BALL HANDLING MECHANISMS FOR MOBILE ROBOTICS

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ABSTRACT

Abstract - This thesis addresses the use of ball handling mechanisms by soccer robots. In order to provide a quality match similar to a real soccer game, these mechanisms are essential for the robot to be able to control the ball, turning cooperation between robots and goal scoring possible.

Two different systems were developed, one to kick the ball and another to help the robot move through the field without losing the ball.

The kicker system consists of an electromagnetic actuator, comprising a power converter (current-mode boost converter), and a solenoid which converts the electrical energy stored in 100V capacitors into the movement of a plunger (kinetic energy). The studied system plans to reach up to 9m/s shots. The dribbling system is achieved by installing a motor and a wheel that acts on the ball keeping it always in the possession of the robot. The systems are developed from theory to practice, and the SocRob platform is used to test the results using both systems.

Results show that the systems were able to perform their duties, the kicker prototype shot the ball with the expected velocity (5.5m/s), indicating that the studied simulations are representative and the new model will be able to achieve the simulated results (9m/s). The dribbler has greatly improved the robot performance with the ball when compared to its previous state, giving the ability to move forward and stop without losing the ball, dribble backwards and perform turns and rotations with higher success rates.

Keywords – Robot soccer, electromagnetic actuator, boost converter, ball handling, ball kicker, ball dribbler.

1. INTRODUCTION

As the interaction between mobile robots and the real world is becoming more and more important, being capable of handling objects as a human would do is a required feature of such robots. In RoboCup [1], there are many challenges fostering robotics and AI research. One such challenge is RoboCup Soccer which is seen worldwide as a benchmark in robotics and has seen many important improvements in recent years. RoboCup proposed a future goal to be shared by all roboticists so they can all evolve and guide themselves towards a common objective, that is, “By mid-21st century, a team of fully autonomous humanoid robot soccer players shall win the soccer game, comply with the official rule of the FIFA, against the winner of the most recent World Cup.” [2], therefore, this league can be compared with a former goal that also took 50 years and was achieved by the supercomputer “Deep Blue” winning a game of chess against the world champion at that time, Garry Kasparov. RoboCup Soccer has multiple leagues, as the Small Size League that features small wheeled robots controlled through computers and cameras on the field. The Middle Size League (MSL) where every robot is a complete player with vision and processing power. And there are the new humanoid leagues where the humanoid motion problems are being solved. All of these leagues have the purpose of sharing knowledge and in the future merge themselves to achieve their final common goal.

The MSL is the main event of RoboCup because it is where the robots have full onboard autonomy, every robot is an agent that has its own knowledge collected by the sensors equipped within the robot (e.g. omnidirectional cameras, compass, and accelerometers). Each robot has to self-localize on the field, localize the ball, and share its knowledge that may or may not be correct. This decentralized control makes this league the closest to a real game of football where every player plays according to its perception of the world and built-in plan. In recent competitions the robots had a significant improvement in the way they interact with the ball. New systems provided the ability to kick and the ability to dribble much more efficiently. This improvement turned the game much closer to our idea of football, and spectators can clearly see in the game and by the final score, the difference in performance of a team with this kind of systems. Every year the rules of the league change in order to force the teams to be closer to the final objective, and since 2012, the rules changed so that players had to make much more use of passes between players by inserting a rule that prohibits a player from crossing the midfield line with the ball. Robots must now pass to a player in the opponent side of the field. This way, without a proper kicking device, it is very difficult to score or complete the passes that are required to comply with the rules.

