Auto-Ball Enterprises

Mar. 26, 2021

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RE: ENSC 405 Design Specification for the Floor General

Please find attached to this letter the design specification document for the Floor General. This reimagined basketball shooting machine aims to provide players with a dynamic, game-like experience. Traditional shooting machines confine players to basic, preset passing patterns, whereas our device will use a combination of motion detection and gesture recognition to adapt to the athlete's custom workout.

This document will detail the different subsystems of the Floor General shooting machine. Technical design aspects including circuit diagrams, mechanical drawings and system hardware will be provided. Justifications for design choices, along with subsystem interactions will also be discussed. The development of the design with respect to the different phases: PoC, prototype and final product will also be distinguished and defined herein.

Auto-Ball Enterprises's team is made up of 6 committed senior engineering students with backgrounds in computer engineering, electronics, and engineering physics. Our diverse multidisciplinary team consists of Rameshwar Kannan, Karan Kakkar, Tal Kazakov, Ramish Khan, Santhosh Nandakumar, and Simone Neufeld.

Thank you for taking the time to review our design specification document. If you have any questions or concerns please contact our CCO, Karan Kakkar at kkakkar@sfu.ca, or contact me with any questions through my canvas inbox.

Sincerely,
Rameshwar Kannan
Chief Executive Officer

K. Rameshwar

AUTO-BALL ENTERPRISES

Design Specification

Company 24

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Abstract

The Floor General is a new, sensor assisted basketball shooting system that is currently under development by Auto-Ball Enterprises. The Floor General takes the standard functionality of a classic basketball shooting machine and enhances it through automation. The device will be able to track a player on the basketball court and deliver a pass to the player upon command. The development team at Auto-Ball Enterprises seeks to remove the constraints of current, pre-programmed basketball shooting machines to better simulate a game-like experience for players while training.

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Glossary of Terms, Abbreviations, and Acronyms

Baud Rate	Number of signal or symbol changes that occur per second
CSI	Camera Serial Interface
DSI	Display Serial Interface
FOV	Field of View
FP	Final Product
GPIO	General Purpose Input/Output
Lazy Susan	A revolving mechanism with a platform mounted on top
Lidar	Light Detection and Ranging
PC	Proof-of-Concept
PT	Prototype
Three Point Line	A semicircle line 23ft away from the basketball
USB	Universal Serial Bus

1 Introduction

1.1 Background

Basketball is one of the most popular sports in the world with a following of approximately 825 million worldwide [1]. Shooting the basketball is a fundamental skill requiring countless hours of practice. Current shooting machines like “Dr.Dish” [2] and “The Gun” [3] (fig. 1.1.1), can pass the ball to a player but only based on a pre-programmed pattern. This greatly limits the freedom of a practicing player to move around the court and shoot from their desired shooting locations.

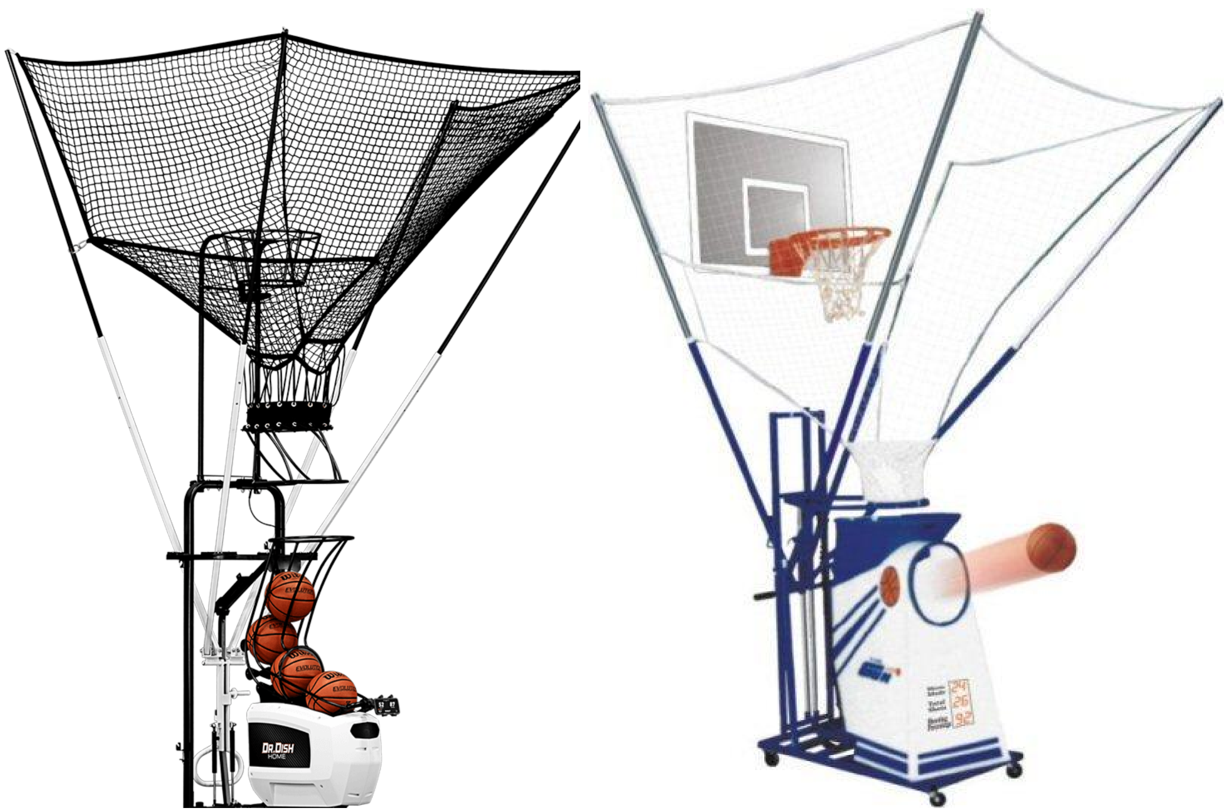

Figure 1.1: Dr. Dish (left) and The Gun (right)

Auto-Ball Enterprises is developing a reimagined basketball shooting machine, featuring real-time tracking of a player’s position enabling automatic passing of the ball to the player’s desired shooting location. The shooting machine will track the players position on the court using a LiDar sensor, take shooting cues/gestures from the player and automatically dispense the optimal pass.

The system will be able to target players within a reasonable shooting distance (within 30 ft) and swivel the launcher to their position. This would effectively allow players to customize their training routines. This product will aim to maximize the training potential of highschool, collegiate, and professional athletes.

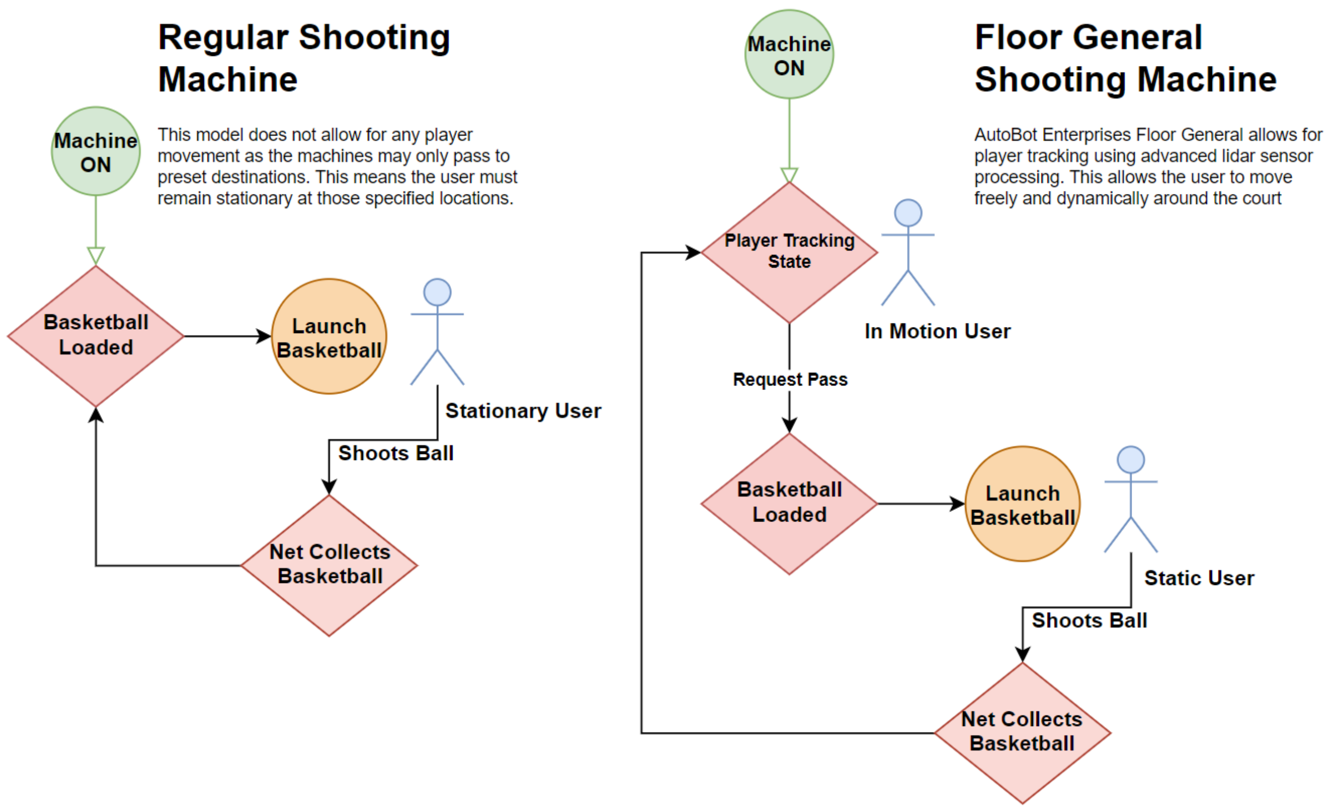

Figure 1.2: Regular Machines (left) and The Floor General (right) Block Diagrams

1.2 Scope

This document outlines the technical aspects of the design for the Floor General shooting machine. The specifications provided here in, describe the different design choices that were made to fulfill the functional requirements as laid out in the Floor General Requirement Specifications document [2]. A detailed description of the components used in each major subsystem along with justifications for using said components will be provided. Furthermore, key design decisions will also be justified.

Details on the user interface and appearance of the product are described in Appendix A of this document. The subsequent supporting test plans to verify the design and functionality of the subsystems are included in Appendix B.

1.3 Intended Audience

This document is mainly for the developers responsible for the design and implementation of the Floor General. These design specifications are meant to serve as a guideline and a reference for the development of the product. This use of this document will entail the quality and functionality of the Floor General shooting machine.

1.4 Design Specification Classification

For the purposes of clarity, readability and conciseness, the following convention will be used to label the design specifications throughout this document:

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

The different design stages will be denoted as follows:

PC	Proof-of-Concept Prototype
PT	Prototype
FP	Final Product

Table 1.1: Naming Convention for Product Stages

2 Design Overview

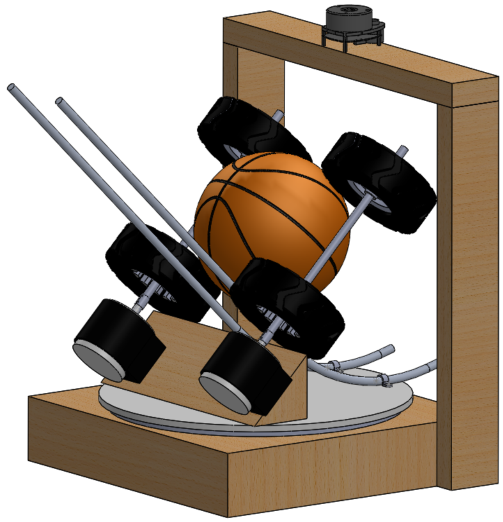

Figure 2.1: Model of the Proof-of-Concept Design

The *Floor General* consists of several main components: the launcher system, the swivelling component, the motion detection and ranging system, and the pass request signaller. The four components are highlighted above in *figure 3* whilst the general design specifications of the device are listed below in table x. Each subsystem has its unique performance specifications which must be fulfilled for the final product of the device.

