SkillCourt Pad Design

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ABSTRACT
Even though roughly 50% of the world's population follows soccer, only 4% actively participates in the sport. At this junction is where SkillCourt rises. Creating and providing an interactive and informative athletic training system geared toward professional and amateur levels of soccer play was the goal of SkillCourt. To facilitate the availability of performance data a device was proposed that can quantify a user's physical exertion and play in statistics such as accuracy, force, and speed. In efforts towards accomplishing this task, the execution of creating what will be referred to as the SkillCourt Pad will be explored within this paper.

KEYWORDS
Skillcourt, Arduino, Potentiometric Sensor, Velocity Sensor, Striking Surface.

1. INTRODUCTION
In 2013, soccer reached an estimated fan base of 3.5 billion people. With this size of a following, it is easy to see that soccer is one of, if not the largest and most beloved sport the world over. In 2006, FIFA conducted a global survey, known as the Big Count, aiming to determine the count of soccer players [1]. The survey determined that there were roughly 265 million professional, registered, and unregistered soccer players worldwide.

1.1 Problem Statement
This paper describes our endeavor to design an athletic apparatus that caters to the requirements of the many involved and interested in the world of soccer. In this report, the authors describe the methods taken to create a durable apparatus for multiple terrains as well as lightweight to enhance the mobility of the gamepad itself. The focus was given to the addition of velocity, position, and force sensors as features to the SkillCourt Pad. The pads must be able to detect an accurate reading of these three sensors when the sports ball (primarily soccer) impacts the pad. There are also LED lights that will be implemented into the pads as markers to where the user should aim to hit. All these features are to be held inside the pads and protected so that the equipment does not become damaged. The velocity aspect will record the speed of the ball upon impact with the pad. The position attribute will discern which side of the pad is hit by the ball. The force feature will approximate the amount of force the pad is struck with by the projectile. All relevant information will be available to the user of the SkillCourt training system. The purpose of recording all this data is for both amateur and professional athletes to have feedback of their performance in hopes of aiding with the improvement.

1.2 Motivation
The design for the SkillCourt pad is aimed primarily towards soccer. Soccer is the most played sport in the world, with an estimated fan base of 3.5 billion people worldwide. As for here, in the United States, the popularity of soccer has been on the rise since the world cup of 1994 which was hosted by the United States. Thus, the market for soccer equipment is always on the rise. The functionality of the SkillCourt pad would catch the attention of just about any type of soccer player, from beginners to professionals. For the beginners, it could be used as more of a game comparing individual scores, since one way of using the design would be to track how many times the target was hit correctly. Whereas for the professionals, the design is useful for group training or even individual training focusing on improving fundamental soccer skills such as passing, accuracy, power, and reaction time.

Additional motivation for our efforts include expanding upon the original design given to us by the proprietor of SkillCourt LLC., Gudmundur Orn Traustason [2]. To assist us in this endeavor we must follow the patent published on February 2, 2016. The goal of the design is to be able to reach the largest group of individuals possible. Since the differences in terrains and climates are strongly considered in the design as well as durability and mobility, there should not be any problems in reaching different countries that have harsh climate conditions. As well, the SkillCourt pad is planned to be available to both soccer clubs and school systems, with the intention of improving the skill level of soccer players globally.

1.3 Literature Survey
1.3.1 Position Sensing
Position sensors are used to measure the distance a body travels from a reference location. Many methodologies for determining position exist, including Potentiometric, Capacitive, Linear Voltage Differential Transformers, Magnetostrictive, Eddy Current, Hall Effect, Fiber-Optic, and Optical [3]. Though many methods exist, few present any reasonable functionality within the SkillCourt Pad ecosystem. The clear majority of the available methods could not work within our reuirements. Many methods require properties that a soccer ball does not possess (such as electrical capacitance for capacitive position sensing or a magnetic field for Hall Effect, Eddy Current, or Magnetostrictive position sensing). While other methods simply measure relative

distance variations and would not be applicable to determining the impact position upon a surface.

One promising method is the potentiometric, or resistive-based position sensors, as they work based on applied pressure rather than any electromagnetism phenomenon. Potentiometric Sensors work on the principle of a semi-flexible material deforming, causing a grid of electrodes to make contact providing a coordinate position upon a plane based on an output voltage.