These particular systems were missing in our robots, thus our team (SocRob) was unable to show good competition results and compete with high tier teams that possess this ability. As a requirement to continue with our team in competitions, it was necessary that such systems were developed. This paper studies the existing systems in the RoboCup community, and the former actuators from the SocRob team, outlining the principal aspects that should be reproduced in the new mechanisms. Then two new systems are developed. A kicker system based in an electromagnetic actuator combined with a current-mode boost converter. And a low cost active dribbling system using only one motor.
The rest of the paper is organized as follows: Section 2, presents the restrictions faced due to RoboCup MSL rules, the robot platform on which this paper will be implemented, the former actuators used to handle the ball, and a review of the state of the art in this kind of actuators; in Section 3 and 4, the kicker system and the dribble system are presented respectively, both sections begin with a theoretical introduction and basic principles of the systems, then the development process, and finally the results; Section 5, reports the work done integrating the systems with the SocRob robots, and shows the final results; and finally, Section 6 presents some conclusions and future work.

2. PROJECT RESEARCH

A. RoboCup Middle Size League rules

RoboCup MSL is a league for soccer robots playing with a FIFA standard size 5 football that has more or less 22cm of diameter, and this year it is dimensioned for 5vs5 players in a field of 18mx12 m, these dimensions are enough so that players can take advantage of long passes throughout the field, and for that, the kicker system has to be able of relatively powerful shots as well as measured and precise passes (whose strength may depend on sensed information, such as the distance to the receiving robot).

There are a set of rules [3] related to the robot geometry and ball manipulation from which the ones relevant in the scope of this paper are:

- “The maximum weight of a robot is 40 kg.”
- “Each robot must possess a configuration of itself and its actuators, where the projection of the robot’s shape onto the floor fits into a square of size at least 30cm × 30cm and at most 52cm × 52cm.”
- “During a game the ball must not enter the convex hull of a robot by more than a third of its diameter except when the robot is stopping the ball. The ball must not enter the convex hull of a robot by more than half of its diameter if the robot is stopping the ball. This case only applies to instantaneous contact between robot and ball lasting no longer than one second. In any case it must be possible for another robot to take possession of the ball.”
- “The robot may exert a force onto the ball only by direct physical contact between robot and ball. Forces exerted onto the ball that hinder the ball from rotating in its natural direction of rotation are allowed for no more than one second and a maximum distance of movement of one meter. Exerting this kind of forces repeatedly is allowed only after a waiting time of at least four seconds. Natural direction of rotation means that the ball is rotating in the direction of its movement.”
- “Ball rotation also implies that the ball is rotating continuously, even if slightly slower than its natural rotation speed. Movements of the ball such as “roll-stop-roll-stop” are not considered a valid ball rotation and will be considered ball holding.”
- “Dribbling the ball backwards, that is, dribbling while the robot is moving towards the opposite direction of its relative position to the ball is allowed for a maximum distance of 2 meters. During the backward dribble the ball must also be rolling in its natural direction. Once any particular robot has dribbled the ball backwards for more than 1 meter, it cannot repeat the same backward dribbling again before the ball has been completely released by that robot or until the robot has engaged a new ball struggle against an opponent robot (i.e. the ball is actively disputed between the two opponent robots for more than 2 seconds).”

These are the rules for this year official competition and development should have in consideration that future competitions will evolve for bigger fields and situations closer to actual 11vs11 football games.

B. State of the Art

There are several kicker and dribbler systems already in use by other teams in RoboCup, a survey of which is available in other studies [4]. Here, the main types of kickers and dribblers will be presented.

Kicker Systems

The Kicker systems developed by RoboCup MSL teams can be classified as:

- **Spring based**: this system can use a motor or any other device to generate a mechanical force to compress a spring and store that energy by locking the system in a high energy state. When it is desired to kick the ball, the spring is unlocked, releasing its energy. This system usually takes a lot of space inside the robot, and it is difficult to shoot with different speeds, so this system was dropped by most of the teams because of the changes in the rules that required passes between team members. Teams who used this system were SocRob and Hibikino-Musashi [5], from Japan.

- **Pneumatic**: this one uses a compressed air tank as a power source to produce the kick. It is the simplest of the three systems, as it simply has pneumatic valves connected to the tank, and by controlling the valves one chooses when to shoot. The disadvantages are that the number of shots one can do is very limited by the size of the air tank, and the speed of the kicks cannot be controlled. The “OpenTribots” from Freiburg University
have a system like this [6] and SocRob also used one in 2002-4.

