Automated Hockey Goalie

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***Abstract*—The lack of a goalie wastes practice time for a lot of people. As computer engineers our solution to this problem is to build a robot to stop the puck and deliver an enjoyable and challenging experience for the user. With the lack of time and financial backing we will be making a scale model to represent the desired full scale design.**

I. Introduction

THE idea for a robotic goalie originated from the lack of participants willing to become a goalie as the allure of scoring causes most players to want to play out. To address this problem we will design a goalie that can track a projectile and move into a position to block the shot. While making a full model would be ideal, we have realized that with the time and resources we have this is not feasible and we will be building a scale model that would be more suited for a game of knee hockey. There is not much documentation for robotic goalies but there is a company, Robokeeper, that has designed an automatic goalie for soccer and street hockey. They mount the goalie to the ground and use a single axis rotation to move the goalie in a circular motion to stop the ball. We believe that that this system is more suited for soccer and want to make our design more hockey focused by using a rail system.

Our design will have our goalie move left to right across the net by having the goalie connected to a chain that will be connected to a gear that is connected to a bag motor. This motor will be connected to a Rev Spark motor controller that will have pulse width modulation signals sent to it by a Jetson Nano. The Jetson Nano will receive input data from a webcam giving information about where the ball is and how much the goalie needs to move. The Jetson Nano will be running a python3 script that will manipulate the input signals from the webcam and convert them into pulse width modulation signals for the motor controller.

The deliverable that we will achieve by the end of the 2022 Fall semester is to have the goalie be able to track a small ball and move the goalie into a position to stop the ball based on its projected flight pattern. We also think it is important to still have spots that players can shoot and still score as shooting on a perfect goalie is as useful and as fun to player development as shooting at no goalie at all. These openings will be created by limiting the movement of the goalie on the track leaving the corners of the net open. For our final demonstration we intend on bringing in the small goal and allowing people to take shots on our project. This is a fun and interactive demonstration which we find draws interest to the project.

II. Related Work

The idea of a robotic goalie is not as common as one might thing and with these goalies acting as a perfect training tool anyone working on them isn't willing to publish their designs. Research has lead us to finding a similar, but fundamentally different product called the RoboKeeper [2]. It is similar in respect the the fact that they use cameras to locate the object and then turn a motor to meet the needed blocking angle. On the other hand they have the motor set in the middle of the net and only turn the blocking piece. Our intention is to have the motor pull an object left to right so there is not a permanent piece blocking a section of the net. Also the national hockey league (NHL) has worked on puck tracking software for television broadcasts that shows the path the puck has taken but the limited resources that we have would make implementing this seem like an unaccomplished feet to take on [4].

III. The Project

A. Project Implementation

The milestones for implementation included the following sections: having the camera track the ball, setting up the Jeston Nano for use, connecting the camera and code to the Jetson Nano, having the Jetson Nano send PWM signals to the motor controller, building the net, mounting the motor to the net, making the goalie, tracking the ball and the goalie at the same time using the same camera, and tracking the ball at high rates of speed. These sections were implemented in this order and acted as a continuous build up to the final project demonstration. The block diagram shown in Fig. 1 shows the design of the project is pretty simple with external factors feeding into the Jetson Nano to do the computations and then sending an appropriate signal to the motor controller to move the goalie into place. Originally we had envision this final task being connected with a hand drawn sketch of how the shooter will see the goalie in the net in shown in Fig. 2 but in the end we decided to move the camera behind the goalie for better tracking of the ball. If we were to translate this camera positioning to the ice the camera would be located behind the glass to prevent damage from stray pucks.