While still maintaining a similar level of accuracy as a resistive touch screen, a series of ultrasound (US) sensors could be used in a method called triangulation. With the use of two or three US sensors, a bit of geometry, and trigonometry, an accurate position within a coordinate system, this would be applied to the striking surface, can be achieved. Finally, a more binary state position sensing can be achieved with the use of force sensors. With the inclusion of multiple force sensors, a comparison of the force readouts of all sensors can provide a general location, left or right, top or bottom, of where the soccer ball made contact.

1.3.2 Materials

Due to the nature of the pads use, as well as its sensitive internal electronic components, the general design of the pad incorporates an outer shell of a single material that can house several layers of other materials. These inner materials would primarily function to give incoming projectiles a surface to rebound off with as much energy as possible and to protect internal electronics from all shock received from the strike of a projectile.

Initially, the first choice to act as a casing was wood due to its cost and ease to work with. However, wood would degrade over time and would not do a sufficient job of protecting internals from external elements. Carbon fiber would be the ideal choice. However the process to mold carbon fiber is extremely costly and outside of the realm of our capabilities. The best choice for our purposes was concluded to be aluminum. Aluminum is easy to manipulate, oxidizes only external layers, has good yield stress for our purposes, and quite affordable [4].

Internal materials consist of two acrylic layers, one being Lexan due to its high-stress tolerance and flexibility, and a second layer to support the initial layer of Lexan as well as to sandwich the sensors. To protect the electronics two material types were explored, rubbers and foams. Polysiloxane polymers, or Silicone as it is commonly known, come in several forms such as gels, resins, fluids and elastomers. For the needs of SkillCourt, elastomers, also known as rubber, were researched. Silicone rubber is an inorganic material not comprised of carbon bonds. Instead it uses silicon and oxygen bonds that are stronger and more flexible than the bonds found in organic rubbers. This allows silicone rubbers to have a higher tolerance to changes in temperature, has a longer lifespan than common rubber, and promotes a higher resilience to ozone and ultraviolet environments [5]. Along with this resilience comes the ability to tailor the silicon rubber formula to the needs of the user, such as altering the tear strength, elongation and compression the material will experience, and the temperature ranges it must tolerate. In industry, there are two major types of silicone rubber, Liquid Silicone Rubber (LSR) and High Consistency Rubber (HCR). For the purposes of SkillCourt, HCR was considered due to its lower cost, broader range of temperature resilience, and better compression set resistance. Due to weight considerations, though, the rubber option is less intriguing and a path towards some form of polyurethane or polystyrene foam was chosen.

1.3.3 Velocity Sensors

Velocity sensors are used to calculate how fast an object is moving. Velocimeters are typically defined as a device for measuring speed, as for fluid flow or sound, but there are some that do measure the speed of a moving object. One type of velocimeter that could be of use are laser surface velocimeters. The purpose of the velocity sensor in the design would be to record the velocity of the ball as it meets the pad. Now, the only problem with this meter is that it is a non-contact optical speed sensor measuring velocity and length of moving surfaces, but the meter uses the Doppler Effect phenomenon which is quite helpful for this problem. This leads to another velocity sensor that uses the Doppler Effect HB100 Doppler Speed Sensor [6]. This sensor can record the speed of an object that is coming at it from tens of meters away which is ideal due to the scoring area in soccer generally, being within 25 meters of the goal posts.

1.4 Current Benefits

As described in this report, the current SkillCourt Pad is capable of measuring the forces applied by a soccer ball. Improvements were also made in the overall construction of the Pad, being capable of withstanding multiple impacts without falling apart as previously familiar. Implementing all the necessary electronics within the Pad’s internal structure aided in the improved portability of the Pad, removing external wires from the system and one less source of failure.

2. DESIGN

2.1 Dimensions

With portability and modularity being an important aspect of the SkillCourt Pad, the footprint of the design will be a defining specification of this product. For modularity purposes, a regular polygonal shape was desired to aid in a tessellating configuration. With a rectangular design, multiple pads can be used in conjunction with one another to produce a larger training area both outdoors and indoors. At 36” wide by 18” tall (91.5 cm by 45.75 cm) the pad will provide a realistic passing area, as these dimensions were chosen to mimic the average stance of a soccer player expecting a pass. The thickness of the pad will be largely dependent upon the volume requirements of the included electronics, but a goal of less than 3” thick (7.5 cm) is desired.