- **Electromagnetic**: which uses a coil with a magnetic plunger inside. When a current is applied to the coil, the plunger accelerates towards the ball. This type of system is referenced as being the best for the application considered here and is being adopted by most of the teams, including the top tier. Usually energy is stored in capacitors at a higher voltage, because the voltage from the batteries cannot produce a proper kick. The discharge time can be controlled to produce kicks with different speeds, and the time required between two kicks is relatively short taking into account the application. “Tech United” uses one of the best systems of this kind [7].

**Dribble Systems**

Regarding dribbling systems, two categories can be found:

- **Passive Systems**: which act as guides so the ball won’t drift away during dribble maneuvers, in this kind of system the ball rotates freely in front of the robot. The flaw of these systems is the inability of dribbling backwards or to perform more aggressive movements. The robots must rely on path planning strategies to control the ball and this reduces a lot the results during the competitions. An example of this approach is the “Hibikino-Musashi” team [8] that uses rubberized arms controlled by a motor.

- **Active Systems**: uses motors coupled to wheels with an adherent surface, in the front of the robot. This wheel is used to force the ball into rotating in the desired direction. This way the ball moves according to the rules and the robot is able to pull the ball to move backwards or can momentarily hold the ball in difficult situations like fast change of directions or a scrum between robots. With this kind of systems, some teams can have a tighter control than others, inducing the ball to rotate substantially slower than the expected and this can give an unfair advantage against better systems closer in spirit to the rules. Most teams use active systems due to the higher performance achieved, adding different mechanical approaches and sensors to help track the ball. “Tech United” uses a two wheeled system with great performance [7].

- **3 Omnidirectional wheels powered by MAXON DC motors (RE35/118776), with a gear ration of 91:6 (MAXON 203116).**

- A network camera with fisheye lens, that is located in the top of the robot, facing down, enabling a 360º surround view. The camera is used for the robot ball detection and self-localization algorithms.

- A compass (HMC6352), to help with localization.

- A microcontroller (Arduino Duemilanove [10]), to control the electronic sensors and actuators at a low level stage.

- A Laptop, for high level tasks, image processing and wireless communications.

The robot was originally equipped with ball handling mechanisms, which never worked properly. Both systems were analyzed and guidelines for the new mechanisms were established in order to solve the problems found.

**Figure 2.2 - SocRob platform**

### 3. KICKER SYSTEM

The kicker system will be based on an electromagnetic reluctance actuator. The basic principle behind the electromagnetic actuator is self-inductance, by passing current through a turn of wire, a magnetic field is formed. With magnetism, magnetic materials can be attracted or repulsed. This actuator is basically a tube of non-magnetic material with several turns of wire (solenoid) to produce a big magnetic field, creating enough force to move a ferromagnetic projectile that is loose at the end of the tube.

**Figure 3.1 - Electromagnetic reluctance actuator [11]**

**C. SocRob Platform**

In 2006, the Institute for Systems and Robotics - Lisbon (ISR-Lisbon) acquired five robots [9] with the intention to participate in the RoboCup MSL league and for general robotics research. Nowadays, the robots are slightly different from the original ones. Some of the initial components were upgraded. At the time the robots consist of:

- A hollow aluminum chassis, with the complete robot projection on the floor fitting a 48cm x 48cm square.

- Two 12V NiMH 10Ah batteries to power the robot.

- 3 Omnidirectional wheels powered by MAXON DC motors (RE35/118776), with a gear ration of 91:6 (MAXON 203116).
The kicker will be composed mainly by a block of capacitors that is charged by a current-mode boost converter, and a solenoid.

A. Boost converter

The boost converter [12] represented in Figure 3.2, is a switch mode DC/DC converter that works by switching between two states consistent with the transistor “on” and “off” state. While the transistor is “on”, $V_L$ is constant and $i_L$ linearly ramps up, increasing the energy in the inductor.

$$V_L = L \frac{di}{dt} \tag{1}$$

Then by turning the transistor “off”, the inductor will create a voltage $V_L$, to maintain the linearity of current, forcing the inductor current to flow through the diode, transferring some energy to the output.

