SkillCourt Autonomous Ball Launcher

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ABSTRACT

SkillCourt is a proposed soccer training system to develop player cognitive and decision making skills using computer-aided technology and automated feedback capabilities. Our goal is to incorporate an autonomous ball delivery system that will track the user and interact with the SkillCourt software; thus, allowing for maximum customization and computer aided training.

Ball delivery systems are already common and widely used in sports such as tennis, football, and baseball. These devices have similar traits in means of function and purpose, but most lack autonomy and diversity in the complexity of delivery. For soccer, there are both advanced and basic machines that are capable of various shots and passes available on the market. On the other hand, these systems do not have automatic and user based capabilities as well as costs that are in reach of a common household or academy.

Our main design concerns will include movement capabilities of the ball delivery mechanism, independent loading and unloading of a ball, user tracking, and automatic delivery integration with the SkillCourt software. The team has delivered a unique prototype with many customizations (i.e. three degrees-of-freedom, micro-controller system, Open Cv tracking, auto loading, and SkillCourt software) of which have been implemented. Lastly, the team will continuously optimize and calibrate the functionality and accuracy of the system. Soccer is a worldwide sport played by nearly every culture and background, an automatic training system will have great potential for both youth and professional levels of global soccer programs.

Keywords

Autonomous, Open CV, SkillCourt, Three degrees of Freedom, Motor Control, Raspberry Pi, Arduino.

1. INTRODUCTION

Ball delivery systems are already widely used for many types of sports across the globe. These devices have similar traits in means of function and purpose, but many lack user interaction capabilities and customizations. The main design has provided movement of various degrees of freedom and a basis for independent loading and unloading of a ball, while player motion tracking and automatic have been provided a strong basis to be accomplished and integrated with the SkillCourt software. The team has worked on a prototype using concepts from commercially available launchers as well as software used to track objects.

Soccer is a worldwide sport played by nearly every culture and background, an automatic training system will have great potential for both youth and professional levels of global soccer programs. By building an automatic ball delivery system with the integration and software capabilities of SkillCourt, we hope to provide a reasonably priced device for all players of the sport.

This launcher has great potential for future work as a working base for developments and improvements can be implemented. Likewise, like any other type of commercial product there must be recognition of similar tools and technologies with similar capabilities. SkillCourt is a new form of soccer training that takes into account the already proven studies of brain growth and soccer drills. This launcher will be integral in the line of products that already exist within SkillCourt Lastly, the team will continuously improve and calibrate the functionality and accuracy of the various components of the system.

1.1 Related Work

Before the launcher can be designed, there must first be understanding of how a ball moves and behaves one launched and through the air. In sports, many characteristics must be considered, for any that incorporate a ball, the aerodynamics of the ball are critical for trajectory prediction and study. Particularly in football, several wind tunnel and computer models have been used to simulate and analyze ball physics. To describe the phenomena associated with footballs traveling in air, the dimensionless value of Reynolds number must be considered. The range of speed varies in the game of football with ranges from 10 mph to 70 mph or 4.5 to 31 meters per second [1].

The industry of ball launching devices is very diverse and ranges across many sports, the biggest consumers being baseball and tennis. Currently there are additional launchers for other sports such as soccer, volleyball, and football though they lack intricacy and do not provide statistics and user feedback. These launchers have capabilities such as speed adjustment, direction and angle customization, and finally unique shots and passes that can be achieved through their respective machines. Some previous works considered are the Sidekick and First Pitch ball launching systems shown in Figure 1. Adjustments for the ball are made through manipulation of tire speeds and angle of the mechanism used to launch the ball [2].Specifications will include structure of the launcher and its changes in direction. Though numerous are available, prices ranges are usually out of reach for lower levels of sports and amateurs. For the launcher proposed in this report, a launcher that is affordable, provides a wide variety of features, and directly interacts with the user will be sought after.

Figure 1. SideKick Ball Launcher

To accomplish the initial goals of this project one must first look into the primary demands of such a device and the possible directions the team can look forward to. The SkillCourt ball launcher delivery device will consist of a two motorized friction wheel assembly that will receive the soccer ball, automatically load, and launch the soccer ball to a specific destination. The uses of motorized wheels will allow accurate ball service with both wet and dry balls. To adjust the trajectory of the soccer ball three degrees-of-freedom will be needed. In other words, the ball launcher will rotate along three axes; this type of motion is described by yaw, roll, and pitch rotation matrix used in aeronautics.

To achieve these motions two assemblies are researched, the Gimbal platform and Stewart platform [3]. These platforms are software-programmable control mechanism that will instruct motion features to the soccer ball. The Gough-Stewart Platform is a parallel robot consisting of six prismatic actuators that are attached in pairs on the base plate and is diagonally connected to three mounting plates displayed in Figure 2 [4]. Trademarked “hexapod” by Geodetic Technology is the term used to describe this 6-jack platform due to its similarity to six legs; this results in a total of six degrees-of-freedom. Other applications of this includes NASA Low impact docking systems and flight simulators.