2.2 Materials

Within professional soccer play, an exerted force of 315 lbf (1420 N) upon the soccer ball is not uncommon, as such designing towards sustaining a minimum of these expectant forces is required. As well as designing towards the expectant forces, a desired feature of the SkillCourt Pad will be interactive illuminating forward faces, because of this a material with translucent properties and strength rated to sustain dynamic impacts of 315 lbf (1420 N) is desirable.

As portability and outdoor use are concerns as well, a lightweight chassis that will also sustain the perils of weathering is required. The chassis would also have to endure impact forces of up to 315 lbf (1420 N), as previously stated above. Achieving this task would come done to either a metal casing or plastic mold. For this design, a choice of aluminum was made, which brings another concern along with it, temperature.

Finally, protecting the electronics from damaging vibrations. Achieving this problem will be the use of a silicone rubber mat or a foam insert to embed the LED's inside, immediately behind the impact surface, and a high impact foam rear housing where most included electronics would be placed.

2.3 Electronics

Force sensors, velocity sensors, position sensors, embedded electronics, and a power supply. A fully enclosed product is the goal for the SkillCourt Pad when it comes to the electronics. As discussed above, the force sensors will be required to register a reading, at least, up to 315 lbf (1420 N). Flexible piezoresistive film force sensors will be used to aid in the pads slim thickness as well as provide an accurate readout of the applied forces.

Determining the velocity of an incoming soccer ball will be achieved using a velocity sensor, namely the HB100 Microwave Sensory. Many velocity sensors work around the principle of optical tracking, this approach does not work for the SkillCourt Pad, as the electronics will not be exposed externally. As such, a system that works around the Doppler effect was chosen. The use of the Doppler effect also poses a challenge though, any object approaching the sensor perpendicularly will not be registered. Fortunately, the sensor will be placed parallel with the striking surface, as readings of any object moving perpendicular to the surface, is undesired.

Detecting the location of impact on the striking surface provides increased functionality of the SkillCourt Pad, in the sense that a single pad can simulate multiple striking zones. An example being, in soccer, when players are passing the soccer ball to another player, special attention must be taken as to which foot they are passing to, as this can be the determining factor between a successful goal and a missed pass. Simulating this scenario in the SkillCourt Pad simply requires the designation between a left and right side, emulating a pass to the left or right foot of a teammate. To achieve this level of position detection no additional electronics were required as a comparison between the readouts of the multiple force sensors can dictate a general location, whether that be more force on the left or right side, of where the ball struck the surface. Another use case for position detection was to aid in the calculation of an accurate force reading. With multiple force sensors located in randomly distributed locations, the readings obtained would not be the true force exerted by the soccer ball, due to the force being equally distributed and not being directly applied to an individual force sensor. As such, if an accurate position of impact is known, statistical methods could be applied to calculate an accurate force. This approach would require the use of either a potentiometric position sensor or a triangulation method using sonar sensors.

Other embedded electronics used within the SkillCourt Pad design were an Atmel based microcontroller, led strips, ambient light sensors, and an enclosed power bank. Due to our desire for the SkillCourt Pad to be a training device, a method of communication between the user and the pad must be available. Accomplishing this task will be a set of led strips behind the striking surface. In this way, the led strips will allow the user to understand whether the pad is expecting a hit and which side (full face, left or right), by lighting in different colors. The ambient light sensor will be used in conjunction with the led strips to vary their brightness in accordance with the surrounding light levels. A microcontroller was chosen as the core electronic to take all the input data available from the force, velocity, position, and ambient light sensors, and produce functional information for the SkillCourt Pad users. Atmel was chosen as the microcontroller manufacturer as the Arduino brand is a global giant and produces cheap, inexpensive hardware available to many. Finally, an internal battery bank was used to supply power to the whole system, allowing for outdoor and indoor use, even if an external power source is unavailable.

3. DESIGN ANALYSIS

3.1 Component Design

Due to a simplistic design footprint, namely rectangular, all the components are designed with the same 36" x 15" frame while the thickness was adjusted to maintain a Factor of Safety (FoS) above one.

3.1.1 Striking Surface

The proper translation of the experienced impact force is critical for accurate force readings. Achieving this goal meant the use of two different sheets of plastic: acrylic and polycarbonate, and a spacer between the sheets that will be used to focus the applied force towards the force sensors. The exposed surface was chosen to be Lexan, a polycarbonate derivative, due to its capabilities in withstanding high impact forces and the support surface was selected to be Plexiglass, an acrylic derivative, to provide a more rigid backing for the striking surface. Both sheets are designed at a thickness of 0.093".