![Figure 3.2 - (Left) Boost converter "on" state, (right) Boost converter "off" state [12]](image)

To make it simpler to understand let’s assume that the components are ideal and the converter is working in a steady state mode that is the continuous conduction mode (CCM). In this mode the converter operation is periodic, and there is always current in the inductor ($i_L$).

The converter waveforms are shown in Figure 3.3, where "D" represents the duty cycle at the gate of the power transistor, meaning that the transistor is “on” during "D", and “off” during "(1 - D)".

![Figure 3.3 - Boost converter waveforms [12]](image)

The inductor voltage ($V_L$) takes two values: $V_{in}$ while it’s “on”. And $-(V_c - V_{in})$ while it’s “off”, this value is the sufficient so the diode becomes forward-biased. While in CCM, the area A and B from $V_L$ are equal so, the input/output voltage ratio can be obtained through:

$$V_{in}(D) = (V_c - V_{in})(1 - D)T_s \tag{2}$$

Resulting,

$$\frac{V_o}{V_{in}} = \frac{1}{1 - D} \quad (V_o > V_{in}) \tag{3}$$

But in our case the load is fully capacitive and this will not be completely true. Without the resistive component in the output, the system will not reach a balance and the capacitor voltage will rise indefinitely. For this application the boost converter has to be disabled (transistor always “off”) when the desired voltage is reached, stopping the charging cycles. But other conclusions can be retrieved from the analysis of CCM that will be true for our application, like the ripple in the inductor current, equation (4) represents how much the inductor current rises or falls during its operating states.

$$\Delta i_L = \frac{1}{L}V_{in}(D)\frac{T_s}{t_{on}} = \frac{1}{L}(V_o - V_{in})(1 - D)\frac{T_s}{t_{off}} \tag{4}$$

The boost converter developed, works like this but does not have a fixed duty cycle, and instead, a maximum $i_L$ current will be defined. When this current is reached, the transistor is turned off and the energy is transferred during the rest of the period. The current is measured with the use of a very small resistor (0.1Ω) and an op-amp, then a dedicated IC, the UCC3803 from Texas Instruments, is used to automatically generate the current dependent pwm wave.

The boost inductor used in the boost converter was handmade and has 40 turns around an EE shape ferrite core and 1mm of air gap, which after analyzed in a precision impedance analyzer (Agilent 4294A), indicated 540mΩ and 311µH at the operating frequency of 32kHz. According to equation (4) the maximum current variation during discharge for an inductor with 300µH and control frequency of 100kHz is 2.7A. This suggests that using this control frequency and a current above 2.7A is enough for the boost to work in CCM during the whole charging process.

The current-mode boost controller developed was submitted to laboratorial tests, from which was concluded that higher currents and higher control frequency resulted in better charging times, up to a point where increasing it past the CMM operation, resulted in smaller improvements. It was chosen to use a maximum current of 3.2A at 120 kHz. With those settings the converter is able to charge the capacitors in 12 seconds but after one kick the capacitors only decrease to 70V and the recharge time is only 5 seconds. Figure 3.4 shows the boost converter waveforms took with the oscilloscope, being clear the operation in CCM mode.
Figure 3.4 – Boost converter real waveforms

The yellow line represents the current in the inductor \( i_L \), measured by a commercial current probe, the control frequency \( f \) is shown as cyan and the magenta waveform is the voltage of the current sensing resistor.

B. Solenoid

The electromagnetic actuator used in the kicker is the reluctance actuator which requires only a solenoid and a ferromagnetic projectile. The magnetic field created by the solenoid creates two separate magnets, one inside the coil and another in the rod, both with the same orientation, thus the rod sees an opposing pole and is attracted to it. This means the projectile will always be attracted to the middle of the coil.

\[ \lambda = LI \]  
\[ L = \frac{N^2}{\mu A} \]  

For the actuator to be effective, all of these factors must be well balanced and this can only be achieved through simulation and experimentation.