Design ID	Description	Corresponding Requirement ID(s)
Des. 2.1.1-	The launching system shall be able to launch an adult sized basketball up to 7 meters horizontally	Req. 3.1.2-SY-PC
Des. 2.1.2-	The Motion Detection and Ranging system shall be able to detect a player movement within a 180 degree semi-circle up to 10 meters.	Req. 3.1.1-SY-PC
Des. 2.1.3-	The swivelling system shall be able to rotate to any angular position between 0 - 180° in the horizontal plane	Req. 3.3.1-SY-PC
Des. 2.1.4-	The pass request signaller must be able to initiate the launching system to pass the user the basketball	Req. 3.2.1-SY-PT

Table 2.1: General Design Requirements

The device will be designed such that it is easy to relocate and setup at any given basketball net. The various components of the system will be protected with covering to keep the electrical components, microcontrollers, and connections intact.

3 Hardware Design

3.1 Microprocessor

Floor General will use Raspberry Pi 3B to execute the system software. The main reason behind the selection of Raspberry Pi was due to its faster clock speed and its ability to run multiple programs concurrently. Although the motors used in Floor General are not impacted by the type of processor being used, certain design requirements should be met for the proper working of Lidar. Lidar communicates with the microprocessor through a serial port at a baud rate of 115200 bps. Higher values for receiver buffer size and clock speed are required to prevent the loss of data. A Raspberry Pi was able to resolve this problem at an affordable cost. In addition, easier integration of components such as a touch screen display, the servo and DC motors using the General Purpose Input/Output (GPIO) pins and bluetooth. Shooting data will be stored on the sd card or on an external storage device such as a USB. The reasons mentioned above make the Raspberry Pi an ideal choice for Floor General.

Figure 3.1: Raspberry Pi B

Design ID	Description	Corresponding Requirement ID(s)
Des. 3.1.1-PC	The microprocessor shall be powered by a 5V DC supply	Req. 3.3.1-EL-PC
Des. 3.1.2-PC	The Raspberry Pi shall provide DSI ports to incorporate a touch screen display	Req. 3.6.8-SY-FP
Des. 3.1.3- PC	The clock speed of the Raspberry Pi shall be 1.2 GHz	Req. 3.1.4-SY-PC

Table 3.1: Design Specifications for the Microprocessor

3.2 LiDar Sensor

The RPLidar A1M8 was chosen to detect the player's location in terms of an angle and radius at a very high resolution with respect to our application. The RPLidar sensor has a range of 0.15 meters to 12 meters and the radius of the 3-point line in an NBA regulation compliant basketball court is 7.24 meters [6]. The Floor General is meant for players to practice shooting from all their common places which are contained in a semicircle with a radius a little larger than the 3-point line. Thus the semicircle within which players are expected to spend the majority of their time practicing fits well within the effective range of the RPLidar. The Floor General is not meant to be used to practice shots further than the RPLidar's effective range. Shots such as the "Half Court Heave" taken from half court (14.325 meters) at the end of a period make up a small percentage of the overall number of shots taken due to the small chance of the ball going in the basket. Professional players prefer not to even attempt it as it reduces their shooting average [7]. The radius measurements taken by the RPLidar have an error of 1% of the radius. At the max expected shooting radius of 8 meters, the error will be ±8 centimeters. This is acceptable for launching a basketball as players rarely receive perfect passes and develop the habit of making micro adjustments to correct for imperfections in a pass.

Design ID	Description	Corresponding Requirement ID(s)
Des. 3.2.1-PC	The RPLidar shall measure the radius and angle for 180 field of view	Req. 3.1.1-SY-PC Req. 3.1.3-SY-PC
Des. 3.2.2-PC	The Lidar shall measure the distance to the player standing 0.15m - 7m away from the device	Req. 3.1.2-SY-PC
Des. 3.2.3-PC	The Lidar shall operate continuously and collect 8000 sample measurements per second	Req. 3.1.4-SY-PC

Table 3.2: Design Specifications for the Lidar Sensor

3.3 Launching Mechanism

The launching mechanism is responsible for delivering the pass to the player. It will be mounted atop the swivelling mechanism, allowing it to pass the ball to the player within a 180° field of view. The launching mechanism is made up of the following components.

1) Brushed DC Motor
2) Speed Controller
3) Flywheel Assembly
4) Launching Guides

The integration of these components form the launching mechanism. The assembly of the launching mechanism will be shown after each individual component is discussed.

3.3.1 DC Motor

The AmpFlow P40-350 pancake brushed DC motor was chosen as the launching motor (fig.3.2). This is a powerful motor at a reasonable price from a reputable manufacturer. The dimensions of the motor are given in figure 3.3 below.

Figure 3.2: AmpFlow P40-350 Pancake Brushed DC Motor

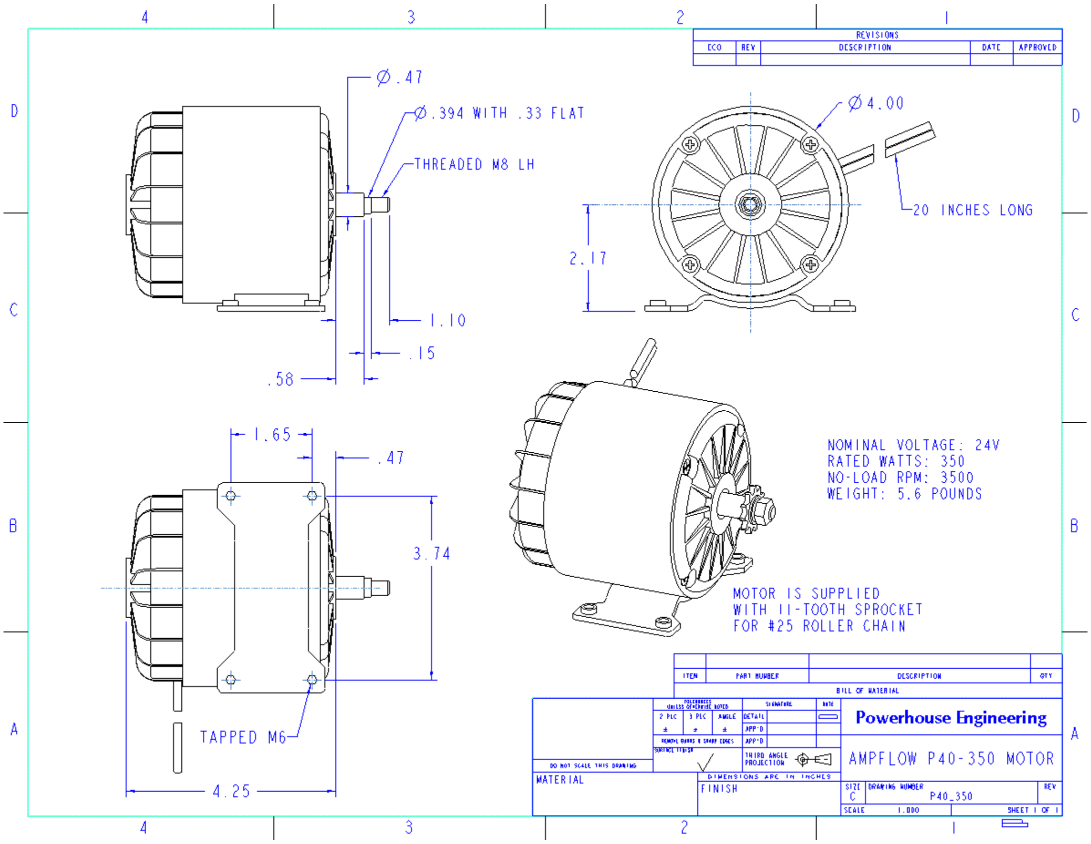

Figure 3.3: AmpFlow P40-350 Pancake Brushed DC Motor Diagram

Motors with similar power ratings have been used in commercial products to launch soccer balls, which are a similar size and weight compared to basketballs. However, a rough calculation is required to ascertain the applicability of this motor for launching a basketball.

To pass the ball to the 3 point line ,which is 23ft (8m) from the basket, the motor must launch the ball at approximately 9m/s. This number comes from the range equation for a body following projectile motion.

$$Range = \frac{v_o^2 \cdot sin(2\theta)}{g}$$

Here v_o is the initial velocity,θis the launch angle and g is the acceleration due to gravity. Taking θ= 45°, g = 10 m/s^2 and substituting 8m for the range, we obtain an initial velocity for the ball at 9m/s.

Therefore, the launching motor must be able to accelerate the basketball, from rest, to a velocity of slightly greater than 9m/s, say 10m/s, to reach the user at chest level standing at the 3 point line.

One approach to determine whether the AmpFlow motor is powerful enough to launch the basketball is to apply the conservation of angular momentum. While the interaction between the flywheel and the ball is not ideal, i.e, the momentum of the flywheel does not strictly transfer over to the basketball with 100% efficiency, a rough estimate of the basketballs launch velocity can be made.

For this calculation, the angular momentum of the flywheel is calculated and all of the momentum from the flywheel is assumed to transfer over to the basketball. The angular momentum, L, of a rotating body is given by the equation x, where I is the moment of inertia of the object and ωis the angular velocity of the body.

$$L = I \cdot \omega$$

The inertia of the flywheel is given by the following equation where M is the mass of the flywheel and R is the radius of the flywheel.

$$I = \frac{1}{2}MR^2$$

Next the angular momentum of the flywheel and the ball are equated. The ball is treated as a point particle with mass m and radius R away from the center of the flywheel.

$$\frac{1}{2}MR^2\omega = mvR$$

Substituting M=1kg, m=0.5kg, R=0.1m, ω=300rad/s we can solve for v, the launch velocity of the basketball.

$$v = \frac{1}{2m}MR\omega = (1)(0.1)(200)/(2 \cdot 0.5) = 30\frac{m}{s}$$

Assuming half the angular momentum from the flywheel is transferred to the ball, the basketball will be launched at 15m/s. This figure is close to our targeted launch velocity of 10 m/s. Of course, numerous simplifications have been made in this calculation, however, this calculation should justify the use of the 350W AmpFlow motor we shortlisted.

Figure 3.4, below shows some key motor parameters when operating at 24V. Since the torque applied by a flywheel on a motor will be approximately ~0.8 Nm, running the motor at ~3000 RPM, the power supply must be able to supply 13A of current to each motor. and 250W of power continuously to the motor.

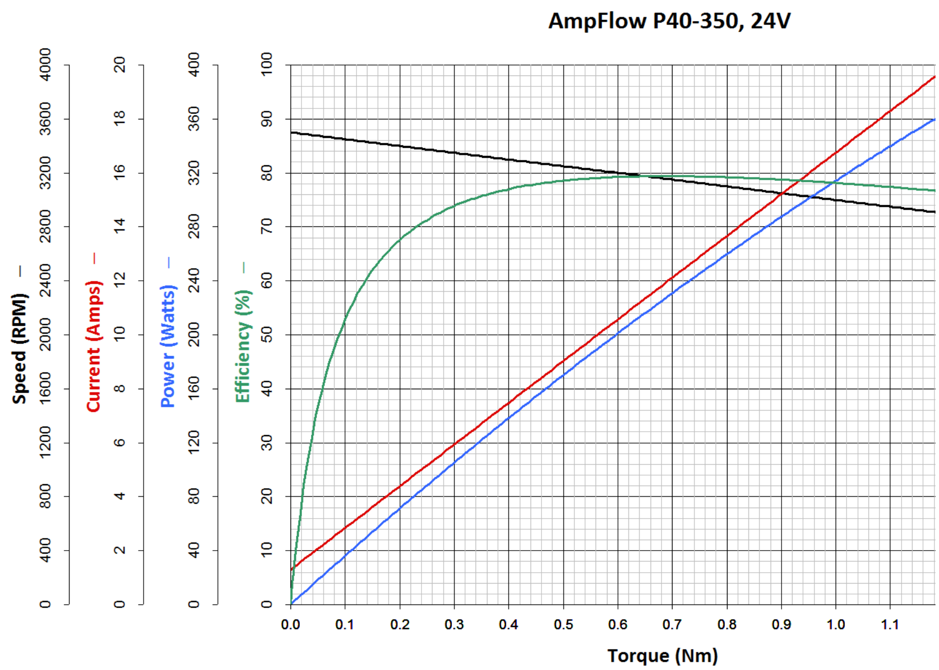

Figure 3.4: Speed, Current, Power, and Efficiency versus Torque for the 350W AmpFlow Motor

3.3.2 Speed Controller

The Sabertooth 2x32 dual motor driver by Dimension Engineering was chosen as the speed controller for the AmpFlow motor discussed in section 3.3.1. This dual channel motor driver is capable of supplying 32 amps to two motors, with peak currents up to 64 amps per motor. It uses regenerative drive and braking for efficient operation.