3.1.2 Vibration Isolation

Due to the high impact forces that are to be expected, vibrations within the pad are inevitable. Dampening the vibrational effects upon the electronics is required for the longevity and accuracy of the electronics [4]. Two sheets of foam are to be used, one for embedding the LED's behind the striking surface, and a second to house the electronics within. As the foam sheets are available in 2" thick sheets, that was the dimensions used in our product.

3.1.3 Housing

Each sheet is independent of the sheets around them. Without a housing, the SkillCourt Pad would have no rigidity. Aluminum was chosen to provide the necessary rigidity as it is both lightweight and durable. The housing was designed in two parts, a front enclosure, and a rear panel. The front enclosure will include a 1" border that will expose the striking surface while also securing the pad within the housing, and the rear panel will be removable to allow ease of access to the internals. The aluminum chosen was a 0.125" thick sheet of 5052-H32 aluminum alloy.

3.1.4 Structural Design

The striking surface will be designed with a spacer between the acrylic and polycarbonate sheets, with the goal of focusing the force of impact upon the force sensors, rather than across the entire support face of the polycarbonate sheet. Behind the striking surface, the electronics will be housed and protected from vibration damage within the two foam sheets. These four layers will be enclosed by an aluminum sheet housing.

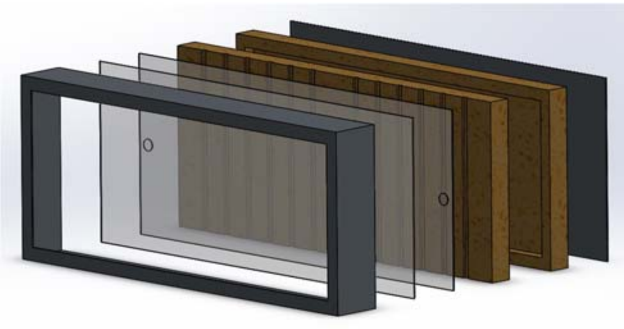


Figure 1. Internal Components and Design of SkillCourt Pad

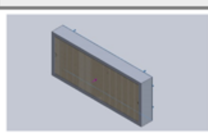
3.2 Finite Element Analysis

Validation of our design was provided using SolidWorks and the Simulation add-in. A static simulation was performed upon the Pad with the setup as described in '5.1.4 Structural Design'. The contact boundaries are defined as 'No Penetration', this allows slippage between surfaces without penetration, for all but one coincident contact surface, the aluminum enclosure and rear panel are defined as 'Bonded', no motion of parts relative to each other.

The pad was supported with a fixed geometry across the rear panel, simulating a condition of being mounted on a wall. A force of 1418 N was applied at the center of the striking surface perpendicular to the plane. A standard mesh was applied and the simulation was run, the results obtained were as follows.

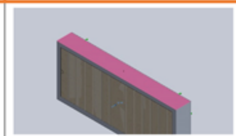
Through the process of using the SolidWorks Simulation features, data was obtained pertaining to applied and resultant forces that occurred within the system, the strain that the system underwent, and the deflection observed upon the components of the system.

Table 1. Loading Conditions for the Support and Applied Forces of the Proposed SkillCourt Pad Design

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** **1 face(s)** **Type:** **Fixed Geometry**

Resultant Forces

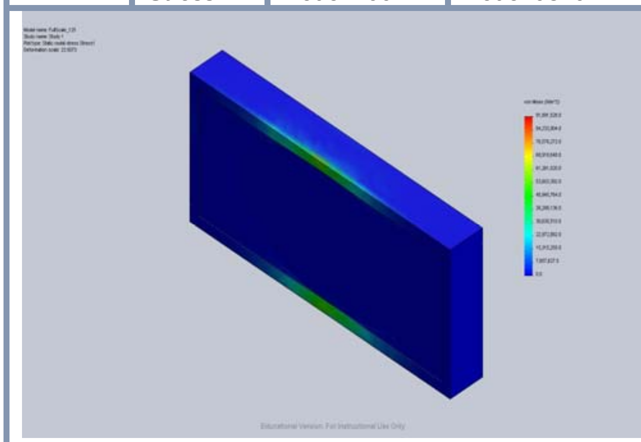
Components	X	Y	Z	Resultant
Reaction force	-0.178337 mN	0.206292 mN	1418 N	1418 N