Finally, there are other characteristics of the solenoid that will have an impact on its design. Given the high inductance of the solenoid, it is difficult to rapidly change current through the circuit. The current growth can be expressed as:

\[ I = \frac{V_L}{R} = (1 - e^{-\frac{R}{L}t}) \]  

Given that the acceleration time is short, the inductance of the solenoid cannot be too large, otherwise current will take too long to rise.

This time window can be estimated by the classic laws of motion. Assuming the acceleration \( a \) is constant, and knowing the length available for acceleration \( x_f \) and the final speed desired \( v_f \), the acceleration time \( t_f \) is given by:

\[ t_f = \frac{2x_f}{v_f} \]

To use the new solenoids a way to discharge the capacitors is needed. For that a “kickboard” was developed where the solenoid and the capacitors will be connected, this board uses a power MOSFET as a switch to control the current pulses and a diode to freewheel the solenoid current once the circuit is opened.

The original solenoid that already existed from the older kicker, was not good enough to reach the desired speeds, so the original solenoid was analyzed with the help of the Finite Element Method Magnetics (FEMM) [13] software, and ways to improve their performance were studied.

First the geometry of the problem had to be drawn, the program is capable of axisymmetric simulation and so, the representation of the solenoid and rod were drawn with the real dimensions from the original solenoid.

Starting from this a deep magnetic simulation can be performed. The software features script like commands with MATLAB integration, to ease the modification of parameters and process iterative simulation. Figure 3.6 represent the magnetic simulation using the original solenoid with 440 turns of wire and a current of 58.7 A.
By comparison of Figure 3.6 and the B-H curve of the steel shown in Figure 3.7, it can be seen that maximum values for B are near 2.3T which is in the saturation region.

The transference of kinetic energy from the rod to the ball has losses.

Several existing works [11] [15] [16], already did a lot of experimentation regarding what is best in terms of solenoid design for their coil guns, and show how most aspects influence the coil-gun. The same rules apply in our case so, there is no need to do those simulations. Only the simulations to see how much improvement can be obtained in our specific case are shown in this paper.

According to the these sources and our solenoid model, the parameters that had room for improvement were simulated to check the individual improvement, and then, a simulation with all of the improvements together is performed to measure the total gain in rod velocity. Those parameters are:

1. Minimize the air gap between the rod and the coil. This will reduce the solenoid section and reduce the length of wire in each turn, thus reducing the solenoid resistance. The nylon tube can have is thickness reduced and the inner radius of the tube could be closer to the core. The gap was reduced from 7mm to 2mm in radius.

2. Minimize the global reluctance of the magnetic path, this is achieved by using a shell of ferromagnetic material around the coil, concentrating the flux lines around the coil. Given that the magnetic permeability of steel is much higher than air, 5mm of shell thickness is enough to conduct most of the flux.

3. Adjust the rod length, the rod length is smaller than the coil and the optimum size in our particular case is the same as the coil (increase in mass was compensated). It was increased from 100mm to 130mm.

4. Adjust the number of turns in the coil, each turn will add more contributions to the magnetic field but will decrease the current in all turns. This should be incremented until the magnetic flux (B) values in the rod are near the saturation region. When near the saturation, increasing the number of turns will have a very low contribution, and the increased inductance opposes the variation of current which will have a negative contribution that reduces the performance.

5. Increase the voltage from the capacitors, the higher voltage will generate a higher current in the coil and increase the magnetic field created.

Changes number 1, 2 and 3 were simulated individually and compared to the original without modifications, Figure 3.9 shows the comparison of the results.

The change number 4 cannot be simulated in FEMM because it uses a fixed current during the simulations and does not model the influence of the inductance in the current.

At the end, Figure 3.11 shows the simulation results of changing parameter number 5, to check how much voltage would be needed to put the original solenoid with the desired power. This change was not shown with the other simulations because it does not involve changing the solenoid, and was not

Friction is not modulated.