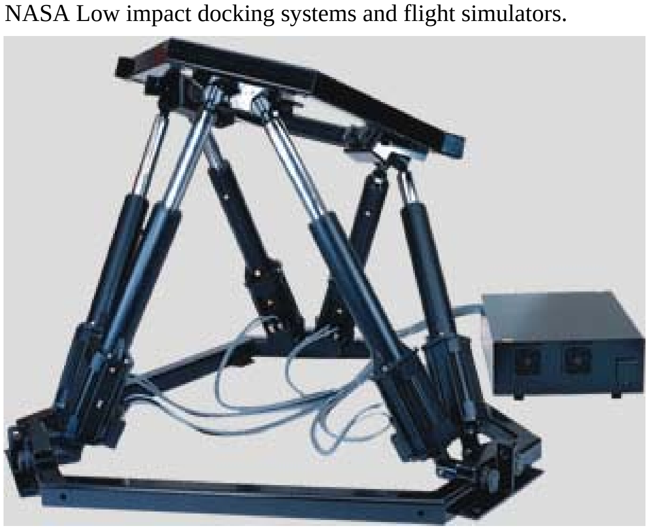

Figure 2. Gough-Steward Platform

Additionally, the research of William Mendez, Yuniesky Rodriguez, Lee Brady, and Sabri Tosunoglu pertaining to the concept of three degrees-of-freedom rotating platforms with high accuracy has been looked in to, allowing a new method of soccer ball launching that can be achieved. A three degree-of-freedom rotary table mechanism contains three gimbals seen in Figure 3, of which act as swiveled supports that allows the rotation of an object about its own axis, each being structurally designed for perpendicular rotation with regards to one another [5].

As one can imagine with different designs each has its own pros and cons, for example an arrangement of outer gimbals would require further actuators would be needed to move a gimbal setup with a high moment of inertia. Likewise, weight can be arranged to where one actuator can move a gimbal depending of the rotation axis. It is understood that a three-degree axis table will need four tranches, the base, the outer, middle and inner gimbals. To reduce torque in the actuators light weight material should be considered such as plastic.

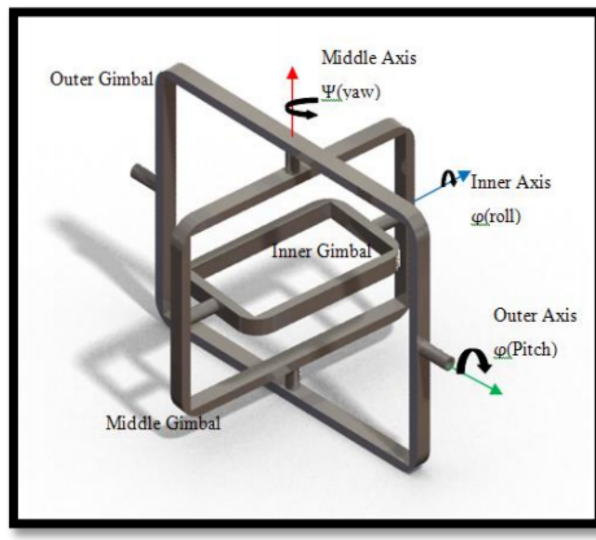

Figure 3. Gimbal Platform

Open CV (Open Source Computer Vision Library) is an open source software library that is used in computer vision and learning applications. Open CV supports Windows, Linux, MacOS, and Android operating systems, and interfaces with C, C++, Java, Python, and MATLAB. Additionally, this software library features algorithms used in face recognition, object identification, motion tracking, three-dimensional object plotting, with potential for other subjects [6]. Open CV software brings a range of applications that is useful in the ball launcher player tracking characteristic.

2. DESIGN COMPONENETS

2.1 3-DOF Platform

For the two degree of freedom platform, the design based on commercial vehicle simulators is made. First, the top platform consists of three legs. One has a universal joint fixed to ground and its rotation about its axis has been removed. This joint will constraint the system to the two degrees of freedom desired. Additionally, the platform has two other legs that consist of a revolute joint, and two spherical joints. The revolute joints represent the input motors, which will be high torque low speed motors, and the spherical to spherical links consist of end rod joints.This configuration is shown in Figure 4.