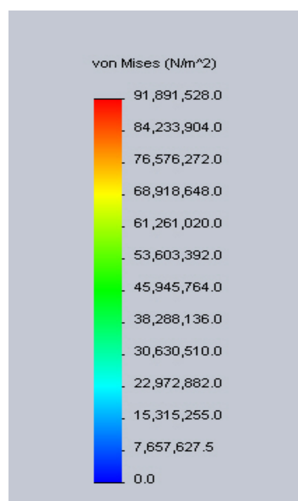
Load name	Load Image	Load Details
Force-1		**Reference:** **Face< 1 >** **Type:** **Apply force** **Values:** **—, 1418, — N**

As stated above, representing a professional kick localized towards the center of the striking surface, a force of 1418 N was applied perpendicularly towards the striking surface located at the geometric center of the plane and the rear panel has an applied fixed geometry support structure.

Table 2. Stress Analysis of the Proposed SkillCourt Pad Design

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.0150068 N/m^2 Node: 4991	9.18915e+007 N/m^2 Node: 9819





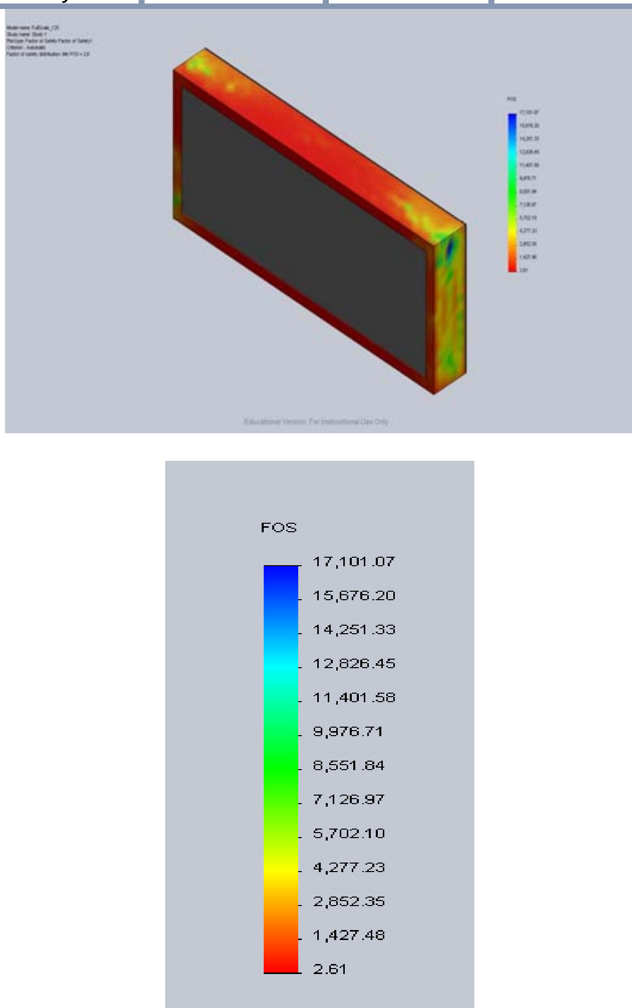
FullScale_125-Study 1-Stress-Stress1

As seen from the data obtained through SolidWorks Report feature, the striking surface has an applied force of 1418 N, and the rear panel absorbs a resultant force of 1418 N. Slight resultant forces in the x and y directions are likely results of any deformation that will be discussed later in the report.

Stress analysis and a factor of safety calculations are used to validate and expose defects in mechanical design. As such, these two features were gathered from the simulation using Von Mises calculations. Our minimum observed factor of safety was 2.6, well above the necessary 1.0 and within any margin of error.

Table 3. Factor of Safety of the Proposed SkillCourt Pad Design

Name	Type	Min	Max
Factor of Safety1	Automatic	2.61178 Node: 9819	17101.1 Node: 7290



FullScale_125-Study 1-Factor of Safety-Factor of Safety1

The deflection of the striking surface is important to take note of, as a deflection too large entails the striking surface contacting with the support surface at an undesired location leading to inaccurate force readings. An observed maximum deflection across the entire system was 3.92 mm. This metric is not a system critical measurement; it lends itself more to a design criterion. This expected deflection must be considered when choosing the spacers between the striking surface and support surface.

