

Improving the Kicking Accuracy in a Soccer Robot

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ABSTRACT

Most of the soccer robots in the Middle Size League of RoboCup use electromagnetic kicking devices that allow to kick the ball with adjustable strength. In order to be efficient to score, the kicking strength should be calculated according to several parameters, namely the physical characteristics of the kicking device, the distance to the target, the velocity of the robot and the floor friction parameters. Moreover, the kicking decision should be taken at a moment in which the actual movement of the robot would result in the ball being released to the target direction, even if it is not physically aligned with it. This paper proposes an algorithm to improve the kicking accuracy, taking into account the described parameters, in a heuristic approach. The experimental results presented in this paper show the effectiveness of the proposed solution to improve the efficiency of the kicking device.

Categories and Subject Descriptors

I.2 [Computing Methodologies]: Artificial Intelligence

Keywords

RoboCup, Middle-Size League, Kicking Device, Calibration, Accuracy

1. INTRODUCTION

RoboCup [3] is a huge commitment from scientific and research groups all over the world on developing better and smarter robots that one day will be able to help us (humans) in our daily lives. In order to achieve this huge desideratum, the RoboCup federation has created an annual competition that creates opportunities for researchers to test their work and exchange technical and scientific information.

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Among those competitions, there is the Soccer Middle-Size League (MSL), a great testbed for multi-agent systems research, due to its rich and dynamic environment. The robots have no standard format, but must fit in a $52cm \times 80cm$ box and are not allowed to weigh more than 40Kg. Each team can have up to five robots (including the goal-keeper) playing a soccer game (two halves of 15 minutes) in a $18m \times 12m$ field and in a fully autonomous way. Teams are identified by a color (either cyan or magenta) and the robots wear body markers with that color and their identification number.

Cooperative Autonomous Mobile roBots with Advanced Distributed Architecture (CAMBADA) [4] is the MSL robotic soccer team from the University of Aveiro. The team development started in 2003 and a steady progress was observed since then, with the participation in several national and international competitions.

Just like as in human soccer, the team that scores more goals usually wins and therefore, the mechanism responsible for kicking the ball is of extreme importance. The majority of the teams participating in the RoboCup Middle-Size League have a device that allows them to kick the ball towards the opponent goal with a satisfactory accuracy. In order to achieve a reasonable level of efficiency, the rule of thumb has generally been to either kick the ball when moving the robot towards the target or with the robot stopped.

The CAMBADA kicker device is an electromagnetic kicker whose main element is an electromechanical solenoid. The solenoid consists of a coil, wound around a movable iron core that produces a magnetic field when an electric current is applied. The magnetic field causes the iron core to move towards the ball, making the lever lift the ball to perform a **lob-shot** (Figure 1).

However, with the fast evolution of this league, games have become much more dynamic, with robots that are able to approach the ball very quickly, which means that waiting for those conditions to kick the ball may cost the time that the opponent team needs to dispute the ball, and thus losing an opportunity to score a goal. The CAMBADA robotic platform has been redesigned for the RoboCup 2013 [2] and 2014 [1], allowing the exploitation of new behaviors, including kicking the ball while moving.

A possible solution to overcome this limitation is to model the output angle and velocity of the ball with respect to

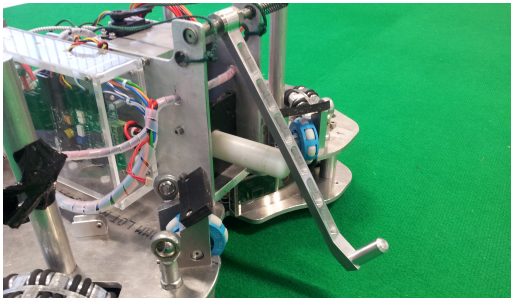


Figure 1: The kicker shaft hitting the lever.

the robot movement and use that model in real-time to predict ball motion. A mathematical model could be useful but some of the variables that influence the output of this system (the rotation and pose of the ball, for example) are impossible to measure. This paper presents a practical approach to solve this problem, taking into account the theoretical motion equations and some extra measurements to study the effect of the robot movement in the output angle of the ball.