In addition to the standard operating modes, this driver features additional signal inputs and power outputs. The auxiliary power outputs can be configured to allow the Sabertooth 2x32 to operate from a power supply independent of a parallel battery. The board layout for the Sabertooth 2x32 motor driver is shown in figure 3.5 below and the mechanical and electrical specifications are listed in table 3.3 and 3.4 respectively.

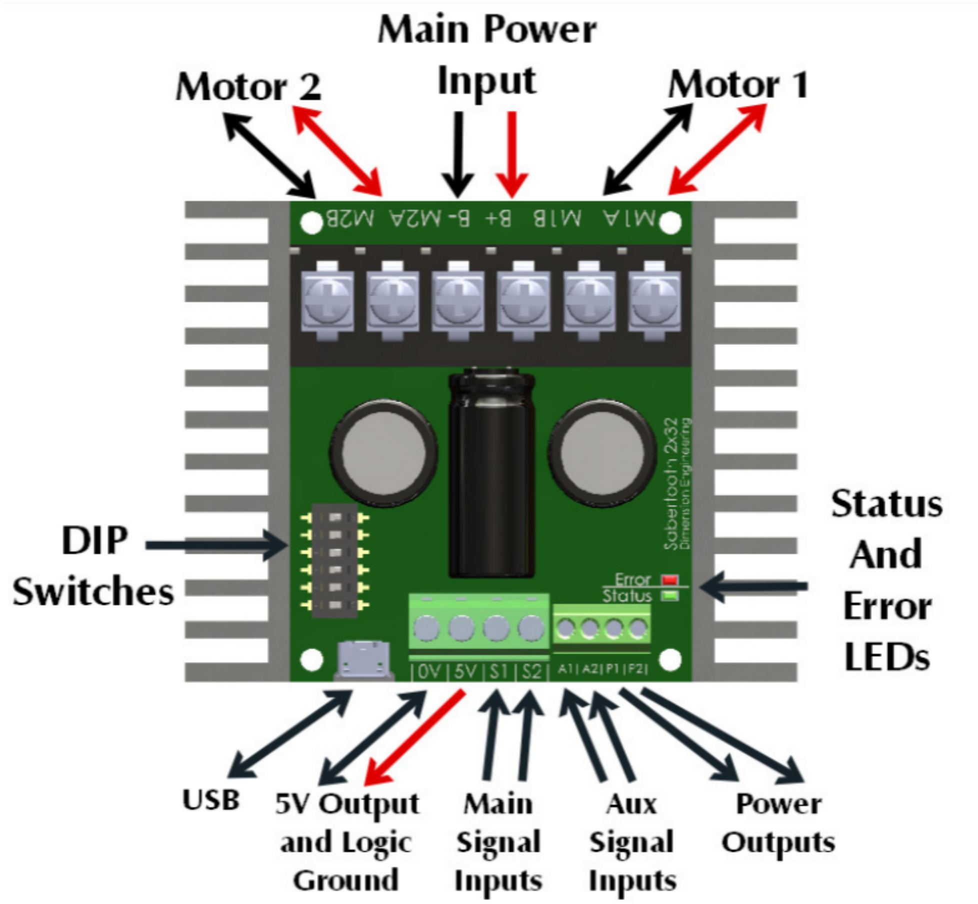

Figure 3.5: Sabertooth 2x32 Motor Driver Board Layout

Mechanical Specifications	
Dimensions	2.75” x 3.5” x 1.0” (70mm x 90 mm x 26mm)
Weight	4.5 ounces (125 g)
Wire Size, Battery	10
Wire Size, Motors	12
Wire Signal	24
Operating Temperature	25°C

Table 3.3: Mechanical Specifications for the Sabertooth Dual Motor Driver

Electrical Specifications			
	Minimum	Typical	Maximum
Input Voltage, B+ and B-	6.0 V	12 V or 24 V	33.6 V
Continuous Output Current, M1 and M2	-	-	32 A
Peak Output Current, M1 and M2	-	-	64 A
Output Voltage M1 and M2	95% of input voltage	-	95% of input voltage
Voltage, P1 and P2	0 V	-	Input voltage + 0.3 V
Output Current, P1 and P2	-	-	8 A, sink only
Output Voltage, 5 V	4.85 V	5 V	5.15 V
Output Current, 5 V	-	-	1 A
Input Voltage, S1 and S2	-0.3 V	0 V - 5 V	12 V
Input Voltage, A1 and A2	-0.3 V	0 V - 5 V	12 V
Output Voltage S2 and A2	0 V	-	3.5 V

Table 3.4: Electrical Specifications for the Sabertooth Dual Motor Driver

This dual motor driver was chosen specifically for its ability to supply high currents to the DC Motors. A less powerful dual driver could have been used namely the Sabertooth 2x25 however the cost of the Sabertooth 2x32 was the same. Also, in case larger, more powerful motors are needed to launch the ball the Sabertooth 2x32 would most likely be capable of supplying the requisite.

3.3.3 Flywheel Assembly

To launch the ball, a system of wheels attached to motors is used. In figure 3.6, one motor rotates clockwise, and the other counter-clockwise, which in turn, causes the two pairs of wheels to rotate and launch the ball.

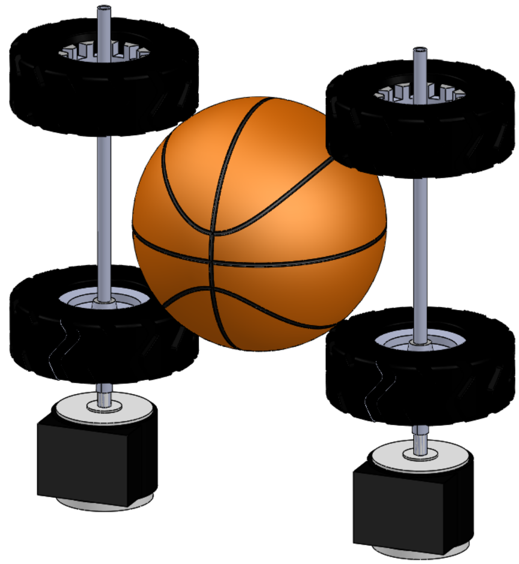

Figure 3.6: Flywheel Assembly

The motor used is the AmpFlow brushed DC motor described in section 3.3.1. The wheels used are shown below in figure 3.7. They have an 8 inch diameter and weigh approximately 385 grams each. The required torque estimated to spin one flywheel was found to be ~0.8 Nm.

Figure 3.7: Wheels Used to Launch Basketball

3.3.4 Launching Guides

To ensure that the ball launches at a 45° angle [Des. 3.3.2-PT], aluminum launching guides are mounted to the full assembly. These guides sit in between the two halves of the flywheel assembly, as to not interfere with launching the ball.

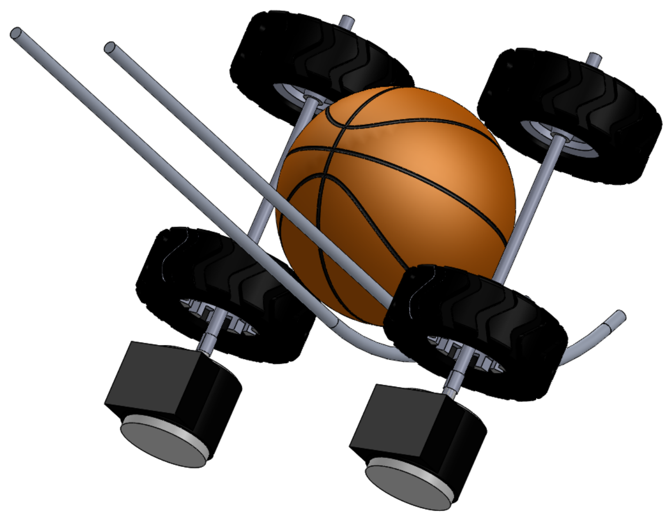

Figure 3.8: Flywheel Assembly with Launching Guides

Table 2.4 below describes the design specifications for the Launching Mechanism

Design ID	Description	Corresponding Requirement ID(s)
Des. 3.3.1-PC	A 350W brushed DC motor shall be used to launch the ball	Req. 3.4.1-SY-PC
Des. 3.3.2-PT	The launcher shall launch a basketball a minimum of 2 m away and a maximum of 7 m away	Req. 3.3.1-HW-PC
Des. 3.3.3-PT	The launcher shall consistently launch the ball at a height between 50 and 60 inches off the ground, the average chest height	Req. 3.4.5-SY-PT
Des. 3.3.4-PT	Aluminum guide rails shall guide that basketball in a 45° angle when launched	Req. 3.4.5-SY-PT

Table 3.5: Design Specifications for the Launching Mechanism

3.4 Swivel Mechanism

The launching mechanism and supporting structures must be able to swivel about the vertical axis to be in-line with the player before initiating the pass. This swiveling action will be performed by the swivel mechanism which contains the following elements:

1) Lazy Susan Swivel
2) Servo Motor
3) Rotating Platform
4) Stationary Base

These elements joined together and collectively form the swiveling mechanism. The assembly of the swivel mechanism will be shown after each individual element is described.

3.4.1 Lazy Susan Swivel

A lazy susan swivel was chosen as they are relatively inexpensive and provide the swiveling action while minimizing friction. Additionally, lazy susan swivels of various sizes are readily available for purchase due to their abundant use in kitchen top turntables.

The swivel contains two concentric circular aluminium rings joined together with steel ball bearings. The durable construction of the swivel enables it to bear weight in the vertical direction and withstand horizontal forces and twisting moments as per Req. 3.3.3-SY-PC. Moreover, the swivel is low profile, which shall enable easy transport of the swivelling system in the prototype device in adherence to Req. 3.3.5-SY-PT. The specifications of the swivel are shown in the table below.

Parameter	Value
Inner Ring Diameter	17”
Outer Ring Diameter	18”
Thickness	0.6”
Load Capacity	220 lbs

Table 3.6: Specifications for the Lazy Susan

Figure 3.9: Image of the Lazy Susan

The lazy susan purchased is shown in the figure above. The outer ring will be connected to the stationary base and will stay in place. The rotating platform, upon which the launching mechanism will rest, will be connected to the rotating inner ring.

The inner ring is able to spin independently of the outer ring. As such the swivel is able to rotate to any angular position between 0 and 180 degrees as required by Req. 3.3.1-SY-PC. The inner ring will spin under the torque provided by the servo motor which is detailed in the next section.

3.4.2 Servo Motor

The servo motor provides the torque to spin the swivel assembly. While there are several ways of providing torque to the swivel assembly, a high-torque hobbyist servo motor was chosen mainly due to its closed loop configuration and ease of use with a microcontroller.