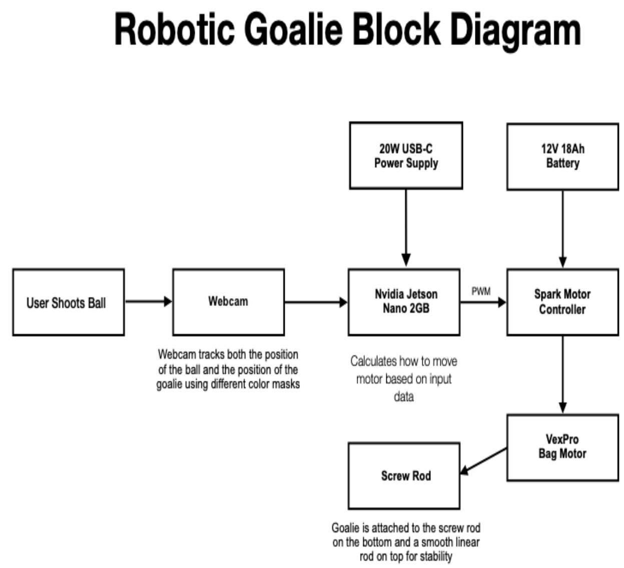


Fig. 1. Final block diagram

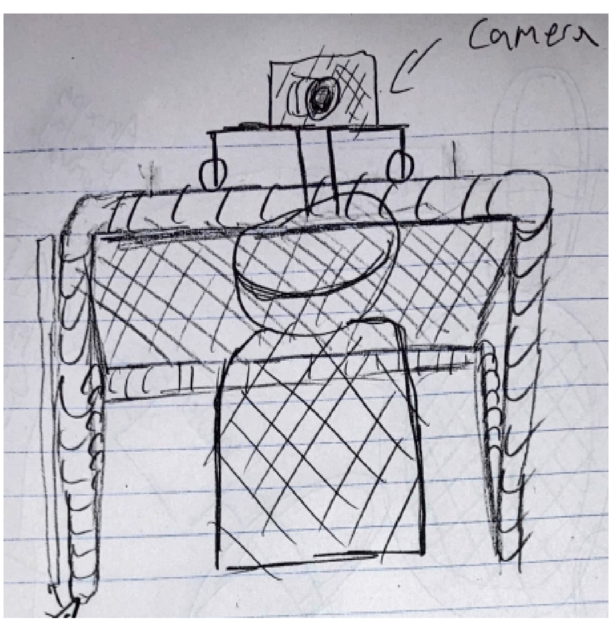


Fig. 2. Initial draft of camera position

B. Tracking System

For tracking both the ball and the goalie we are using OpenCV [1] to get the current frame of the camera input every ten milliseconds. Although this seems like a fast refresh rate, we are limited by the thirty frames per second that the camera shoots at effectively slowing down our system to one one-hundredth of the speed it could utilize. Once we have this frame we convert it into a hue saturation value (HSV) frame for color masking. This conversion from RGB to HSV is important for color distinction between similar colors as to eliminate background noise from other objects.

1) Goalie Tracking: For tracking the goalie, we are using a blue color mask. Originally, we were going to use a red color mask because we thought blue would have more background noise but the red electrical tape was to shinny to get an accurate read on the on the tape which lead to us using blue masking tape which showed up perfectly. As expected anyone who was wearing blue was picked up on the color mask. Thankfully, with the camera now being behind the net we were able to set bounds to make sure that only contours within the goal area were considered when checking were the goalie was which worked perfectly.

2) Ball Tracking: While setting a range was good for the goalie, the same solution would not work for the ball because the ball could come from anywhere and we needed to be able to track it from unknown starting locations. For this, we chose to use a width and height requirement for the contours so we were not tracking background noise when the ball was not in frame. This lead to more problems as now the ball was sometimes the same size as background noise because the mask was not picking up the whole ball in bright lighting conditions. To fix this, we use a five by five dilation kernel on the mask to increase the size area around the ball This helped fill in gaps in the mask where the ball was and allowing the contour to get a better estimation of where the ball was. This dilation did increase the background noise size, but now that the whole ball was being seen it was as simple as increasing the width and height requirements so only the ball was being tracked.

C. Tracking Flaws

This biggest issue with this system is making sure we are tracking the correct object when multiple are on screen. The solution we came up with was to sort each of the contours by size and then track the largest of the contour within the mask. This was done with the idea that if multiple balls are in frame the largest one is most likely the one that is closest and therefor the one that needs to be stopped. This solution works great except when someone wearing yellow is in frame and takes up more pixels than the ball. Matt was taking ECE4640 and spent the last couple weeks in the semester learning about image classification and believes if we had this information earlier could have implemented a neural network to scan the image for a ball shaped object in the frame to get a better estimate of where the ball was in these rare instances of foreign yellow objects being in the frame. At the same time there is a debate in the hockey world about using black stick tape to better hide the puck from the goalie and the idea is the same as our problem of a black puck in front of a black surface leads to an unknown location of a puck for a goaltender. Of course the human goalie uses a brain as it's neural network so this isn't as much of a problem for them.