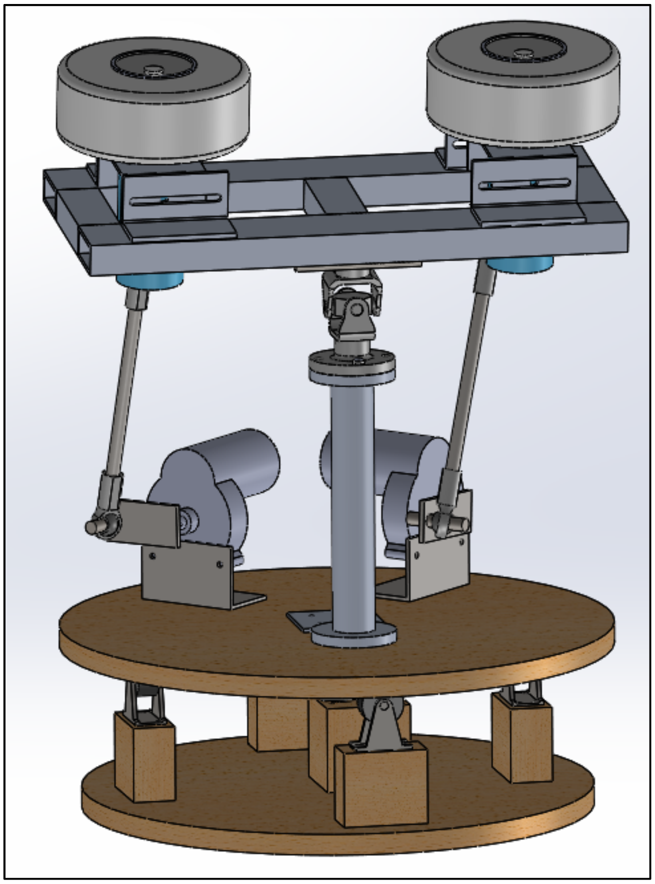

Figure 4. 3-DOF Platform

This platform is of utmost importance as it will provide the ability for shot customization in terms of lobs, driven, curved, and angled shots. The final platform of yaw will allow for slow rotation and player tracking both in reverse in forward motions, the key to the platform will be the motors used to provide these operations, of which will be controlled wirelessly. The yaw platform was supported with a quartet of rigid caster wheels which evenly distributed to vertical load of the platform.

2.2 DC Motors

The two flywheels provide the necessary force to launch a ball as it is pushed through them, this function is of dire need to the user's desire to provide different speeds of shots and curves. Curves are assured as one motor can be controlled to rotate faster than one another. The motors used were repurposed from an already existing softball machine, and so were not ideal for soccer ball purposes but still provide a necessary punch. These motors are rated at 90 volts, 3 amps, and 4500 RPM which, through testing, was found to be sufficient for this prototype. Likewise two high torque motors were used to operate the two degree of free of pitch and roll, of which could be stopped to ensure a desired degree. These motors were rated 12 volts, 15 amps, with a torque of 30 Nm and 160 RPM which was more than enough for the prototype's purposes. For the yaw platform a high torque motor with a maximum speed of 12 RPM and torque of 12Nm was used for player tracking, of which was capable of rotating up to 200lbs of force. All of these motors were controlled individually as will be discussed in the next section.

2.3 Motor Control

For the control of all motors in the system, they must both be able to be controlled by the user, but also intake information from another and convert it information to be used in player tracking or shot manipulation. The first motors to be modified by the user will be the flywheels, as the user will tell the launcher what kind of pass or shot they want, thus telling the Raspberry Pi and later the Arduinos to adjust the speed of the flywheels. After a speed has been determined, the angle of the pass or shot must also be changed, Raspberry Pi will also do this by communicating to the Arduinos controlling the two degree of freedom platform which will adjust the pitch and roll of the launcher as a whole. Each of these motions will control the vertical and horizontal angles of the shot respectively as designated by the user. Lastly, the yaw motion of the platform that will both track the user and predict its position will be controlled by the Arduino, but will intake information by the Raspberry Pi of which will compute the other inputs into the equations needed to find ideal future position of the user.

Beginning with the flywheels, the motors must have complete control, this will be done using a combination of N-Channel power mosfets, Pulse Width Modulation, and the Arduino. This circuit can be seen in Figure 5.

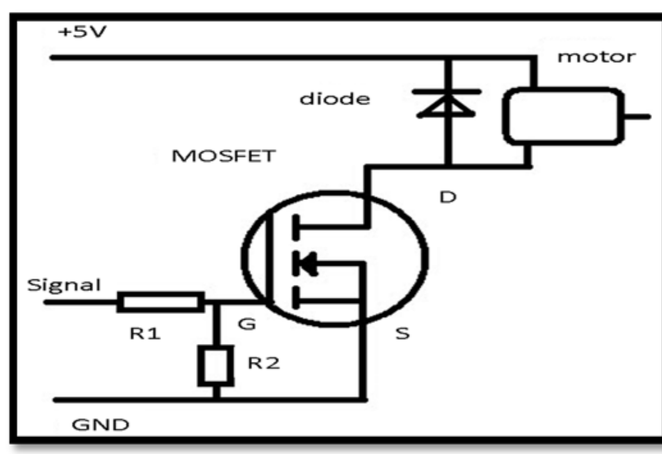

Figure 5. Flywheel Motor Control

This simple yet effective circuit will allow for simultaneous control of the flywheel motors regardless of their high power capabilities, a Schottky Diode is used for protection of the motor from the power source and the N-Channel mosfet acts as a switch [7]. Next the two degree of free platform will be controlled by their own individual motors, of which will be controlled using a Monster Moto Shield Driver, of which will be able to simultaneously control the two motors for speed, braking, and reverse and forward actions. This shield is illustrated in Figure 6.