A simplified calculation of the torque required of the servo motor can be performed by making some assumptions:

1) Assume (as a worst case) the entire mass of the load on the swivel is rotated at a distance R away from the servo motor
2) Use a commonly cited coefficient of friction for steel ball bearings of 0.0015 as an estimate of the friction between the inner and outer ring of the lazy susan
3) Assume the entire torque of the servo is applied at distance R

The following calculations are made as per these assumptions.

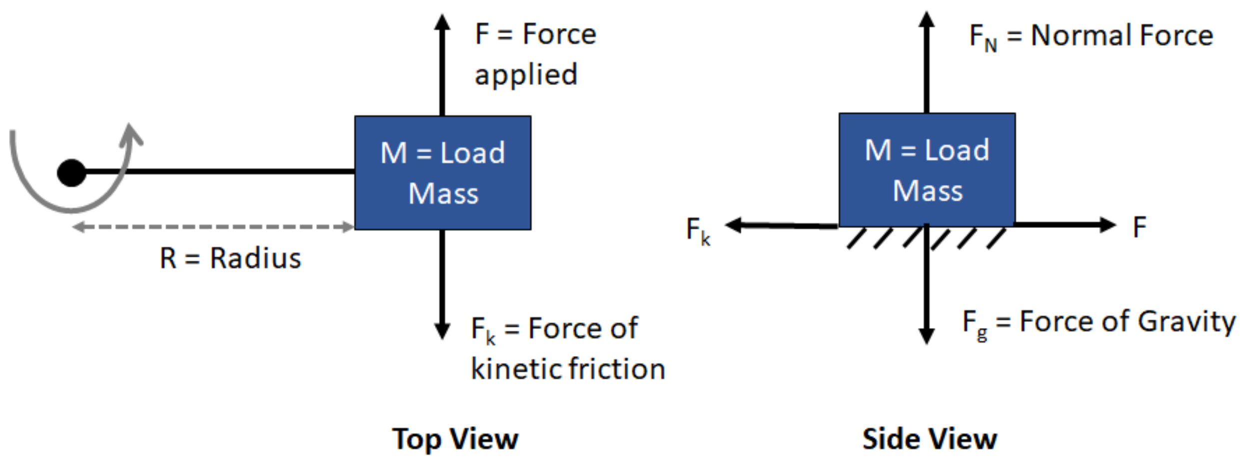

Figure 3.10: Free Body Diagram of the Simplified Swivel Assembly

Figure 3.10 shows the free body diagram of the simplified swivel assembly. The servo provides a torque which manifests as a force, F, applied on a mass M at a distance of R.

To accelerate the mass,

$$F > F_k$$

The force of friction $F_k = \mu F_N$ where F_N equals to the force due to gravity, namely, $M \cdot g$

$$F > \mu M g$$

Using the definition of torque and substituting the least amount of required for F we get

$$\begin{aligned} \tau &\triangleq F \times R \\ &= F R \\ &= \mu M g R \end{aligned}$$

Substituting μ=0.0015, M=10kg, g=10m/s^2 and R=0.33m in the above equation, we get a required torque of 0.5kgcm. This, of course, is an imperfect calculation and the low torque obtained suggests one of our assumptions may not be appropriate.

The most likely assumption to not hold would be the small coefficient of friction of 0.0015 which was assumed between the inner and outer ring of the lazy susan. Using μ=0.015 (10x that of previously assumed) yields a required torque of 5kgcm. This is still comparatively a small amount of torque. However, if we assume a safety factor of 10x, the required torque would be 50kgcm. This figure seems more plausible since servo motors of comparable torque are used for high-end RC vehicle and robotics applications.

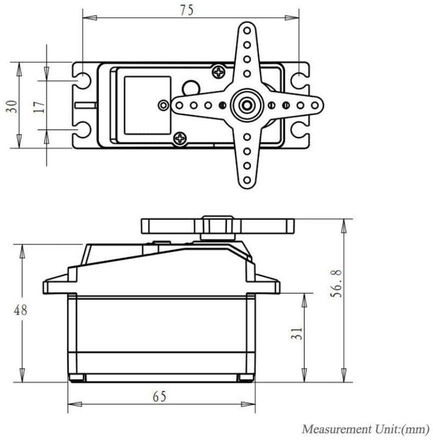

Figure 3.11: High Torque Digital Servo Motor Diagram

	6V	7.4V	8.4V
Idle Current	4mA	5mA	6mA
Operating Speed	0.17sec/60°	0.15sec/60°	0.13sec/60°
Stall Torque	58 kg-cm	65 kg-cm	70 kg-cm
Stall Current	3.5A	5A	6.2A

Table 3.7: Electrical and Mechanical Specification of the Servo Motor at various Operating Voltages

The dimensions of the servo motor and the electrical and mechanical specifications are given in Figure 13 and Table 8 respectively.

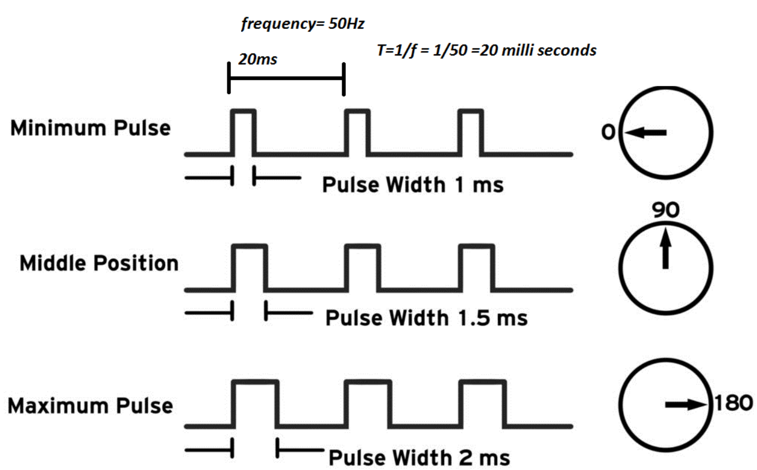

Figure 3.12: PWM Signals to Control the Angular Position of the Servo Motor

The angular position of the servo motor will be controlled by a PWM pin from the Raspberry Pi. The pulse width of the PWM signal determines the angular position of the servo. The pulse width can be controlled in the software easily to produce the desired angle for the servo motor. Figure 14 below shows how various pulse widths correspond to various angular positions of the motor.

3.4.3 Rotating Platform and Stationary Base

The rotating platform is designed to sit on top of the Lazy Susan Swivel, and will be rotated by the servo motor to the specified angle signal. The rotating platform will hold the mass of the framing of the launcher, thus it must be wide, steady and support approximately 20lb's of weight. One of the crucial factors of the rotating platform is that it must avoid physical disruption of any connections/wiring of the device during its rotation. Having taken this into account Autobot Enterprises has emphasized in its design to keep the rotating platform to a miniscule size that still supports the launcher mechanism of the device. In relation to the servo motor, the central mass of the launcher mechanism sits centered on top of the rotating platform, allowing for the minimization of opposing torque forces on the servo motor. This will in turn lead to better acceleration times on the rotation action while the device is running.

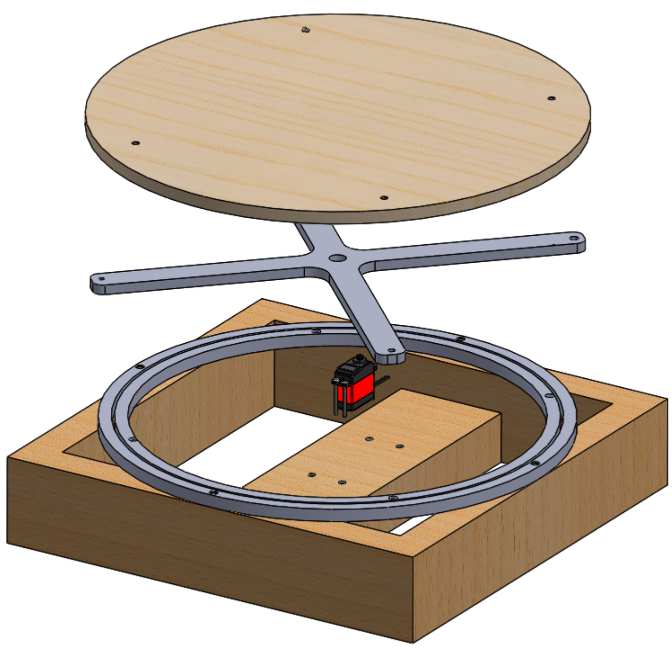

Figure 3.13: Exploded View of the Swivel Mechanism

The stationary base will provide support to the entire swivel and launching assembly. For the PoC, the base will not have wheels to aid in transportation. However, this feature will be added in the prototype phase.

The swivel mechanism must be able to meet the following design specifications.

Design ID	Description	Corresponding Requirement ID(s)
Des. 3.4.1-PC	The swivel action will be provided by a heavy-duty lazy susan swivel with steel ball bearings	Req. 3.3.1-SY-PC Req. 3.3.2-SY-PC Req. 3.3.4-SY-PT
Des. 3.4.2-PC	The servo motor will provide the torque to rotate the lazy susan	Req. 3.3.1-SY-PC Req. 3.3.2-SY-PC
Des. 3.4.3-PC	The servo motor will be controlled by the Raspberry Pi to start at an initial angle of 90°	Req. 3.3.4-SY-PT
Des. 3.4.4-PC	Wheels on the base of the swivel mechanism will enable easy transportation of the device	Req. 3.3.5-SY-PT

Table 3.8: Design Specifications for the Swivel Mechanism

3.5 Ball Collection Method

A net shaped funnel system will be used for collection both made and missed shots. Ideally, the ball will always land in the funnel after a missed shot, realistically, it is expected to land within the funnel the majority of the time.

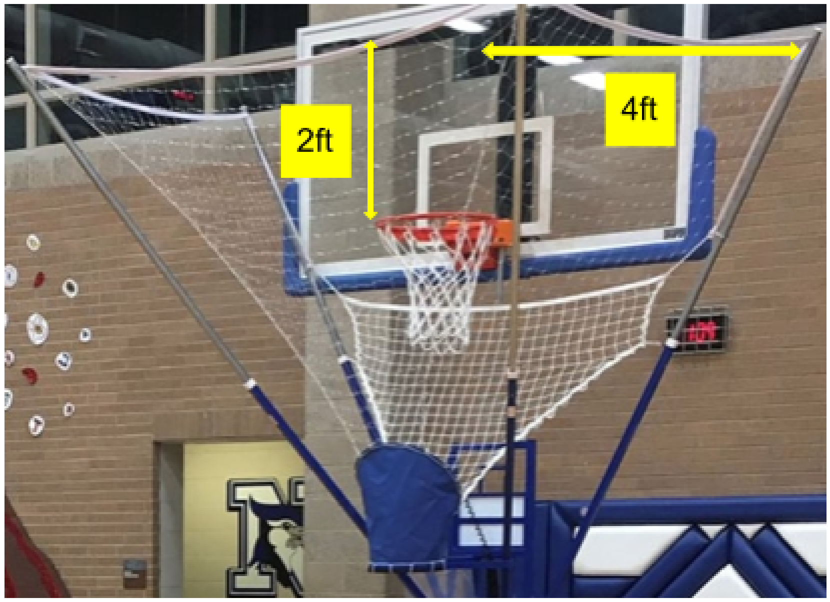

Figure 3.14: Example of a Funnel System to Catch Made and Missed Shots. Adapted from [3]

Design ID	Description	Corresponding Requirement ID(s)
Des. 3.5.1-PT	The arms of the net will collapse for storage and transportation	Req. 3.6.1-SY-PT
Des. 3.5.2-PT	The ball collection net will extend 2 feet above the rim of the basketball hoop and 4 feet away from the rim in the horizontal direction	Req. 3.5.1-SY-PT and Req. 3.5.2-SY-PT
Des. 3.5.2-PT	The rods suspending the net will be made from hollow aluminum tubing	Req. 3.5.3-SY-PT

Table 3.9: Design Specifications for the Ball Collection Net

4. Power Distribution System

The power distribution system refers to the system which provides electrical power for all the electronics, motors and microcontrollers incorporated in the Floor General.
As per Req. 3.6.6-SY-FP, the Floor General and all its electronics must be powered by a standard 120V-60Hz AC wall outlet. Consequently, using a lead acid battery was not considered as a suitable power source. Moreover, using a lead acid battery poses additional safety risks and is ill-suited for our sustainability requirements outlined in Table 9.1 of the requirements document.