We also had an issue tracking the ball when it moved to fast, as the mask was not able to pick up the color of the ball in a motion blurred state. We believe a camera with a higher refresh rate would eliminate this problem as each frame would have a lower exposure time which significantly reduces the amount of motion blur and provides a better frame for the color mask. We did try using a Gaussian blur but the motion blur effected the color saturation enough that it still was not getting picked up by the mask. We also looked into using background subtraction to show where the ball was, but the camera auto focus and general movement of users in the background made this a worse solution that using the color mask.

D. Prediction

Once we had the ball tracking down, we needed a way to predict were the ball was going to be when it reached the goal so our goalie had a change to stop it. Because the shot is more or less straight as higher speeds, we are assuming linear motion and using a linear slope equation. We store the previous x0 and y0 values of where the ball is and subtract those from the new values x1 and y1 to give us the equation:

$$\frac{y1 - y0}{x1 - x0} \tag{1}$$

The only problem with this was when the ball was moving in a straight line towards the goal causing a large slope in either direction or continuously swapping between one direction and another. To compensate for this, every time we calculated the slope we checked if the slope was greater than five or less than negative five as these were large slope values and only occurred when the x values were similar. If these parameters were true for the slope, we knew the ball was moving in a straight line towards the goal and set the slope to be zero. Once we changed the position of the camera to be behind the goalie, we did add a variable called distanceLeft which would scale the slope to be greater the farther away the ball was from the bottom of the goalie as the field of view gets smaller the farther into the distance you go so the final equation is:

$$\frac{y1 - y0}{x1 - x0} * distanceLeft \tag{2}$$

E. Moving the goalie

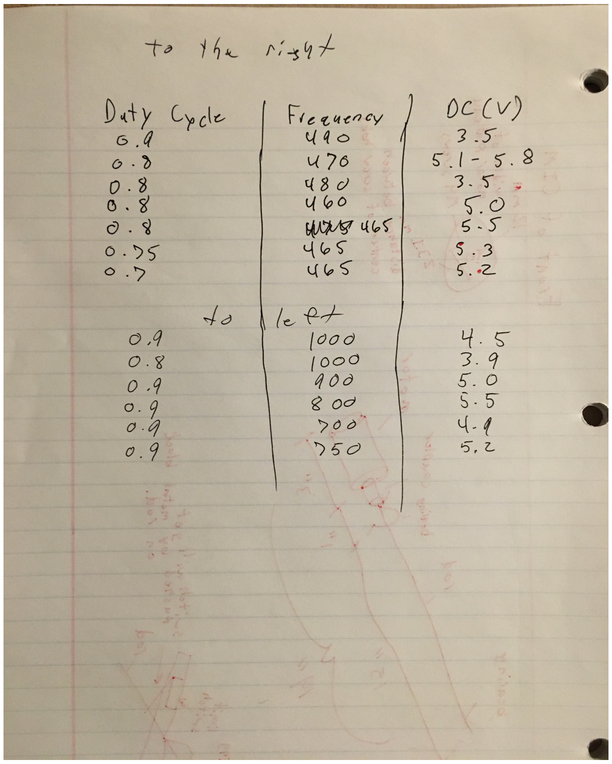
To move the goalie we are keeping track of the current position of the goalie. If there isn't a ball on screen the goalie rests at the center of the net to be in the optimal position for the next shot to come. Once the ball is in frame and we have a predicted point of where the ball is going to be when it will get to the net. We then start moving the goalie in the direction of this point by sending PWM signals to the motor controller. Unfortunately the Spark motor controller documentation [3] was not helpful when setting our PWM values using the RPi.GPIO python library as the values we used were not what the documentation said which lead to hours of testing our PWM with an oscilloscope to make sure we were actually sending a signal as well as pluggin in numbers until the motor spun. After we knew that the documentation values were wrong we hooked up a multimeter to the output of the motor controller and ran a script to cycle between different frequencies and duty cycles until we found the highest output voltage that was similar moving in both directions as seen in Fig. 3

The motor we used was a 12V VexPro bag motor. Although this motor was donated to our project, it was exactly what we needed because it was compact, had a high rpm, and had low torque. Low torque seems like a bad thing, but with our setup having a negligible load allowed us to move at a high rate of speed with no harm to users or the system itself If the ball was ever stuck between the goalie and the post, which would sometimes happen if the ball was slowly moving at an angle towards the net. Fig. 4 shows a graph of the rpm and stall torque values to prove the above statements.

