Result	Comment
Des 6.2.1-POC	The movement of the Puck-Hoover™ works as intended, using move forward, move backwards, turn left, and turn right commands	Pass / Fail	
Des 6.2.3-EP	The movement of the Puck-Hoover™ is controlled autonomously when set to a roam start	Pass / Fail	

C   Appendix C: Alternative Solutions

C.1   Computer Vision Library

C.1.1   TensorFlow

TensorFlow is a machine learning library which supports object detection and it does so by first training the model that will be used for the to detect objects in an image. With enough training data, this option can be better at classifying a puck. However, given the lack of complexity in the appearance of a puck, a custom trained model may not be required. The TensorFlow Library does include list of already known objects that the object detection can classify but a hockey puck is not one of the known objects.

C.1.2   JeVois

JeVois is a all-in-one smart machine vision system which contains a video sensor, quad core CPU, USB video, and serial port. It is intended to be a plug and play solution to computer vision. The main issue with this option is that it costs $50 for something that can be done with a cheaper sensor and a free computer vision library. The JeVois is also intended to be used for a wide range of applications which result in it containing features that would not be needed for our purposes.

C.2   Image Sensors

C.2.1   KEYESTUDIO Fisheye Wide Angle Lens with OV5647 Sensor

This KeyeStudio module uses the same sensor as the one that we decided to use but it is equipped with a fish eye lens. This option was considered because the wide angle lens could help the Puck-Hoover™ detect pucks but after further deliberation, it was decided not to chose this option. The main concern was about how much the fish eye lens will distort the image which will affect the vision systems image processing. Additionally, the wide angle aspect of the may not an advantage depending on how the detection and autonomous moving algorithms will operate.

C.2.2   Arducam 8MP 1080P USB Camera Module

The Arducam is a USB camera that should have similar specs to the OV5647 Sensor but has a much high price point due to how generally the camera can be used. This option was not used because it will have a lower performance with the raspberry pi since it connects via USB, compared to the sensor that we are using which connects directly to the board via the 2-lane MIPI CSI camera port.

C.2.3 Lithium Ion and Polymer

Lithium batteries whether it be in the form of lithium ion cells or lithium polymer pouch cells are a great fit in RC applications due to their light weight, and rapid charge rate. The main concern is the battery's highly volatile nature in extreme temperatures and would not be suitable for our purposes. Significant weather proofing and temperature monitoring will need to be done to ensure the health of the battery is maintained during the operation of the PuckHoover™