A 750W ATX computer power supply was modified to solve the power requirements of the Floor General. A 750W supply was chosen to accommodate dual 350W AmpFlo motors used in the launching mechanism leaving 50W for the servo motor and the microcontroller. While this does not leave much headroom for additional power, it is highly unlikely that both launching motors will be running continuously at peak power for an extended period of time.

The pinout of a standard 24 pin atx wire and a PCB adaptor is shown in figure 4.1. The 24 pin connector has 3.3,5 and +/-12V rails.

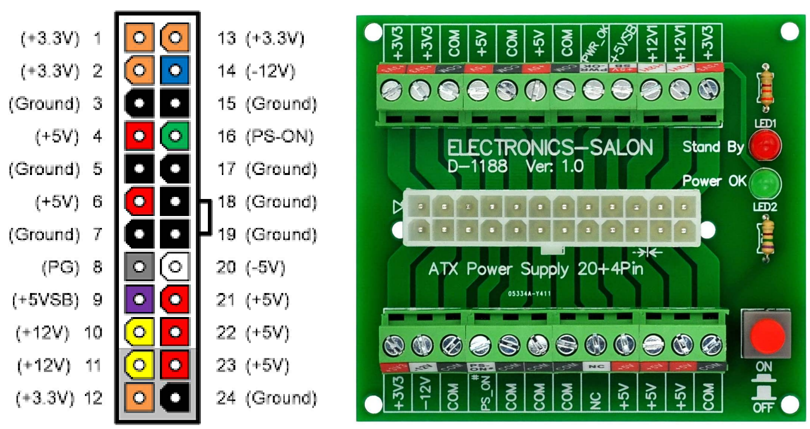

Figure 4.1: 24 Connector Pinout and (Left) and Breakout PCB (Right)

Several key connections need to be made on the 24 pin connector before the power supply can be turned on and be able to supply power. The PCB adaptor is used to easily make the wiring connections to draw power from the PSU. The wiring of the 24 pin connector is shown in figure 4.2. When the switch between pin 14 and 15 is closed and an appropriate load is across the 5V or 12 V rail, the ‘POWER OK’ LED should come on and the power supply should be ready to supply power.

The 3.3V rail will be used to power the Raspberry Pi and the 12V rails will be used to power the launching motor. Additional wires will have to be used in conjunction with the 24 pin connector to supply power to the launching motors. The 12V rails from the 24 pin and other wires such as the molex and 6 pin PCIe connectors can provide upto 60A of current and ~700W of power.

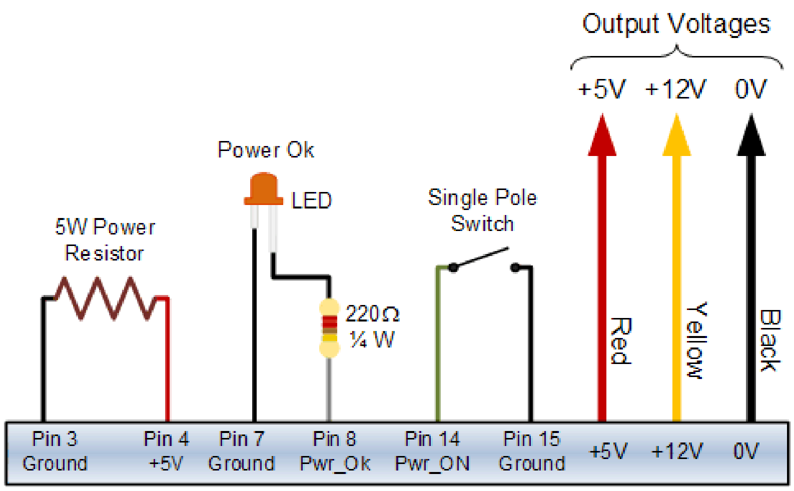

Figure 4.2: Wiring of the 24 Pin Connector

Design ID	Description	Corresponding Requirement ID(s)
Des. 4.1-PC	Device will be powered by a modified 750W ATX Supply	Req. 3.3.3-EL-PT, Req. 3.3.1-EL-PC
Des. 4.2-PC	The ATX supply chosen has built in Overcurrent and short-circuit protection	Req. 3.3.5-EL-FP
Des. 4.3-PC	The high voltage components are housed inside the ATX Supply and are inaccessible to the user	Req. 3.3.4-EL-PT
Des. 4.4-PT	The user will have access to a switch with turns off all power to the device	Req. 3.3.6-EL-FP

Table 4.1: Design Specifications for the Power Distribution System

5 Software Design

The software component of Floor General plays a pivotal role in synchronizing multiple subsystems of the device, The software part is divided into two sections: Raspberry Pi

Programming and Mobile Application. The software run on Raspberry Pi will be responsible for processing Lidar data in real time, controlling the motor drivers of launching and swivelling mechanism and detecting user signals. A mobile application will be developed to enhance the user experience by storing and displaying basketball statistics such as field goal percentage on a user's smartphone. The software design will be meticulously engineered to provide a dynamic system to end users. For the Proof of Concept, the software will be able to get the player's location on a basketball court and trigger the mechanical system to launch the ball. Methods to process sound based signals or remote control signals will be added to the prototype.

5.1 Raspberry Pi Software

Due to its faster clock speed, Raspberry Pi will be used as Floor General's microprocessor. To support the communication of lidar with external applications, most of the programming will be done in Python with calls to C++ functions or CPython. Python was chosen as it offers a wide range of predefined functions to easily implement complex data processing algorithms. Moreover, pre-built C++ applications will be run in sequence with lidar to efficiently process and collect raw data with high degree of accuracy and CPython offers the ease of using Python with the speed of C++. The collected raw data will be filtered further to get distance and angle for a 180 field of view. In addition, the data can be logged and stored in an external memory for debugging purposes.

The motor drivers will be controlled from Python scripts based on the results obtained from the RPLidar. Moreover, the Python scripts will also handle the output LEDs that indicate the state of the machine. The scripts will be uploaded to Raspberry Pi through SSH. The following state diagram shows the behavioural representation of Floor General's software system.

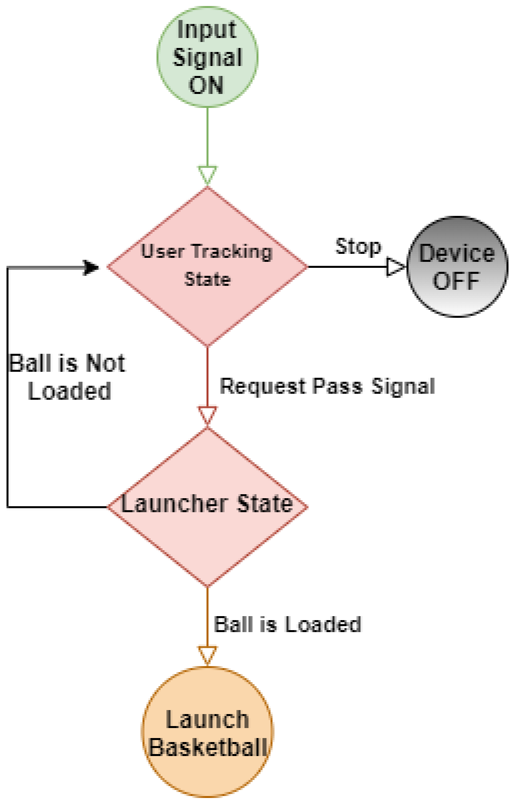

Figure 5.1: State Diagram of Floor General's Microprocessor

Design ID	Description	Corresponding Requirement ID(s)
Des. 5.1.1-PC	The Python program will continuously receive and process Lidar data	Req. 3.2.1-SW-PC
Des. 5.1.2-PC	The player's location will be computed from the distance and angle measurement collected using lidar	Req. 3.2.2-SW-PC
Des. 5.1.3-PC	The rotating angle of the servo motor will be set by the software	Req. 3.2.3-SW-PC
Des. 5.1.4-PC	The software sequence will execute a wait function to detect user signal	Req. 3.2.4-SW-PC
Des. 5.1.5-PC	The software will calibrate and run a health check on the Lidar and motors within 20 seconds of device startup	Req. 3.2.6-SW-PC
Des. 5.1.6-PC	The initial position of the servo motor and DC motor will be set to a default value by the software at device	Req. 3.2.7-SW-PC

	startup	
Des. 5.1.7-PC	Any errors or exceptions caught during Lidar operation will reset the Lidar	Req. 3.2.8-SW-PT
Des. 5.1.8-PT	An error message to reboot the system will be printed on the LED display if any part of the device is unresponsive	Req. 3.2.9-SW-PT
Des. 5.1.9-FP	The software will use default values for launching speed and rate of rotation if user input is not provided	Req. 3.2.10-SW-FP

Table 5.1: Software Design Requirements

5.2 Mobile Application Software

The mobile application will be concise; its main purpose is to allow the user to have a graphical interface to set up a workout, and view statistical data that will be received from the software sensor components of the device. In order to retrieve and process incoming data from the device, the mobile application will require database connectivity through Google Firebase. The mobile application will be developed in the final stages of design, as the product undergoes preparation to hit the market.

Conclusion

With the current constraints of todays' basketball shooting machines, the engineers of Auto-Ball Enterprises have been inspired to revolutionize and re-design a product that will allow for modularization of various features into a single device. In turn, this will allow players, coaches and other users to experience a true game-like feel when practicing a jump shot.

The Floor General is a state of the art system embedded with various sensors that allow features that have never been seen on a standard typical shooting machine. One of the primary features that adds a flavor of uniqueness is the addition of a lidar sensor, which allows for user detection in the system. One of the key decisions in the Floor General design is the integration of the servo motor and the launcher platform, as the document highlights above. As discussed, the servo motor will rotate the launcher platform to the specified angle indicated by the lidar sensor. This simple yet effective design alongside the lazy susan swivel base will allow for easy rotation even with the mass of the launcher motors directly on the platform. Lastly, the ball collection net is a simple yet efficacious part of the design, which will feed the basketball to the launcher component of the device.

Providing a user interface that is simplistic and intuitive is vital to the user, and is designed to provide statistics and configuration of workouts. Part of the mobile application device is currently designed to be stored on a network database which will allow the user to have their statistics stored in real-time. While the mobile application is not directly related to the design, the engineering team at Auto-Ball Enterprises is confident it will bring forth the best possible experience for their users.

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Appendix A
User Interface and Appearance Design

A.1 Introduction

The Floor General's user interface (UI) aims to provide a simple and straightforward means to setup, operate, and take down the device. It is imperative that the shooting cue used to trigger the ball pass is seamlessly integrated into the design to ensure that player performance is unaffected. A mobile application is intended to provide the user with a convenient way to view their personal statistics and track progression.

1.1 Purpose

This appendix will describe the different design aspects of the user interface and provide brief justifications for design decisions. Furthermore, emphasis will be put on how the design decisions account for the critical elements of UI interaction outlined in Don Norman's, *The Design of Everyday Things*.

1.2 Scope

The user interface and appearance design will cover the following 5 key topics:

1. **User Analysis**
   This section lists the various users and defines how each user interacts with the machine.
2. **Technical Analysis**
   This section describes how the design decisions that were made take into consideration the "Seven Elements of UI Interaction" (discoverability, feedback, conceptual models, affordances, signifiers, mappings, and constraints).
3. **Engineering Standards**
   This section will outline the Engineering Standards which overarch the user interface of the machine
4. **Analytical Usability Testing**
   This section outlines a series of rigorous tests which will be performed by company employees to determine any flaws or shortcomings of the design.