F. Net Construction

The overall structure of the net is an upside down U shape with some small risers inside of each post for the screw rod to rest on allowing the user to score under the threaded rod as seen in Fig. 5.

Originally, the plan was for users to score in the upper corners of the net, so having the screw rod on the bottom would lead to less direct shots and chances of damaging



to the right

Duty Cycle	Frequency	DC (V)
0.9	490	3.5
0.8	470	5.1 - 5.8
0.8	480	3.5
0.8	460	5.0
0.8	465	5.5
0.75	465	5.3
0.7	465	5.2
to left		
0.9	1000	4.5
0.8	1000	3.9
0.9	900	5.0
0.9	800	5.5
0.9	700	4.9
0.9	750	5.2

Fig. 3. PWM output values

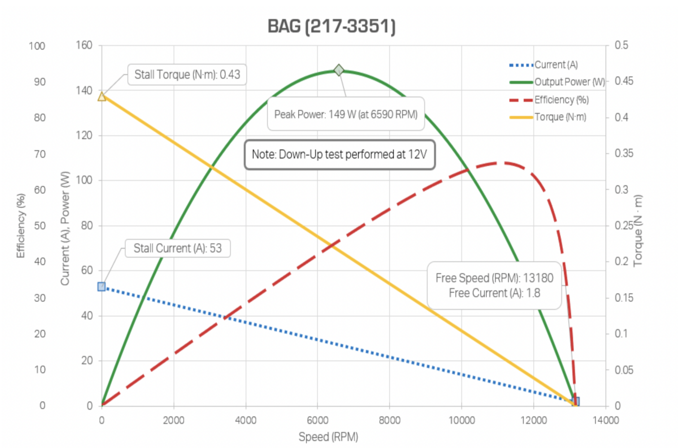


Fig. 4. Motor RPM and Torque Graph

the system. This became a problem when the camera was not able to track the ball at high rates of speed due to the low refresh rate. Having this information. a better plan would have been to have the screw rod under the crossbar and the support rod on top of the cross bar to allow for the entire bottom of the net to be open allowing more space for the user to score. The current design has the motor going through a hole in the wooden post and is being supported by a piece of metal screwed into the inside of the post and then using the build in holes in the motor to mount it to the metal using bolts. The metal is a dremel cut piece of an old electrical box because it