4. ELECTRONICS

Ensuring accurate readings from the included force and velocity sensors is a required task in providing a quality product for end users. Accomplishing this task requires calibration of the sensors against known inputs and correlating the outputs from the sensors to the known values. Through this process, signal relationships are created, and desired measurements are possible.

4.1 HB100 Velocity Sensor Calibration

Calibration of the HB100 was done through the simplification of the Doppler equation:

$$F_d = 2V * \left(\frac{F_t}{c}\right) * \cos\theta \qquad Eq. 1$$

In which, F_d is the Doppler frequency (the sensor input to the Arduino), V is the velocity of the target object (the output desired from sensor), F_t is the transition frequency (10.525 GHz for the HB100 sensor), c being the speed of light, and θ is the angle between the target object and the normal axis of the sensor (assumed to be zero for simplification purposes). Once all conditions and assumptions are substituted into the equation, the velocity of the target object then becomes a function inversely related to the targets reflected Doppler frequency:

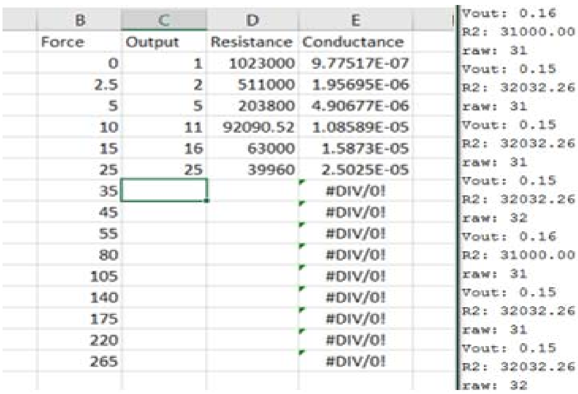
$$F_d = kV \qquad Eq. 2$$

In this equation, constant k is found through substitution of all the values and is 19.49 for velocity in kilometers per hour (km/hr) or 31.36 for velocity in miles per hour (mph).
Though simple to implement, this method overlooks the effects of off angled strikes, causing slight inaccuracies in readings. This method also does not take into consideration variation in the supplied transmitted frequency. Due to both variables being set to a constant value, the accuracy of the readings will be hampered, but ultimately still useful for gauging player performance improvement. Possible improvements to this method of calibration would be to implement a method of determining the angle of the incoming target object as well as determining a correction factor for the theoretical relationship through real world testing.

4.2 Force Sensor Calibration

Flexiforce force sensors are designed, such that, as the applied force is increased, the resistance decreases causing an increase in signal reading. If comparing output signal to resistance, the outcome is a power relation. This type of relationship is too sporadic in nature, as large changes in resistance are seen at low input forces with very little difference in resistance at high force inputs. For this reason, Flexiforce recommends relating the conductance of their force sensors to the input force, conductance being the inverse of resistance. Through this method, a linear calibration curve can be found and used to relate the force sensor signal to an applied force accurately.

Calculating the calibration curve for the force sensor required placing weights of known values atop a platform, whose additional weight was taken into consideration by attributing this unknown weight, from the platform, as the zero point. With each additional weight, a change in input signal was observed from the Arduino and correlated to a resistance value of the force sensor using a voltage divider circuit with a 10 kΩ resistor.



B	C	D	E
Force	Output	Resistance	Conductance
0	1	1023000	9.77517E-07
2.5	2	511000	1.95695E-06
5	5	203800	4.90677E-06
10	11	92090.52	1.08589E-05
15	16	63000	1.5873E-05
25	25	39960	2.5025E-05
35			#DIV/0!
45			#DIV/0!
55			#DIV/0!
80			#DIV/0!
105			#DIV/0!
140			#DIV/0!
175			#DIV/0!
220			#DIV/0!
265			#DIV/0!

```
Vout: 0.16
R2: 31000.00
raw: 31
Vout: 0.15
R2: 32032.26
raw: 31
Vout: 0.15
R2: 32032.26
raw: 31
Vout: 0.15
R2: 32032.26
raw: 32
Vout: 0.16
R2: 31000.00
raw: 31
Vout: 0.15
R2: 32032.26
raw: 31
Vout: 0.15
R2: 32032.26
raw: 32
```

Figure 2. Collecting of Input Data from Force Sensor

With the data collected and plotted, a linear trend line can be graphed and the correlation equation is obtained. This correlation equation is then used in the program that runs on the hardware. The equation was found to be:

$$Force \cong 2x10^6 * Conductance - 25 \qquad Eq.3$$

From this equation, the applied force is found with the units of pounds (lbs), to convert to kilograms, a conversion factor of 0.453592 can be multiplied to the found results.