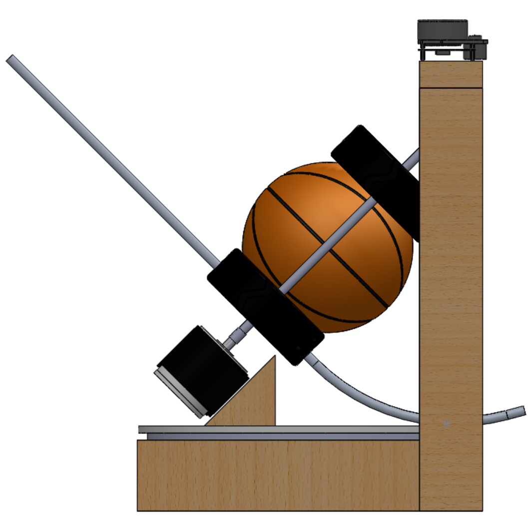
5. **Empirical Usability Testing**
   This section outlines a series of tests which will be performed to determine the ease of use from the user's perspective

A.2 Appearance

The two main subsystems of the Floor General are the shooting machine and the accompanying training app. The machine and app UI are designed in accordance with the "Seven Elements of UI Interaction" [8], as outlined in *The Design of Everyday Things*.

2.1 Machine and App Appearance

The UI of the device will be continuously upgraded during the various development phases. During the PoC phase, the Floor General will have the basic mechanical framework to launch the basketball to the user and retrieve made shots. This will include a platform for the swivel mechanism, guide rails for the launching mechanism, and a stand for the LiDar sensor. The appearance and polish of the device will not be of primary concern during the PoC phase as the development team will be the only users.



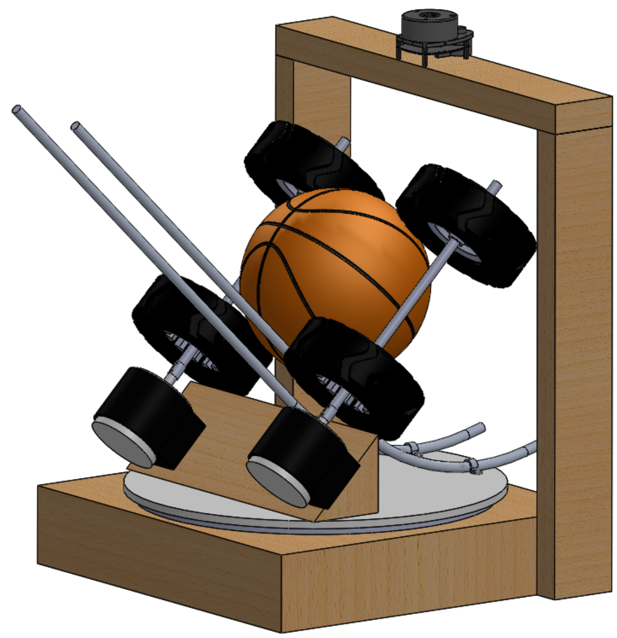


Figure A1: Basic Model of the Proof-of-Concept Device

The prototype device will primarily focus on improving the performance of the shooting machine to make the Floor General a viable replacement for existing shooting machines. A number of appearance and interface upgrades will be incorporated into the prototype device to improve user interaction with the device. The mechanical framework of the prototype will be enhanced by a large net canopy which will be used to retrieve made *and* missed shots, and a chassis will be added to enclose the various system components. The UI features will include a touch screen and status LEDs to provide configurability and continuous feedback to the user.

Figure A2: Final Product Device Model. Adapted from [9].

Initial implementation of the accompanying training app will also be developed in this stage. The app’s main purpose will be to record the user’s shooting statistics during practice. It may also be used to load the user's preferred method of training onto the Floor General, directly from the user’s smartphone. Through the app, the user will be able to track their progress and determine key statistics like shooting percentage from various locations on the court. This data will be displayed on the user’s smartphone as shown in the mockup in figure A3.

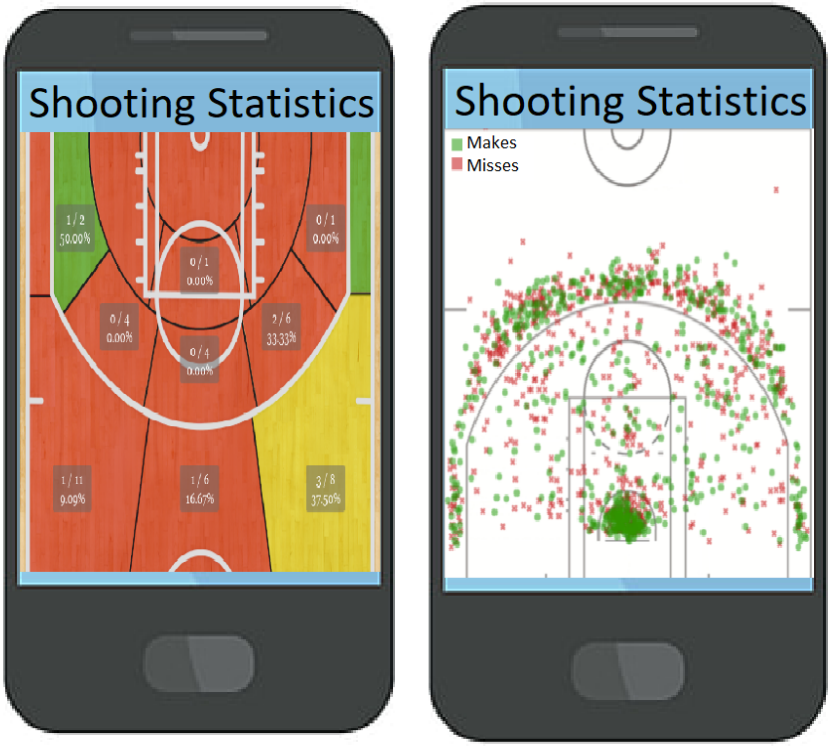


Figure A3: App Mockup

The final product will polish the features implemented in the prototype. Revisions and additions will be made based on evaluations of the prototype.

A.3 User Analysis

This section describes the types of users interacting with the Floor General and the way in which they will interact with the machine. The target market for our product consists of basketball teams varying from high school to the professional level. As such, the Floor General is designed with three tiers of users: the players, the equipment managers and company employees.

A screen will provide a GUI for players to setup and configure the type of training they require. On-screen and physical buttons will provide a way to interact with the features the Floor General has to offer. The PoC device will feature a remote clicker which the user will keep on their person while training. The clicker will be embedded into a wristband worn by the user. They will use the clicker to send a ‘shooting cue’ signal to the machine and launch the ball. In the prototype phase, the shooting cue may be initiated via a voice command or physical gesture.

Figure A4: Wristband User Signal Representation

Equipment managers are expected to set up the hardware for the Floor General. Typically, the equipment managers will transport the machine from the storage area to the court and set up the machine and netting. However, if directed, they should also be able to configure the software for the player, prior to practice.

Company employees may be required to interact with the machine in the field, for testing, evaluation and maintenance purposes. For this reason, easy access to the microprocessor's I/O ports and electrical wiring will be critical.

A.4 Technical Analysis

4.1 Discoverability

The concept of discoverability states, "it is possible to determine what actions are possible and the current state of the device" [8]. The Floor General aims to uphold this principle by providing a simple UI which is intuitive for all users.

Throughout its operation the Floor General will be in 1 of 3 states: an initialization state, a setup state, and a go state. The initialization state will commence when the machine is powered on and the touchscreen panel displays the company logo. More importantly, internal checks for power, hardware, and software will be performed in this state. Following initialization, the system will enter the setup state where the user can select their desired training type. After the setup is complete the system will enter the go state where it will begin passing the ball to the user according to one of two available training modes selected in the setup state. The traditional mode will pass basketballs based on a predefined pattern and frequency. The second mode is the automatic tracking mode which will pass the ball upon a passing cue initiated by the player. In addition, players will be able to configure various parameters in each of the two training modes in the setup state. For instance, if the traditional mode is selected the user will have the option of selecting the locations of where the ball will be passed, the number passes to be thrown at each spot, the interval of time between passes, and total number passes thrown. On the other hand, if the player chooses the automatic tracking mode, parameters like player height (to adjust LiDar), randomizing pass locations, number of passes per shooting cue, and delay between passes can all be set. All user defined parameters will have appropriate constraints associated with them. LED indicators will be used to relay the state of the device to the player. The details of this will be discussed in the feedback and signifiers section.

The company logo displayed on the chassis of the machine will convey to all users that the machine is strictly for dispensing basketballs. This will prevent equipment managers or users who may not be familiar with the technology from using the machine for any other purpose.

4.2 Feedback

The idea of feedback dictates that, "there is full and continuous information about the results of actions and the current state of the product or service. After an action has been executed, it is easy to determine the new state" [8].

At the PoC phase, the user interface will provide basic feedback to the developers. Power on and power good LEDs will be used to confirm power supply is functioning properly. In addition, an LED will be used to provide motor controller status and a LiDar data acquisition LED will ensure player tracking is functioning as expected.

In the final product stage, players will have access to a more detailed UI. Setup and configuration of training modes and parameters will be done through a touchscreen located on the side panel of the machine device. Three LEDs located on the front of the machine will be used to indicate the three states of machine: initialization, setup and go. A blinking LED in any of these states will signal that an error has occurred in that state. A pair of LEDs located on the front panel (at the mouth of the canon) will signal to the user two key pieces of information. First, if in the automatic tracking mode, the 'user signal' LED will blink if the shooting cue from the user is detected. Following the detection of a shooting cue from the user, the 'launch' LED will blink to signal an incoming pass. The blinking of the launch LED will provide a temporal reference enabling the user to position their body appropriately in anticipation of an incoming pass. An LED HEX display also located on the front panel will display the player's shooting percentage during their training session.

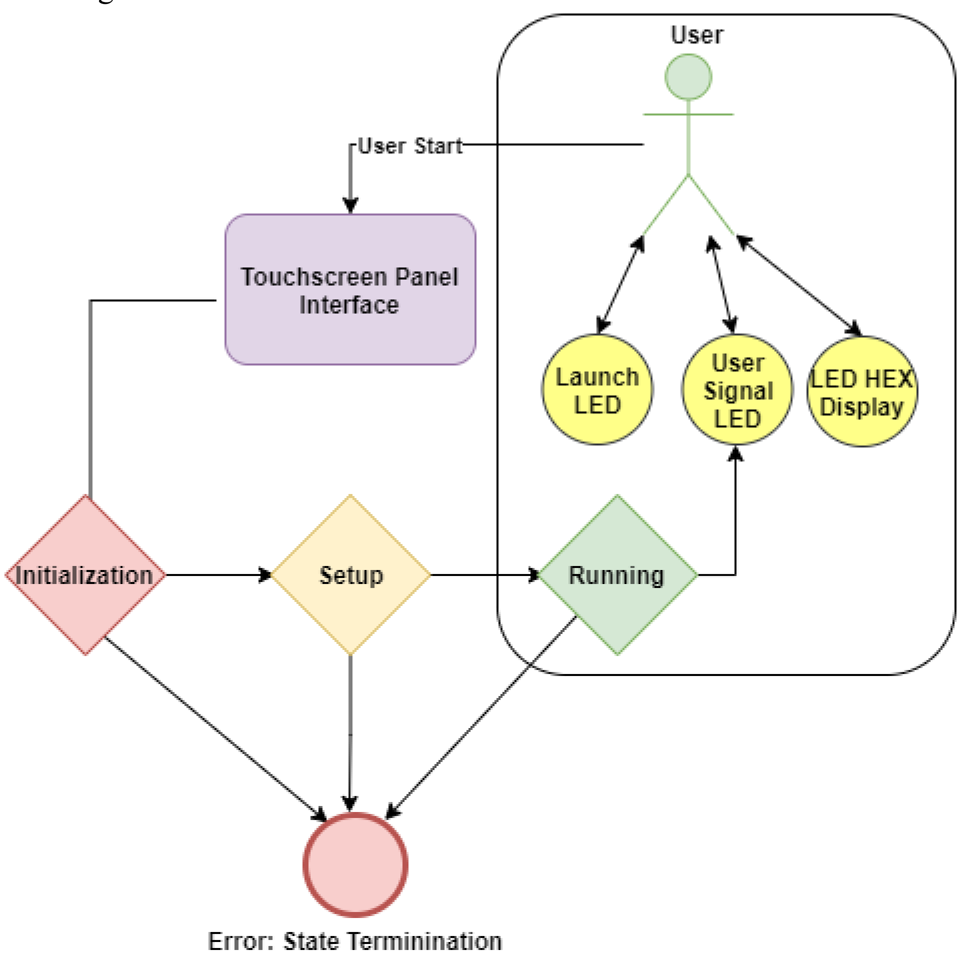


Figure A5: User Initialization of Device Running State

4.3 Conceptual Models

Conceptual Models can be summarized as the user's ability to extrapolate common or past experiences with a new experience.