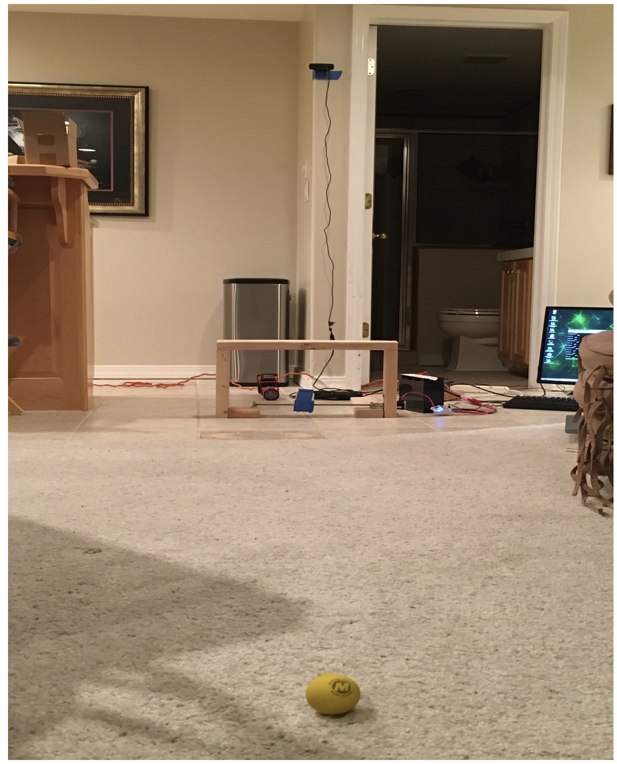


Fig. 5. Location of camera behind the goal

was a strong piece of metal we had lying around that had a clear punch hole already in it Fig. 6. For stability one of the screw rod risers is longer to prevent the net from tipping backwards on hard shots. To line up the top bar with the screw rod we needed something long and straight so staying on theme we flipped the net upside down and used an old hockey stick to to line up the top bar to get screwed into the crossbar as the wood risers were not perfectly flush with the crossbar so we couldn't use a ruler to get an accurate measurement of how far back the top bar needed to be to align with the screw rod.

G. *Making the Goalie*

The goalie was a basic outline of legendary Sharks goaltender Evgeni Nabokov. The original plan was to have a goalie in butterfly position as it is the most common goaltending stile in hockey and would allow for the upper corners to be open for the user to shoot at. This plan fell apart when we had to keep the ball on the ground to track it and we decided to go with a stand up goaltender which was the stile used in the eighties. However pictures from the eighties did not help us as they were far away shots and this picture of Nabokov hugging the post was the best we could do. The outline was made from tracing the picture and then scaling it to fit our net ensuring that the height was ten inches and

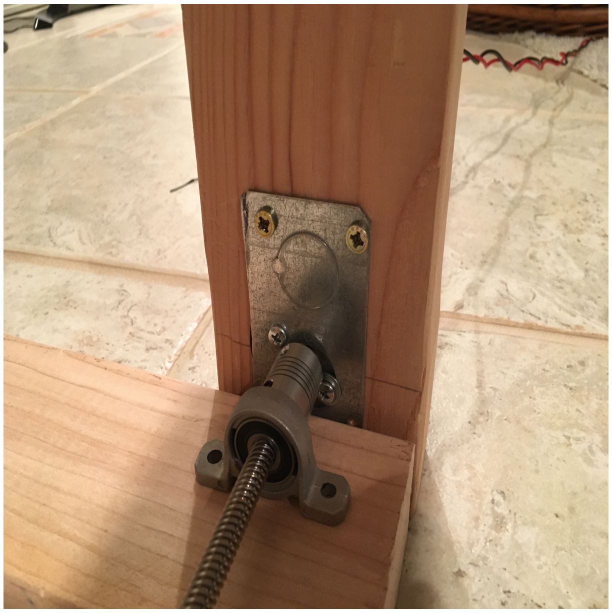


Fig. 6. Motor metal support bracket

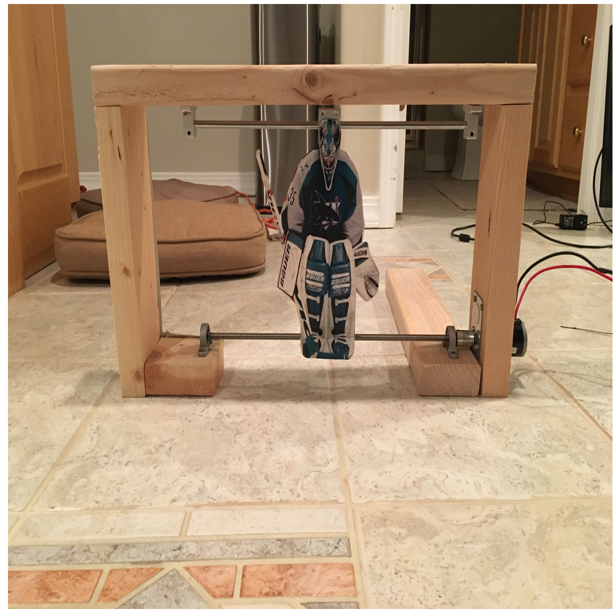


Fig. 7. View from the front of the net

the width of the legpads was three inches. This outline was then put into Adobe Illustrator where the line color was set to red and had a 0.001pt width which are the setting for the Skaggs Catholic Center laser cutters that were used to cut the goalie out of clear cast acrylic. Blue masking tape was put on the front of the goalie and then a paper cutout of the picture we used was put on top of that to give the goalie a realistic look Fig. 7 Fig. 8. The way the camera is positioned the crossbar gets in the way and will block the ball for a small period of time. To keep the goalie from moving back to the center once the ball is out of frame we have a half second time delay that keeps the goalie in the position or moving towards the last predicted spot to keep the goalie from moving away from the ball once it is behind the crossbar.