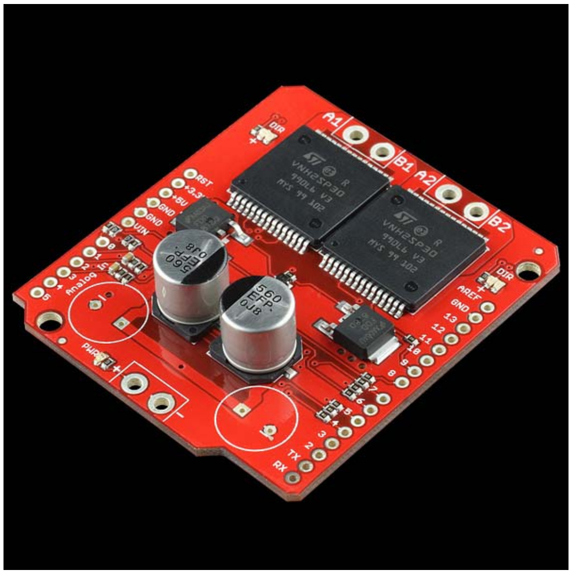

Figure 6. Monster Moto Shield

This shield acts similarly to an H-Bridge, of which can be a collection of mosfets and is used for various types of motor control. The code for the driver could then be used through Arduino to provide a wide range of user inputs and customization abilities.

Finally the yaw platform motor will be intertwined with a Raspberry Pi with serial control, allowing for the Pi to process information and deliver a command to the Arduino. By interacting with the Open Cv capabilities, the Pi will direct the Arduino to move the motor in the desired direction to achieve player tracking, this will be further explain in Player Tracking.

2.4 Wireless Control

The prototype and product's main goal is to accomplish the autonomous nature of the launcher, for this to occur there must be components that will allow for wireless control of the five dc motors.

The chosen Wi-Fi module was the ESP8266 of has various traits which aided in the decision with cost and power capabilities being of utmost importance. With the module's ability to quickly be installed and used with an Arduino or any other micro controller, the ESP 8266 could be implemented as simply as Wi-Fi transmitter [8].

The module is shown in Figure 7, and provides ports for use in microcontrollers, of which will be wired to the various Arduinos. Not only is the module compatible to the Arduino and its economically efficient, it is also very powerful for its size and cost as it has a memory of 1MB and data speeds acceptable for our purpose.

Five Wi-Fi transmitters will be used to control the motors with each motor controlled in its own right, with information being fed to a wireless server controlled by a computer and eventually the Raspberry Pi.

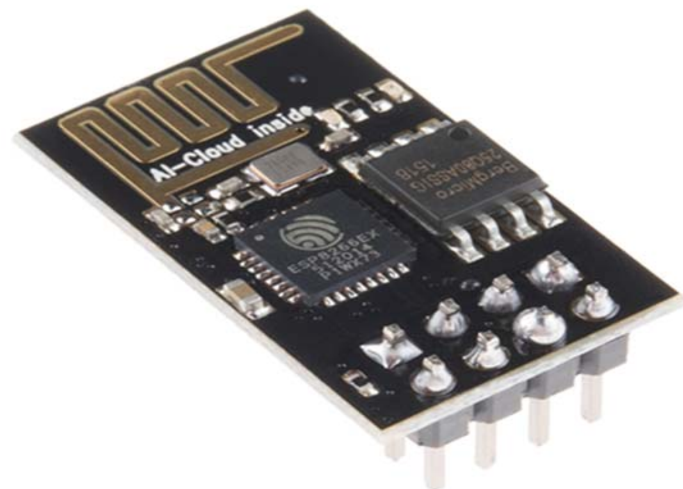

Figure 7. ESP8266 Wi-Fi Transmitter for Arduino

2.5 Power Supply

With emphasis on being able to use the ball launcher on a soccer field with little to no hazards to other players on the field, safety is of great concern. This concern has risen the challenge of using portable batteries as the power source for the launcher as well as other electrical components such as the Raspberry Pi and Arduino Uno, all of which will be operated wirelessly.

Primarily, the RPI and Arduino are usually powered by a usb power source from a computer or outlet, consequentially a set of alkaline batteries can also be used as a wireless power source solely for the proving of independent power. An adapter employed along with a set of alkaline batteries are used for the processing devices while a much larger and higher capacity battery is used to power the motors.