A majority of players using this machine will have prior experience using a traditional shooting machine or some method of traditional training, i.e. a passer passing them the ball based on a passing cue, likely both. The automatic tracking feature will be intuitive for the players since it mimics another player passing them the ball. The machine's ability to track, acknowledge (via an LED triggered by the shooting cue) and deliver the pass to the recipient is analogous to how the player would receive a pass from another human player.

4.4 Affordances

Affordances relate to how intuitive an object is to use. The Floor General will use various affordances to make operation of the machine intuitive for all users. The compact and modular design of the machine will allow for easy transportation for users who wish to transport the machine (i.e. equipment managers, individual players). The onboard touch screen will have user friendly prompts to simplify configuration of parameters. Since the LiDar will not be relatable to most users, a label will be printed to notify the user to avoid putting anything in front of it which may disrupt its performance.

4.5 Signifiers

The effective use of signifiers in the Floor General will ensure discoverability and that the feedback is well communicated and comprehensible by the users.

LEDs will be the primary signifiers used by the Floor General. As previously mentioned, each state will have a designated LED to inform users about the machine's current and future states. Moreover, a flashing LED will signal to the user that an error has occurred in that state. For example, if an unidentified person or object comes too close to the machine prior to launching the ball, the go state LED will blink and will temporarily halt the machine. Finally, an LED HEX display located on the front panel of the machine will display the number of shots attempted, number of shots made and the player's shoot percentage. This feature will allow the player to get real time feedback on his or her performance during their training session.

4.6 Mappings

The development team will adhere to the principles of good mapping by optimizing, "spatial layout and temporal contiguity" [8].

The Floor General's GUI will follow a typical smartphone arrangement: title on top, information on options and a way to interact in the middle, and forward/backward buttons at the bottom. For the traditional training method an image of the court will be shown on the screen and the user will be able to select the shooting spots. Such mapping is the most intuitive and will require little to no explanation. Furthermore, any physical and on screen buttons will be labelled to indicate their intended functions.

4.7 Constraints

The development team will attempt to ease interpretation by "providing physical, logical, semantic, and cultural constraints to guide actions" [8].

The constraints of the Floor General will be made transparent to all users. The logo present on the body of the Floor General should indicate to users that the machine is strictly for launching basketballs. The need to power the device from a standard wall outlet will indicate to the user that the device is for indoor use only. The 180° field of view and range of motion of the machine can be understood intuitively since all shots taken by the player will fall into this range. Maintaining a safe distance from the machine while it is operating is a logical constraint which can be easily navigated by the user. All configurable user inputs will be structured within the constraints of the device. This way there is a low probability that the device malfunctions due to any user defined input. A label will be used to remind the user to lock the wheels of the platform so that the machine remains stationary throughout its operation

A.5 Engineering Standards

Standard Identifier	**Standard Description**
IEEE 1012-2016 [10]	IEEE Standard for System and Software Verification and Validation
ISO/IEC 24755:2007 [11]	Information technology — Screen icons and symbols for personal mobile communication

	devices
IEC 60417 [12]	Graphical symbols for use on equipment
IEEE P360 [13]	Standard for wearable consumer electronic devices
ISO/IEC TR 11580:2007 [14]	Information technology — Framework for describing user interface objects, actions and attributes
ISO 9241-11:2018 [15]	Ergonomics of human-system interaction — Part 11: Usability: Definitions and concepts
IEC 61310-1:2007 [16]	Safety of machinery - Indication, marking and actuation - Part 1: Requirements for visual, acoustic and tactile signals
IEC 61310-2:2007 [17]	It gives general rules on marking for identification of machinery, for safe use related to mechanical and electrical hazards, and for the avoidance of hazards arising from incorrect connections

A.6 Analytical Usability Testing

This section outlines the tests to be performed to evaluate the User Interface (UI) of the machine. These tests will help the designers to identify issues in the UI and make necessary improvements to enhance user experience.

6.1 General Tests

- Press the start button and ensure that the display turns on
- Hold the power button for 3 seconds and verify that the device turns off
- The current state of the device and training mode are displayed on the screen
- The training mode can be set by pressing the respective buttons on the device
- The first LED turns red when the device enters into error state
- The first LED changes to amber when the device is in standby

- The second LED flashes amber upon receiving a user signal
- The third LED blinks after the ball has been launched
- The power button and the LEDs are labeled appropriately

6.2 Onboard Display

- The display shows the company logo at start up
- The user can select the training mode and set parameters using the touch screen
- Simple statistics such as field goal percentage (shots made/shots attempted), are displayed on the screen
- The screen shows a message to reboot the device when it is in error state
- The display does not show technical engineering terms not known to users
- The user can easily navigate and view device instructions on the display
- All symbols seen on the screen are conventional
- The response time of touch screen is less than 1 second
- The display automatically turns off when the device enters standby mode

6.3 Remote Clicker

- The clicker is compact in size and easy to carry
- Press the first button to signal the machine to pass the ball and ensure that the second LED glows amber
- Press the second button to switch between two available training modes and check that the current training mode changes on the display
- The physical buttons are properly labeled and easy to read
- May be an LED or something on the clicker to indicate the current training mode (when the user is away from the machine)

6.4 Mobile Application User Interface

The mobile application will be tested through a combination of unit testing and integration tests to ensure that all features are functional, intuitive and easily accessible for the user. Figure A6 below highlights the overview of the manual testing procedures that will be conducted to verify functionality. The program startup will load the system and have a waiting screen with the company logo. It will direct the user to the Home Screen Interface where the user will be able to click a variety of options/features in the application. The testing will make certain that all buttons redirect the user to the specified location, such as the 'Workout Configuration' and the 'Statistics and Progression' menus. Lastly the test plan will carry out that the user may end the workout configuration page and return to the main menu, where the user can choose to configure another workout, view statistics or terminate the program application.

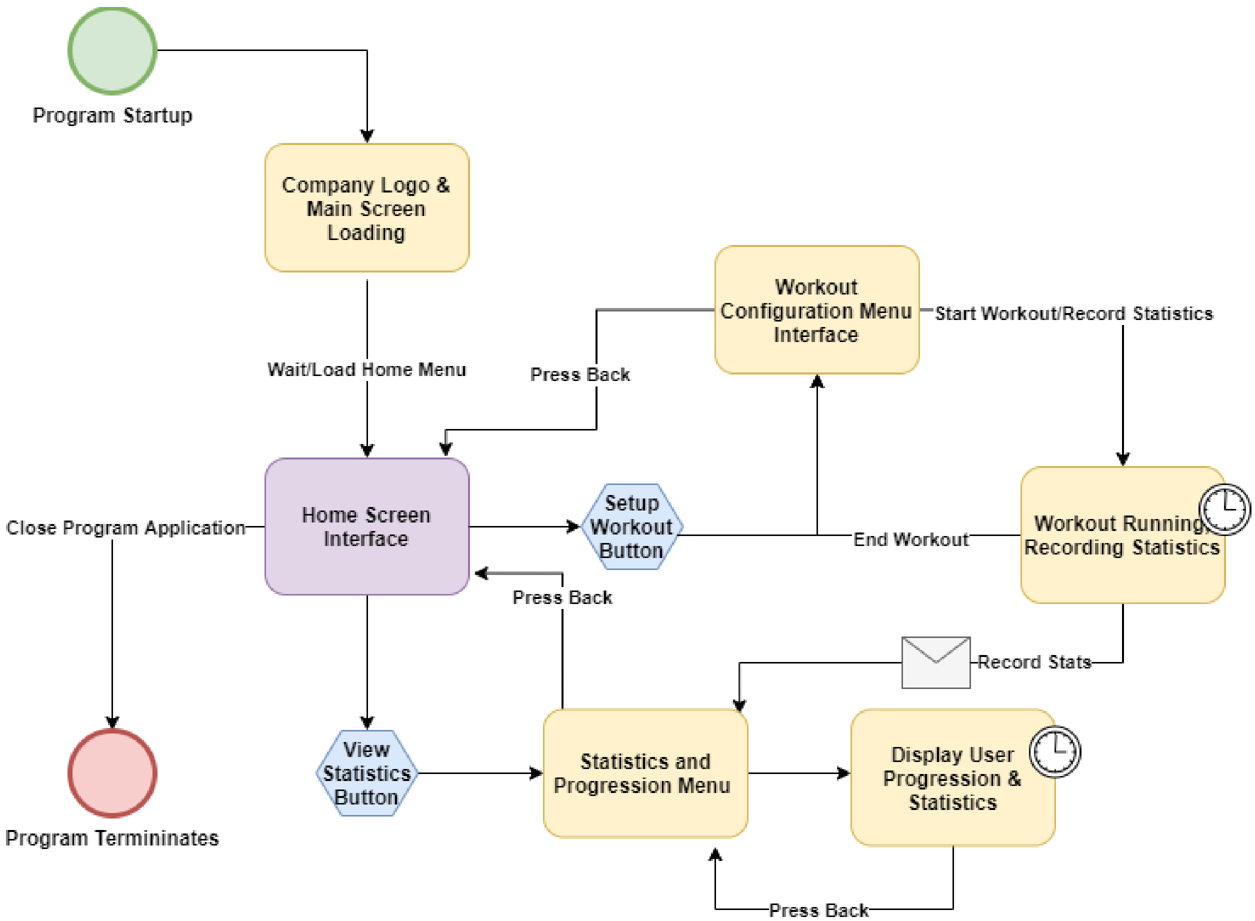


Figure A6: Mobile Application Usability Testing Overview

Some general tests that will be done on the mobile application are listed below.

- Select the bluetooth option on Smartphone and connect to the device named "Floor General". Open the application and verify that the device connected status is achieved
- Create a new profile and ensure that the data gets stored
- Symbols used in navigation toolbar are generic

- The navigation toolbar provides options to switch between different profiles and display requested statistics
- Highlighted text at the top indicates the profile and data being viewed
- Charts and graphs displaying the statistics are labeled correctly

A.7 Empirical Usability Testing

Development driven by the feedback from target users would enhance the quality of service offered by Floor General. Empirical testing provides a method to analyze the features of a product through user's feedback. These tests are carried out during the final phase of the prototype design to maximize the feedback collected from users.

In addition to team members, a selection of users from high school and collegiate basketball players will be identified to evaluate the usability of the device. Documentations such as device setup instructions , safety and troubleshooting instructions will be provided to the users. User's consent will be collected before starting the test session. Moreover, the users will be asked to complete an entry survey regarding their previous experience with similar machines.
By observing the user's interaction with the machine and getting them to complete an exit survey, the design team will be able to acquire constructive feedback. The exit survey component of the test session will be divided into two segments: Shooting Machine and Mobile Application

7.1 Shooting Machine

As the shooting machine forms the core part of our product, user interaction with the device will predominantly happen through LED display and remote clicker. Therefore, it is important for our company to collect maximum feedback in this segment. Due to limitations in the number of devices, the overall testing period is expected to take longer. The following list shows the questions that will be included in the survey.