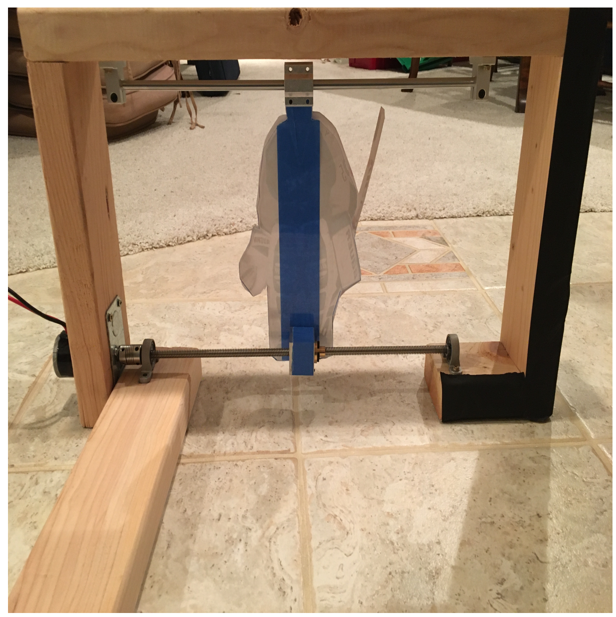


Fig. 8. View from the back of the net

IV. Conclusion

When we started this project neither of us had any experience with computer vision or circular to linear motion. This started out as a crazy dream and after nine months of work turned into a fun project to work on and interact with. We are very pleased with the current state of the goalie for the budget we used. Our ability to adapt to the challenges that we did not foresee was our biggest strength in this project as almost every part and idea from the initial plan at the end of the spring semester to the current iteration changed over the course of three months and we were able to pull it off.

A. What's Next

The future for this project looks bright as it will continue to be developed in hopes of one day getting to preform in on ice events. For the current situation we would like to see an upgrade to the camera and increase the scale to allow true hockey players to be challenged by the system similar to that of the Robokeeper. We think this could be a great recruiting tool in hopes of getting more students involved with the hockey team in a school that is increasing it's exposure to science and technology and teaching kids how basic engineering can be used to develop their own systems to improve their lives and the lives of others.

Acknowledgment

The authors would like to thank Skaggs Catholic Center for loaning us the bag motor, spark motor controller, 12V 18Ah battery, and Logitech 920 webcam. We would also like to thank Ramya Selvan at NVIDIA for donating the Jetson Nano. A special acknowledgment goes to Eric Browning for mentoring the group with physical design elements.

Parts

B. Bill of Materials

Wood and screws to build net - cost: $0

40cm Screw Rod Kit. cost: $40

11"x14" Acrylic Sheet. cost: $9

Metal for mounting motor to goal - Donated by Skaggs Catholic Center, cost: $0

12V DC bag motor - Donated by Skaggs Catholic Center, cost: $0

Motor Controller - Donated by Skaggs Catholic Center, cost: $0

Logitech C920 Webcam - Donated by Skaggs Catholic Center, cost: $0

Jetson Nano 2GB - Donated by Ramya Selvan at NVIDIA, cost: $0

Total cost: $49 USD

C. Vendor List

Amazon
https://www.amazon.com/dp/B08NZSX5FR

Home Depot
https://www.homedepot.com/p/11-in-x-14-in-Non-glare-Styrene-Sheet-1S11143A/202771350

Vex Robotics
https://www.vexrobotics.com/217-3351.html

Rev Robotics
https://www.revrobotics.com/rev-11-1200

References

[1] Opencv library. Website.
[2] Robokeeper hockey. Website.
[3] Spark motor controller manual. Website.
[4] R. Cavallaro. The foxtrax hockey puck tracking system. *IEEE Computer Graphics and Applications*, 17(2):6–12, 1997.