The simulation results give an estimated final velocity of 6.35m/s, which is the expected given the real performance of the kicker. The test results shown in Figure 3.13 achieved 5.5m/s with about 0.31 m/s of standard deviation. The reasons for the simulation to differ from reality are:

- The steel used from the material library may be a poor match for the steel we are using.
- The simulation uses constant current when it should be dynamic.
- Eddy currents induced by motion are not modulated.

To study how to maximize the performance, scripts were written to calculate the forces applied in the rod at different positions and varying dimensions. The software can calculate many different things, one of which is the “z” part of steady-state weighted stress tensor force”, this integral is used in the coil gun example [14], made by the author of the program, to compute the magnetic force felt by the rod.

\[ W = F \times d \]  

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implemented because of being expensive. The capacitors and power components do not support a higher voltage.

Figure 3.9 - Simulation results for individual improvements

Figure 3.9 shows that each of the changes simulated resulted in improvements in the final velocity of the rod. The improvement achieved by increasing the length of the rod is good and is larger than it seems because the rod also increased its mass. The magnetic shell simulation becomes flat near the middle of the rod. This only happens because the rod in the simulation is smaller than the coil, but since the longer rod is more efficient, this will not happen if both changes are made simultaneously. When all the above improvements are put together the simulation shown in Figure 3.10 predicts a final velocity of 9m/s, which is close to the desired objective, and possibly enough for the desired application.

Figure 3.10 - Solenoid simulations with all the improvements

Finally the simulation changing the capacitors voltage is done. Figure 3.11 shows how much the voltage of the capacitors, influence the rod velocities. The result is that the original solenoid, using 200V as a power source, would be enough to shot the ball at more than 10m/s. This was not the solution sought because it would be expensive, and the lower voltage is less dangerous.

Figure 3.11 - Rod velocity vs. Voltage

To design the solenoid and be able to fit it inside the robot, a 3D model of the robot was drawn with precise dimensions. Then the model of the solenoid with all the improvements and appropriate supports were designed. The rod also was redesigned for the new dimensions and a wider ring was added to the back of the rod to stop it from jumping out of the solenoid.

Figure 3.12- Planar cut view of the solenoid inside the robot

The final solenoid/rod design parameters are summarized in the next table.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Voltage [V]</td>
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</tr>
<tr>
<td>Capacitor [mF]</td>
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<td>Coil inductance [mH]</td>
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<tr>
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</tr>
<tr>
<td>Shell thickness [mm]</td>
<td>5</td>
</tr>
</tbody>
</table>

* Values calculated based on the other parameters.

Unfortunately the optimized solenoid was not built, and only the test results of the original solenoid are shown. Some of the
tests are shown as videos in a Youtube channel created for this paper [17].
The test results with the original solenoid were measured recurring to a sonar based speed trap was used in a setup that had the two sonars at a distance of 1.3 meters from each other. The first thing to find was the correct time of discharge to produce its most powerful shot. Results from Figure 3.13 shows that stronger kicks were achieved with a current pulse of 45ms.

This variations in speed for the same pulse are not problematic when shooting parallel to the ground, but robots from RoboCup are already making use of lob shots and that will require a much more precise kick for the robot to be able to aim correctly.

4. DRIBBLING SYSTEM

The dribbling system came into need because soccer robots must react faster to gameplay situations and also because the kicker system cannot perform a proper kick if the ball is not correctly positioned in front of the robot. In the beginning, MSL robots only used passive systems that relied in path planning strategies, but the robot accuracy, concerning its own position and ball detection, has some error and delay, and this made it difficult for the robot to compensate the movements of the ball with success. Simple tasks like stopping the ball required the robot to rotate around the ball to push it from the other side. This had to be very fast to be good enough for the current level of the competition, and there is the added problem that opponent robots could block the paths needed to drive the ball. The concept of using a motor to control a soccer ball is very easy to understand. If the ball is put in contact with something that has more adherence than between the ball and the floor, the ball will adhere to that surface. If that surface is a wheel controlled by a motor, the rotation of the wheel will force a rotation on the ball. For this to happen the wheel must have an adherent surface and the motor must have enough torque to move the weight of the ball and win the friction on the floor.