Table 4. Gathered Experimental Data for Force Sensor Calibration

Force (lbs)	Input	Resistance	Conductance
0	1	1023000	9.78E-07
2.5	2	511000	1.96E-06
5	5	203800	4.91E-06
10	11	92091	1.09E-05
15	16	63000	1.59E-05
25	25	39960	2.50E-05
35	32	31000	3.23E-05
45	38	25947	3.85E-05
55	42	23381	4.28E-05
80	50	19480	5.13E-05
105	62	15516	6.44E-05
140	67	14284	7.00E-05
175	77	12299	8.13E-05
220	87	10770	9.28E-05
265	96	9667	1.03E-04

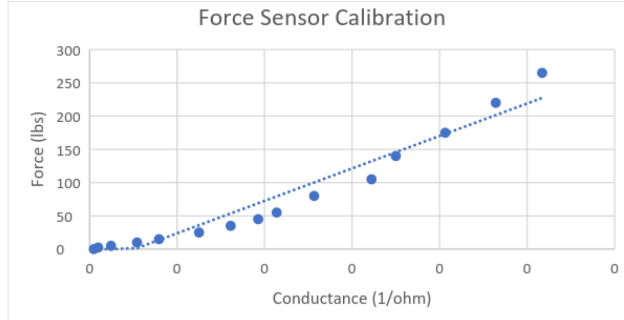


Figure 3. Experimental Force Sensor Calibration Curve

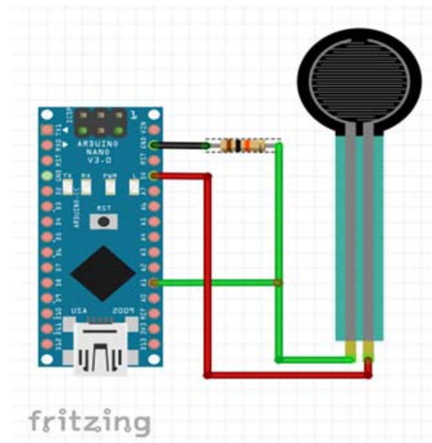


Figure 4. Voltage Divider Circuit Used for Calibration of a Force Sensor

5. PART LIST AND COST ANALYSIS

Table 5. Cost Analysis of SkillCourt Pad Prototype

Materials	Cost	Material	Cost
Plywood	$7.07	Lexan	$16.31
Foam	$29.54	Plexiglass	$9.55
Fasteners	$0.94	---	---
		Subtotal	$63.41
Electronics	**Cost**	**Part**	**Cost**
Force Sensor	$39.00	Arduino	$34.99
LED Strip	$26.99	Battery	$19.53
Voltage Regulator	$10.99	Resistors	$0.55
Switch	$2.70	Battery Connector	$0.60
		Subtotal	$135.35
		Total	$198.76

6. FUTURE WORK

Most products are subject to various design and manufacturing improvements, and the SkillCourt Pad is no exception. Areas in which the pad can vastly improve are the material selection and quality as well as the electronics and their housing. There are materials available that are a better choice for the SkillCourt Pad enclosure such as carbon fiber which has a high strength to weight ratio. Carbon fiber also has a very heat tolerance depending on its treatment during manufacturing as well as low thermal expansion.

Similar improvements can be made for electronics. Currently, the foam enclosure is suitable enough to reduce shock to the electronics, however over time either due to mechanical fatigue or thermal deformation the foam would no longer be suitable as a means of dampening and would have to be replaced. To this end, another means of housing the electronics could be implemented such as suspending the electronics in the SkillCourt Pad itself or embedding them in some form of silicone. For example, a brand name Silicone rubber known as Dragon Skin has satisfactory mechanical and thermal properties suitable for acting as an enclosure.

7. ACKNOWLEDGMENTS

The authors extend their thanks to SkillCourt LLC and Guðmundur Traustason, who sponsored the project and holds the intellectual property (patents and trademark rights) as the creator of SkillCourt projects.

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