There are numerous challenges when determining the necessary battery for an application, it is even more difficult when costs, weight, and capacity times are all important variables needed for a product to succeed and function as intended. The typical battery found in many cases is the lead-acid battery due to its relatively inexpensive costs and multi-purpose ability, though it does have drawbacks such as its weight. Other types of batteries include Nickel-Metal Hydride, Nickel Cadmium, Lithium Ion, Lithium Ion Polymer, and Alkaline. Each having their own pros and cons relative to their use. With some having greater energy to weight ratios than others, but with relatively high costs. For the purpose of this project, the lead acid battery will be used to cut costs but also because of its uses. [9]

Portable dc batteries like car batteries are usually rated in with a range of 12-15 v and 40-45 amphs thus proving quite a large energy capacity, though are also fairly heavy. Finding a dc power source for the flywheels motors is a difficult task, this is due to the heavy needs of the motors. Originally the dc motor specifications as previously mentioned are a max of 90 volts and 3 amps. This indicates that the motors can retain a maximum of 270 watts of power, though for this prototype a variable speed will be reached in the range of 40-60 volts and 3 amps, with possible power input of 120-200 volts.

A boost converter can be created by building a circuit consisting of diodes, transistors, a capacitor, and or an inductor, thought this would require far more research and experience. By purchasing a readymade device, reliability is greatly increased. Similarly to how voltage will be controlled through the motors, voltage is increased through the boost converter by tracing advantage of the inner resistance of an inductor [10].

Due to the uses of the prototype, the two degree of freedom and yaw motors will only operate for small amounts of time, while the flywheels will run continuously. These requirements essentially translate to three motors requiring doses of power for shorts periods, and the others large amounts of continuous power and draining the batteries quicker. By using a pair of 12v 15amh rechargeable battery, testing and usage of the motors will be used for continuous amounts of time. Figure 8 shows the battery that is used, and another that holds a higher capacity and may be also considered in the future.

Figure 8. Universal Power Group Rechargeable Battery

2.6 Player Tracking

Object detection and segmentation is the task that Open CV computer vison is developed for, this field of work is still an open problem that is still being researched today. One of the easiest ways to detect and separate an object from the background is a color based method. With the assumption that the object being tracked is a complete separate and distinguishable color from the background, a successfully object segmentation can occur. For the tracking of the soccer player an assumed color of purple is chosen to differentiate the object from the surroundings. The webcam will be procced through a binary threshold, provided to use through Open CV function that will allow the thresholding to the color purple. That is to say the video image would be converted to black and white pixels in a separate window, where the white (1) color depicts the finding of purple color in the image and the black (0) pixels depict lack of purple color. This can be seen in Figure 9. Open CV process this by capturing an image and video in an 8-bit, unsigned integer, and BGR format [11].

Figure 9 describes the color array broken down to its Blue, Green, and Red primaries. It is true that the BGR color space, (integer values rages from 0 to 255) can be suitable for color segmentation, however, the HSV color space is the most suitable color space for image segmentation. The HSV stands for hue, saturation, and value

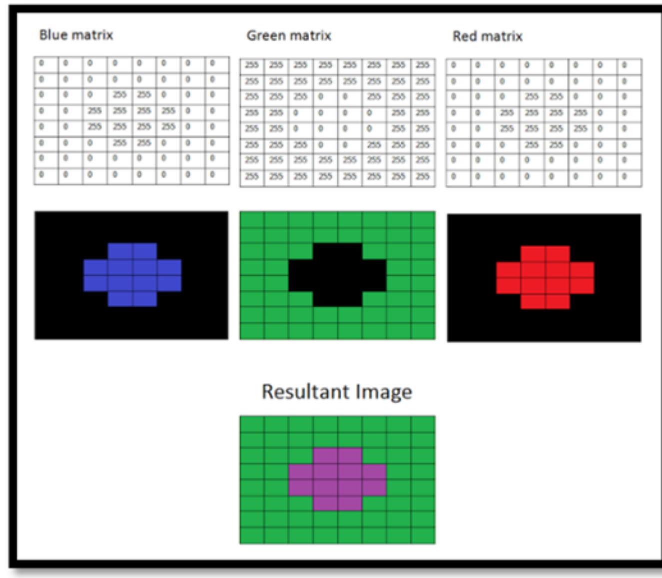

Figure 9. Open CV Color Detection and Building of Matrix

(brightness). Unlike RGB, HSV separates the image intensity, or luma, thus getting better information from the color space thus distinguishably the color from one another easier. Open CV makes the use of HSV simple, thanks to a prebuilt function that converts between RGB and HSV to be implemented. The range for hue, saturation, and value are respectively 0-170, 0-255, and 0-255. The hue represents the color, the amount of the color mixed with white is its saturation, and value is the amount mixed with respect to black. In the development of using the Open CV library to track objects the integer value is determined by using multiple track bars that can slide to the desirable range, described in Table 1 for hue integers. The saturation and value track bar is used to get rid of the white noise the webcam may pick up due to lighting and surface of the object [12].