The contact between the ball and the dribbler wheel is indispensable for the system to act. The wheel support must have angular movement by means of a hinge, so the ball can stay in contact with the wheel in a wider range of positions.

\textbf{Figure 3.13 - Experimental results varying the current pulse}

During this experiment it was noticed that between trials with all the parameters as close as possible, the ball velocity still varied more than the maximum error expected from the speed trap. The standard deviation for the 45ms pulse was 0.31m/s. This means that the final velocity is very dependable from the geometric factors between ball and kicker. What gave this difference in strength, could have been slight variations in the position of the ball and rod:

- The rod must hit the center of the ball. If the rod does not hit the center of the ball, the ball is kicked slower, and misaligned.
- For the 45ms pulse to work correctly, the rod must always have the same initial position. This was tested and it was concluded that the best performance is achieved if the rod begins slightly inside the coil. This happens because the capacitors lose voltage during the discharge, and in the initial part of the movement, the forces are not very strong.
- The distance between the ball and the solenoid just always be the same. Shots were made varying the distance between the ball and the rod. It was found that shooting the ball too close to the thrust rod, resulted in lower speeds. And the distance for which the rod collides with maximum speed also was not the best. The best results were when the rod was almost at full speed. In this situation the rod is still receiving force favorable to the movement and shooting the ball has the best results. In all the results from Figure 3.13, the ball was in that optimal position, and that is why the 70ms pulse still has good results, the rod hits the ball before the force becomes negative.

\textbf{Figure 4.1 - Active dribbler concept, adapted from [18]}

The system developed for SocRob uses only one motor and has a low power motor with only an open-loop controller, thus the system is very simple and low cost. Although, the use of two wheels and dedicated sensors to create a feedback control loop grants the system abilities impossible to reproduce with only one wheel. On both approaches, the desired velocities of the wheels are related with the velocity of the robot by a direction dependent gain, this means that when the robot is moving forward, the objective is making the ball spin slower than the robot movement, keeping it pressed to the robot, and when the robot moves sideways...
is moving backwards, the ball must spin more than the velocity of the robot, again keeping it pressed against the robot. To choose the appropriate motor to dribble the ball some calculations must be done, the motor torque must overcome the ball rotational inertia [19] which can be calculated by Newton’s second law for rotation,

$$\tau = I \times \alpha ; \quad \alpha = \frac{a}{r}$$

(10)

Where, $\alpha$ is the angular acceleration and $I$ is the moment of inertia of a spherical shell which is known by,

$$I = \frac{2}{3}mr^2$$

(11)

The other requirement for the motor is its linear velocity that must be able to match the robot velocity. Thus, the motor rotations per minute (RPM) must be

$$RPM = \frac{v}{2\pi r} \times 60$$

(12)

Wheels from RC modeling were used coupled with low cost 500RPM motors. This motors does not provide any feedback. Thus, only an open-loop controller is done feed-forwarding the speed of the robot to the dribbler.

A H-bridge was used to rotate the motor in both directions. And a support was designed to hold the motor in the front of the robot, with the required axis for rotational movement so the wheel can adapt to the ball position.

Figure 4.2 - SocRob robot with ball handling systems installed

The dribbler support has a detachable motor support, so other motors could be used in the future. The method of control which achieved best results was to rotate the wheel backwards at maximum speed when moving backwards, and to rotate the wheel backwards only 5% when moving forward. This only works because the low power motor does not have the strength to force the ball to rotate when the robot is stopped.

With this the robot was able to move forward, backwards and brake without losing the ball.