- How would you rate the overall performance of the device on a scale of 1-5?
- How easy was the device setup process on a scale of 1-5?
- Was the LED feedback visually easy to understand?
- Were the information displayed on the screen readable and understandable?
- Was it easy to navigate and change the settings using the touch screen display?
- If any error occurred, how long did it take to resolve it?
- Were the instructions easy to follow during the error recovery process?

- Was the remote clicker compact in size and easy to use?
- Were you able to switch between training modes without walking to the machine?
- How would you rate the intuitiveness of the user interface on a scale of 1-5?
- How would you rate the reliability of the basketball launching mechanism on a scale of 1-5?
- How safe did you feel while interacting and operating with Floor General on a scale of 1-5?
- How natural did it feel to reposition and receive a pass from the device?

7.2 Mobile Application

As the mobile application can be installed on multiple devices, the design team can load test data on the application and perform empirical testing. Questions that will be included in this segment of the survey are listed below.

- Was it easy to connect to FloorGeneral through bluetooth?
- Were buttons, tabs, toggles and slides easy to view and interact with?
- How easy was the navigation through the mobile interface on a scale of 1-5?
- How easy was the workout configuration setup prior to training on a scale of 1-5?
- How accurate and reliable was the statistics measured on a scale of 1-5?
- Describe any improvements to the interface aspects of the mobile application

A.8 Conclusion

The UI design of the Floor General aims to deliver an intuitive platform which caters to all its users. The implementation of the UI will be rooted in the critical elements of UI interactions described in Don Norman's, "Design of Everyday Things". Using these fundamental principles, the development team at Auto-Ball Enterprises were able to compile and summarize key aspects of a robust yet simple interface outlined in the appendix. Auto-Ball Enterprises plans to demo the Floor General PoC to student athletes in our local community to get audience specific feedback on ease-of-use. In the prototyping phase, the team will work on developing a compact chassis to house all system components and the user interface. In the prototype demo, we plan to showcase the appearance and user interface objectives outlined here.

Appendix B

Supporting Test Procedures

Name:		Initials:
Hardware Test Plan		
Test Description	Expected Output	Pass/Fail
● Connect a 5V DC supply to Raspberry PI	The Red and Green LEDs on the Raspberry Pi should blink	❑ Pass ❑ Fail
● Connect a 5V DC supply to V_MOTO and MOTO_CTRL pins of the lidar. ● GND pin of the lidar should be connected to common ground	Lidar should start spinning	❑ Pass ❑ Fail
● Connect the Lidar to the Raspberry Pi using USB to UART converter ● Run the command on the Raspberry Pi terminal “ls /dev/*USB*”	“/dev/ttyUSB0” is listed as one of the devices	❑ Pass ❑ Fail
● Measure the voltage supplied to Lidar’s scanner	The voltage should be 5V	❑ Pass ❑ Fail
● Stand 2 m away from the ball launcher and request a pass	The ball should launch and be at a height between 50 and 60 inches off the ground when it reaches the tester	❑ Pass ❑ Fail
● Stand 7 m away from the ball launcher and request a pass	The ball should launch and be at a height between 50 and 60 inches off the ground when it reaches the tester	❑ Pass ❑ Fail

Name:		Initials:
Software Test Plan		
Test Description	Expected Output	Pass/Fail
● Run the health check function on the Raspberry Pi ● Health check function ensures that the lidar, motors and other electrical components are ready for operation	The function will return the status "Device Ready "	❑ Pass ❑ Fail
● Stand in 180° field of view and 2-7m away from Lidar ● Execute the function to capture distance and angle using Lidar ● Repeat the test by varying the location	The computed distance to the player should be printed on the terminal	❑ Pass ❑ Fail
● Perform a stress test by running the Lidar's scanner function for 2 hours ● Log the distance, angle and errors	Lidar exhibits error free operation and measured values are logged	❑ Pass ❑ Fail
● Force the Lidar into error state	The software will reset the Lidar and start the data collection again	❑ Pass ❑ Fail
● Drive the servo motor and DC motor through software ● Repeat the test varying the motor speed from min to max	Visually observe the change of motor speed	❑ Pass ❑ Fail
● Press the signal button on the remote clicker to trigger the launcher	The software should be able to recognize the signal	❑ Pass ❑ Fail
● Press the signal button from various locations on the basketball court	The software should recognize the signal if the user is within 7 m radius	❑ Pass ❑ Fail

Name:		Initials:
Electrical Test Plan		
Test Description	Expected Output	Pass/Fail
• The 3.3, 5 and 12V rails should output the appropriate voltages	3.3V, 5V, 12V on the 3 rails respectively	❑ Pass ❑ Fail
• The master switch should turn on the PSU	Power good pin should be high and corresponding LED should light up	❑ Pass ❑ Fail
• Operate the machine for 2 hours	The device should not overheat	❑ Pass ❑ Fail

Name:		Initials:
System Test Plan		
Test Description	Expected Output	Pass/Fail
• Turn on the master switch	The device calibrated automatically and "Device Ready" message is printed on the screen	❑ Pass ❑ Fail
• Load a basketball into the machine • Stand in the 180 field of view and 2m-7m away from the machine • Press the pass signal on the remote clicker • Repeat the test from different locations on the basketball court	The ball is launched towards the user	❑ Pass ❑ Fail
• Empty the shooting cue of the machine • Stand in the 180 field of view and 2m-7m away from the machine • Press the pass signal on the remote clicker	The launching and swivelling systems remain stationary and an error message is printed on the display	❑ Pass ❑ Fail
• Force the device into error state by not powering the launcher • Stand in the 180 field of view and 2m-7m	The machine can find that the launcher is unresponsive and an error message is printed on the	❑ Pass ❑ Fail

away from the machine ● Signal the machine by using the remote clicker	display	

Appendix C
Supporting Design Options

The section outlines the design options that were considered during the initial development phase of the product. For each subsystem, an appropriate option was chosen to satisfy the requirement specifications and enhance the performance of the machine. The subsystems of the machine consist of the following components.

- Microprocessor
- Motion Detection/Ranging System
- Launching Mechanism
- Swivelling Mechanism
- Request/Pass Mechanism

C.1. Microprocessor

The requirements Req. 3.2.1-SW-PC and Req. 3.2.2-SW-PC indicate that the Floor General should be able to continuously track the player and compute the player's location. To satisfy this requirement, The Arduino and Raspberry Pi platforms were considered to initiate and sustain the process of collecting and parsing through the data from the Lidar.

During the initial testing of the Lidar an Arduino Uno was used, with a clock speed of 16 MHz and limited onboard memory, to collect and parse raw data. Significant data loss was the main issue, as each time the data was sampled random non-sequential distance and angle measurements were returned, causing instability in the ranging system. It was impossible to range at a specific angle without waiting for a significant time and waiting to get lucky that angle was sampled. Further experimentation revealed that data was severely congested and constantly being overwritten before being extracted at the Arduino's Rx buffer due to the high transmission rate from Lidar. The Lidar transmission speed could be reduced by spinning it at a lower RPM, but this would increase the delay between a user sending a request for a basketball and the ball being launched. Next a Raspberry Pi 3b was tested with a significantly faster clock speed of 1.2 GHz. This opened up more options for integrating components using bluetooth and different coding languages like Python. The Raspberry Pi also has a Linux environment and a proper ide with full debugging capabilities. Thus the Raspberry Pi was selected to resolve the problems mentioned previously and guarantee a faster rate for reading the data from the receiver buffer.

C.2. Motion Detection/Ranging System

The requirements Req. 3.1.1-SY-PC and Req. 3.1.2-SY-PC state that the Floor General will have a 180° field of view (FOV) and detect player movement within a minimum 7m semicircle. Two methods were researched to fulfill these requirements, using a 2 camera setup and a Lidar sensor. The 2 cameras would function similar to human eyes, by using parallax. This would require both the cameras to be calibrated and the distance between calculated during the initialization phase. Achieving and maintaining this level of calibration will be difficult over a long period of time in an environment where basketballs may hit the Floor General. Furthermore, the player may be as far as 7m away from the camera and the player will appear very small in the frame. The cameras will have to be high resolution to be able to take a valid picture that can be used to determine the distance and angle. This will also require more compute power to be able to run the necessary algorithms in a reasonable amount of time and not create a noticeable delay between a user sending a request for a basketball and the ball being launched. Moreover, the cameras will have to be constantly rotated to be able to take pictures of the player anywhere on the court, this may require another motor or increasing the use of the current motor and the total power used significantly. Thus the Lidar sensor was chosen as it handled most of these problems already. The Lidar has 360° FOV using a built in motor which uses significantly less power and the Lidar calculates distances and angles itself reducing the required compute power.

C.3. Launching Mechanism

To launch the basketball, a brushed DC motor was chosen, for a multitude of reasons. They typically offer high efficiency and simple speed control. Their ability to start and stop quickly are an asset to the design of the launching mechanism. And in most cases, they are the motor of choice for applications which require a low duty cycle. In addition, at high speeds they can develop a high torque while still remaining relatively quiet. Although a brushless DC motor provides all these features along with a longer lifespan than that of its brushed counterpart, it comes at a significantly higher cost.

A stepper motor was never taken into consideration since these motors are not efficient and tend to heat up even when they are not running. Moreover, they have low torque becoming fairly noisy at high speeds. They also have a low power intensity and a low torque-to-inertia ratio.

After deliberating the pros and cons of each type of motor and their suitable applications, the development team chose to proceed with a brushed DC motor.

Initial testing used a single motor to launch the ball, but for the prototype having two motors rotating in opposite directions will be more viable. It is possible to launch the ball with one motor, but for accuracy and reliability two motors were chosen instead.

The axles of the flywheels are made of aluminum rods, additionally, the guide rails for the basketball are made of similar aluminum rods. Other options which were briefly considered were steel, wood, or plastic rods. The main things to consider when choosing a material to use were that it should be relatively lightweight [Req. 3.6.1-SY-PT and Req. 3.3.6-HW-PT], easily machined, durable, and available to purchase in specific dimensions. Ultimately aluminum was chosen over steel because of the lower density and easier machinability of aluminum. Aluminum was also chosen over wood or plastic due to its strength.

C.4. Swivelling Mechanism

A custom ball bearing swivel solution to provide the swivel action was briefly considered to provide more flexibility and customization options. However, a custom solution, with less friction and more a robust design would have been too expensive for the project. Instead, an off the shelf 18” lazy susan swivel with bearings was deemed suitable for our project.

An equivalently spec’d stepper motor was briefly considered to drive the swivel assembly. However, a stepper motor would require calibration upon start-up as it would not have positional feedback.

C.5. Request/Pass Mechanism

As per the requirements Req. 3.2.1-SY-PT, Req. 3.2.2-SY-PT and Req. 3.2.3-SY-PT, the device should receive a user signal and initiate the ball launcher to pass the basketball. To build this mechanism, the design options considered were training a pixy-2 camera to detect hand gestures, speech recognition system and a wearable remote clicker.

Although this part of the system is still in early development phase, implementation of a wearable remote clicker takes precedence over its counterparts. An RF remote clicker can be tuned to a certain frequency (433 MHz) to send a signal to a receiver module located in the machine. The Raspberry Pi can process the received signal and alert the launching mechanism. The wide operating range of the wireless transmitter module and its compact design make it a good choice for Floor General.

Training a pixy-2 camera to recognize hand gestures would involve development of complex machine learning algorithms. In addition, detecting hand gestures over a semicircle of radius 2m to 7m would require a high resolution camera and increase the complexity of the design. As Floor General will predominantly be used in a basketball court, the background noise caused by thudding of basketballs poses a challenge in implementing a speech recognition system. This problem can be overcome by attaching a wireless microphone to the player. Furthermore, this type of design might cause discomfort to basketball players. Comparing all the viable options , the remote clicker offers a reliable model to build a robust Request Pass mechanism.