Table 1. Values of Hue Integers to Threshold Specific Colors

Threshold Specific Color	Values of Hue Integers
Orange	0-22
Yellow	22-38
Green	38-75
Blue	75-130
Violet	130-160
Red	160-179

After thresholding the image binary image may contain numerous imperfections, white isolated object might be visible at random areas on the screen, this may be due to white noise or a small object

with the same color. To get rid of this a morphological opening technique is applied. Morphological image processing is a collection of non-linear operations shape or form of the image. Typically the Morphological technique probes the image with a structuring element that transform a “hit” pixel to the desired color. The structuring element can be thought of as a binary matrix of pixels that restructures the pixel values of 1’s or 0’s. For Open CV color tracking two commonly used morphological operations are erosion and dilation. A square erosion matrix shrinks an image by stripping away layer from the boundary of the regions, eliminating small details. Whereas, dilation, is completely opposite, it adds layers of pixels to the boundary region. Combination of these creates a compound operations opening or closing filters that can eliminate noisy details while not damaging the object of interest.
After detecting the object, locating the real world position X and Y coordinates of the object. To describe objects after segmentation, Open CV image moment function is used. Image moment is a weighted average of the pixels intensities use to find the orientation and the centroid of the object. Using the 0th central moments the binary image is equal to the white area of the image in pixels. An example of this method is done by assuming the binary image is less than or equal to 10000 pixels, no object is detected since the expected object will have an area greater than 10000 pixels. This method can only work with 1 of the particular object. Shape detection and tracking using contours. Open Cv contour function allow sequences of points of vertices to create “white patch” polygons. Open CV provides a basis for player that is both accurate and reasonable for the purposes of this launcher and its tracking capabilities. In order to work together with the yaw platform, a program was devised using C++, that was able to control a motor to ensure the target was always in the designated location, providing proof of concept. This is shown in Figure 10.

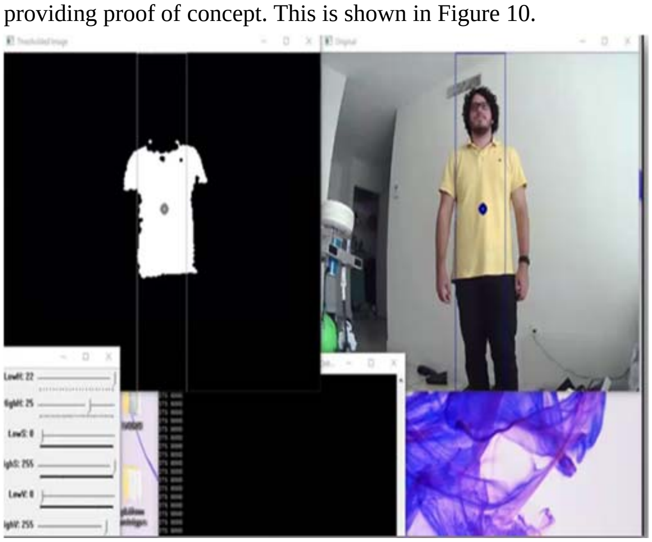

Figure 10. Object Detection, Color Recognition and Motor Movement

3. DESIGN ANALYSIS

3.1 Vibration Analysis

For the design of the platform, the only component experiencing hard vibrations directly is the flywheel motor mounts. Therefore, a natural frequency study was done for 10 nodes and evaluated against the different rotations of each motor. To elaborate more, since the motors bought from JUGS are certified to be balanced, the only vibrations in the system come from the rotational speed of the system. Assuming that only this vibration is transferred to the mount, the resonant frequencies are evaluated. Using SolidWorks Simulations, the natural frequencies of the mount were found; see Figure 11 and Table 2.
For the simulation, the weld of the mount was simulated as accurately as possible, the remote load of the motor, and gravity were considered.

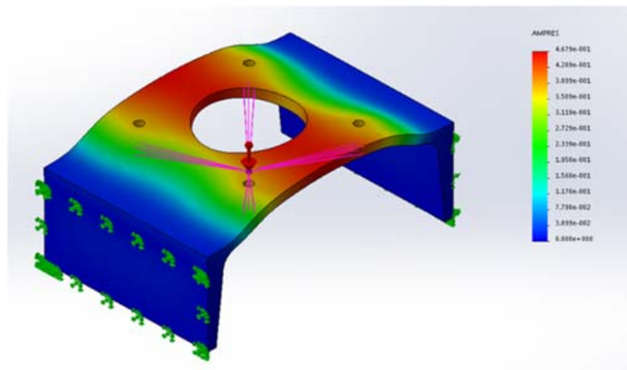

Figure 11. Vibration Analysis via SolidWorks Simulation

The natural frequencies for 10 nodes were obtained and displayed in Table 2. Next, assuming the range of rotational velocities used in the flywheels goes from 1000 to 4000 rpm, the range of vibration frequencies will be equal to 16.67 Hz to 66.67 Hz. Therefore, none of the frequencies inside the range of rpm used will cause resonance in the motor mount.