Rotating and turning with the ball had a higher percentage of lost balls if moving fast, but given that the movements are much harder the results were also good. Although, the lost balls were also due to the robot having a flat front with spring “fingers”, shown in Figure 4.2. Sometimes these spring fingers fling the ball away. The front of the robot must be changed to a concave structure that will not only help drive the ball better but also work as a protection so the dribbler does not receive damage.

Compared to what the robot used to do without the dribbler, the improvements were big. The results can also be seen in the Youtube channel [17].

5. CASE STUDY IN A SOCCER ROBOT

As a case study the autonomous behaviors of the soccer robots were tested exploiting the new systems installed. The test conducted was to run the “BehaviorBaseAttack”, this behavior is a sequence of actions that lead the robot to find and catch the ball, then the robot turns to the opposite goal, and kicks the ball.

The robot uses the camera to detect the ball. This information was also used input to control the dribbler.

The kicker system did not have any difference from the results in section 3. The main software only needs to send the kick signal and strength to the microcontroller, and the kick is executed if the kicker is ready. Sometimes the kicker tried to shoot and missed the ball, this occurs due to inaccurate knowledge of ball possession. This problem can be solved having a better way of detecting the possession of the ball. The ball position given by the camera has some errors.

Regarding the dribbler system, in first place, the feedback from the camera had to be disabled. As happened with the kicker, the camera detection of the ball has errors, but in the dribbler the consequences were more serious. If the robot tried to dribble the ball forward with the information of not having the ball then the robot would get stuck against the ball.

In the meantime the dribbler works assuming the robot always has the ball. With this change the dribbler worked like in section 4. The robot behaviors sometimes improved the dribbler performance and other times did worse. The situation where the dribbler performance was improved was during rotations and turning. The combination of the dribbler system with the previous path planning movements resulted in increased performance. Other times the robot did not get close to the ball for the dribbler to act, due to self-localization and ball detection errors. This means that the robot behaviors and predicates need more adaptation.

The results show that the dribbler can improve performance not only by adapting the dribbler system to the various situations, but as well by adapting the behaviors to the dribbler.

After optimizing the “BehaviorBaseAttack” the robot was able to catch the ball, rotate to the goal without losing the ball, and shoot, scoring a goal. A rate of success was not calculated, because most of the times the robot self-localization was the problem and the rate of success would not represent the performance of the systems developed in this paper.

6. CONCLUSIONS

This paper reports the development steps of building new ball handling actuators for a mobile soccer robot.

The original objective of the paper was accomplished, endowing the SocRob soccer robots with stable kicker and dribbler systems.

For the kicker, the choice was an electromagnetic system. The new power converter has a higher efficiency, recharging the
capacitors and enabling a full power kick every 5 seconds. The solenoid equipped in the robot shoots the ball with half the velocity intended (5m/s) but a deep analysis on how to achieve the desired launch velocity (9m/s) was performed and is yet to be implemented in a prototype. The dribbler system also improved the robot ability to drive the ball through the field, and to keep the ball ready to be shot by the kicker system. The use of only one low-cost motor in the dribbling mechanism was successful and resulted in an efficient dribbling mechanism, leaving room for future improvements.

For future work, the implementation of the optimized solenoid, improving the ball launch speed is a must do. With this improvement it will be possible to explore the potential of lob shots. For the lob shots a new mechanical system has to be developed as well. A good option would be a front leg, on which the developed kicker would collide. With the option of moving the leg up and down, the angle at which the ball is fired could be chosen. Building the frontal protection of the robot also proved to be necessary and should be done for future use. The new sensors to help detect the ball possession are not critical but would be a good improvement. The auxiliary detection can be achieved through potentiometers attached to the dribbler support like “Tech United” uses, or simply using infrared sensors pointed specifically to detect the ball. The prototype circuit boards used in this paper were made out of strip boards. Even though the prototypes are fully functional, for the next robots, they should be redesigned for printed circuit boards (PCB).

The adaptation of the autonomous behaviors must also be done. The pass between robots requires special attention because the strength of the pass must be chosen according to the conditions.

REFERENCES