Table 2. Motor Mount Natural Frequencies

Mode No.	Frequency (Rad/sec)	Frequency (Hertz)	Period (Seconds)
1	3819	607.9	1.65E-03
2	7962	1267.2	7.89E-04
3	9520	1515.1	6.60E-04
4	25486	4056.3	2.47E-04
5	33781	5376.5	1.86E-04
6	39153	6231.4	1.60E-04
7	41883	6665.9	1.50E-04
8	55722	8868.4	1.13E-04
9	57573	9163.1	1.09E-04
10	60328	9601.5	1.04E-04

3.2 Stress Analysis

Since multiple components of the system need to be manufactured to fit the proposed design, some of them turned out to look not strong enough, and stress analysis was done to clear out any doubts on their designs. First, the motor mounts were tested to hold the motor-wheel assembly weighing 15 lbs (Figure 12).

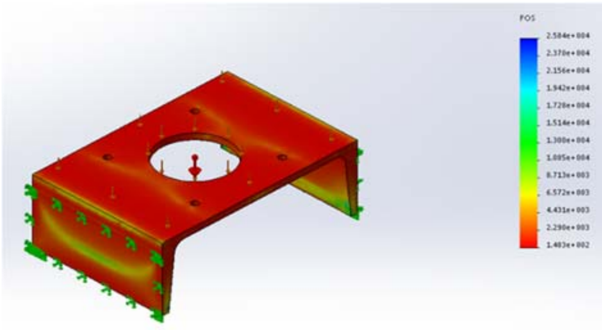

Figure 12. Motor Mount FOS Stress Analysis

While the figure color scheme is misleading, thanks to the material selected for the motor mount, the minimum safety factor was 148.3, which is relatively high, but was needed to make sure the vibrations of the motor would not be an issue in the future.

The next component that was tested were the tabs joining the spherical joints to the top platform seen in Figure 13. Initially, the component consisted of a single tab connected to a threaded rod held in place by steel nuts. However, the safety factor of a single tab for an estimated load of 50 lbs, was of 1.6. Therefore, a second tab was added, and the threaded rod was elongated to allow enough clearance for all bolts needed.

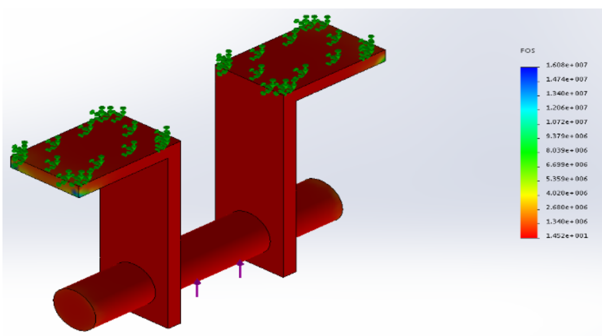

Figure 13. Tab FOS Stress Analysis

Adding the second tab in the component increased its safety factor to a minimum of 14.5, which gives an overall safe contingency for one of the least safe items. Similarly, the link connected to the motors in the 2-DOF platform will have a similar structure and therefore, needed to be analyzed (Figure 14).

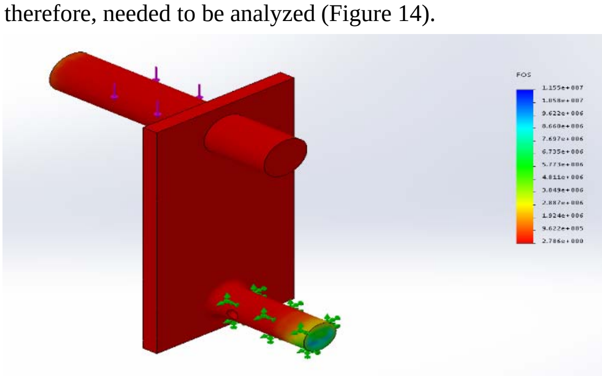

Figure 14. Motor link FOS Stress Analysis

Consequently, it was found that the link connected to the motors and spherical joints would have the lowest safety factor with a value of 2.8 seen in Figure 15. However, it is important to note that this component was analyzed under a load of 100 lbs. which is relatively higher than what is expected. The last component that was analyzed using the same method was the bottom platform that is providing the yaw motion. Since the budget is the biggest design constrain, there are multiple components that will be made of wood, including this platform. Therefore, for this component, materials were researched previously and pine was selected as the best available wood for the platform. The data of the material was obtained online, and a custom material was created on SolidWorks to simulate pine wood.

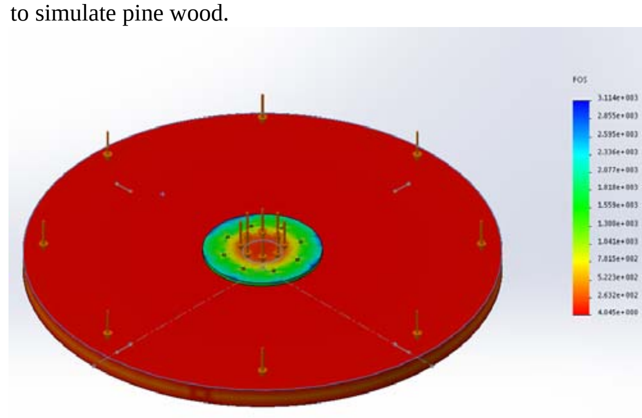

Figure 15. Wood and Hub Yaw Platform Stress Analysis

The component was rated under 200 lbs. which is double the maximum amount of weight expected to account for any miscalculations on the overall system design. The minimum safety factor found was of 4. Something that needs to be considered when evaluating this component is that there would be four more supports on it that will be caster wheels to help distribute the load while avoiding any friction on it. Therefore, the component will experience less critical loads through its body as it is seen in its stress analysis.

Overall, all critical components were evaluated depending on its design due to their design needs to fit the prototype that will be done. For the rest of the components that will be purchased, all of them are rated from their manufacturer. Therefore, the team did not see a need to simulate those components. However, the team made sure that the ratings on all components exceeded expectations, as it was mentioned, to account for calculation errors.

4. PROTOTYPE APPLICATION

Given the demands of the sponsor and the needs of the SkillCourt training methods, the launcher was destined to be incomplete due to lack of skills in electrical and computer software programming. The end goal of the prototype was to be able to completely control the various customizations of the launcher and constitute them into a realistic soccer drill. This application could only succeed with additional assistance from software engineers who could provide a simplistic yet meaningful application for a user. This possible application was depicted in Figure 16.

Due to the many demands of the launcher, the severe lack for implementation of the wireless and autonomous control are of great potential. The future for the launcher will be directly correlated to the skills of the Electrical and Computer software engineers. These

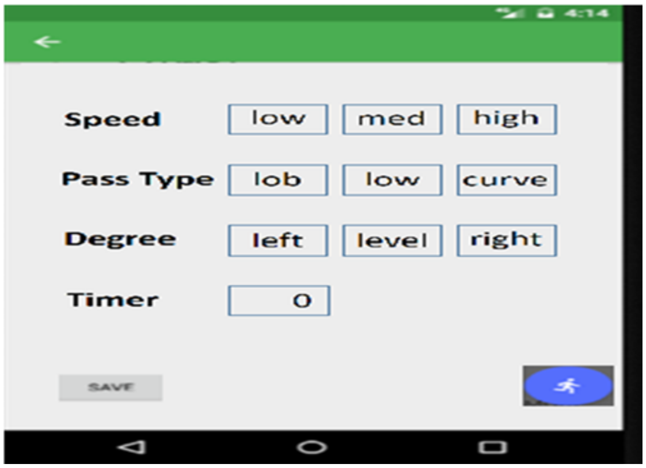

Figure 16. Ideal SkillCourt Application Control

future works will directly ensure that the launcher does achieve safety requirements and complete autonomy through its electrical and computer software capabilities.

5. PARTS LIST

Table 3. Prototype Parts List

Part	Number of Parts	Part	Number of Parts
Aluminum Rectangular Tubing	1	Arduino Uno	4
Aluminum Rectangular Tubing	1	Raspberry Pi	1
Threaded Steel Links	2	Arduino Monster Moto Shield	1
Steel Ball Joint Ends	4	Rechargeable Battery	2
Steel U-Joint	1	Boost Converter	2
Aluminum Tube	1	N-Mosfet (Flywheels)	2
Steel Disk	1	Diode (Flywheels)	2
Low Carbon Steel Channel	1	Diode (2DOF)	2
Steel link	2	Diode (Yaw)	1
Low Carbon Steel Rectangular Bar	1	Yaw Motion Motor	1
Low Carbon Steel Rod	1	Two DOF Motor	2
Grade 8 Steel Fully Threaded Rod	1	Flywheel Motor	2
Aluminum Disk	2	Rigid Caster Wheels	4
Grade A36 U Channel	1	Term Block (2 positions)	10

6. FUTURE WORK

With any product there is always room for improvement, whether it best manufacturing costs or durability of the machine. For this launcher, the areas that can and will be improved in the future include programming, electrical, and material properties. The reason behind most of the components used were of cost and practical use, future work would include using material from a supplier that will come cheaper and just as sufficient or of higher quality with a slightly higher price. Material chosen could also be reclaimed after a substantial duration of use rather than tossed in a landfill.

Work regarding the automated collection and loading of the launcher previously mentioned is still under design and manufacturing considerations, but will become an integral necessity. This component of the SkillCourt ball launcher is a projected within itself, and requires careful safety considerations and automated control, similar to those of the motors. Overall, continuous work will be done for both the launcher and automatic loading which will require assistance from electrical and computer teams.

Likewise, the motors and batteries used may by swapped for those of an eco-friendly nature allowing for recycling of products and being certified for bio friendly uses. Obviously programming is at the core nature of the prototype, future work will include improving upon the processing power and response time of the Arduinos and Raspberry Pi used in this system and finally the SkillCourt application. The launcher relies on all components to successfully run simultaneously in a smooth operation, this will be a key trait that will need to be continuously monitored, compared, with many continuous trials made.

7. ACKNOWLEDGMENTS

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