Although the proposed methodology was directly applied to a soccer robot, the algorithm can be applied in several different situations in which a robot needs to release an object to a target while moving, with strict timing constraints.

In Section 2 a calibration procedure based on the use of a laser range finder to analyze the ball trajectory and estimate some parameters of the kicking device is presented. Section 3 presents the effect of the robot movement on the ball trajectory and proposes an algorithm to adjust the kicking order accordingly to the robot movement. Finally, Section 4 presents experimental results showing the effectiveness of the proposed algorithm and the discussion on the usefulness of this approach.

2. KICKER DEVICE CALIBRATION

The calibration procedure allows a characterization of the system in terms of the output angle and velocity of the ball. Over the years, the kicking device of the robots has been configured individually for each robot with a methodology of kicking from several setpoint distances with different kick powers and then matching a polynomial function to estimate the necessary kick power for any distance to the goal.

Particularly in an older platform, we always verified that there were differences between robots and also differences within the same robot over time. However, visually registering the point where the ball hit the ground was the only way to evaluate the ball trajectory.

At some point, we felt the need to have some precise tool to analyze the ball trajectory so a battery of tests could be created in order to try to, one by one, isolate the factors that could provoke such differences. When a laser range finder became available, the idea to use it to get precise measurements of the ball immediately came up.

2.1 Laser range lob analyzer

This tool extracts the ball trajectory of a given lob shoot using the measurements of a laser range finder. The plane of the lob shot and the laser plane need to be aligned, which is achieved by positioning the robot and the laser in a straight line and ensuring that the ball is shot on that plane (Fig-

ure 2). The visual application starts by gathering the points for a given number of cycles and extracts a “background” based on them. This implies that, before kicking the ball, we need to keep the kicking plane clean of moving objects.

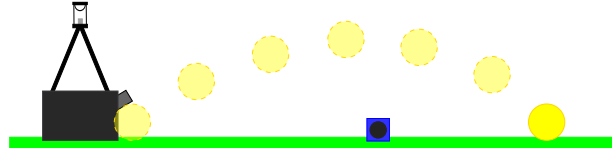


Figure 2: Illustration of the setup for measuring the ball kick trajectory.

After extracting the background, the points detected by the laser range finder that are matched to the background model are considered the ball. This means that the captures must be performed in a controlled way to avoid anyone or anything besides the ball to cross the laser capture plane. Taking that into account and given the small noise, a simple distance clustering is performed over the points extracted and the limits of the cluster are estimated. Since we consider the ball as a single point on its center, and given the limits of the cluster, we project the middle point of the cluster by a ball radius (11 cm) in the direction angularly opposing the Laser Range Finder, which is the observation point. This projection is exemplified in Figure 3

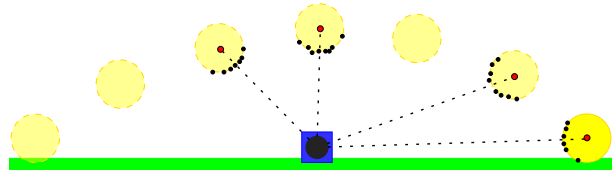


Figure 3: Illustration of the projection of the ball center based on points perceived by the laser range. Several examples over the trajectory are illustrated.

In Figure 4 we have a screenshot of the application, where the background data is represented in green and the current object in black. The estimated ball center is the red dot and the laser, which is the origin of the Cartesian system, is the blue dot.

The described tool enables the user to have an instant visual representation of the data being acquired by the Laser Range Finder, but also to record and replay that data it for the user to validate its correctness.

When creating the new platform, the kicking device was designed and implemented such that its repeatability was as good as possible. For verifying this assumption, we used the data provided by this tool for a set of kick powers on each robot. The obtained results confirmed a quite acceptable repeatability on each robot (Figure 5). With these results, we were also able to extract the kick parabola for each of the used setpoint kick powers and introduce an analytical configuration of the kicker on our robots.

2.2 Kick power estimation

The previous kicker approach was based on a table relating distance with kick power, extracted by having the robot kick

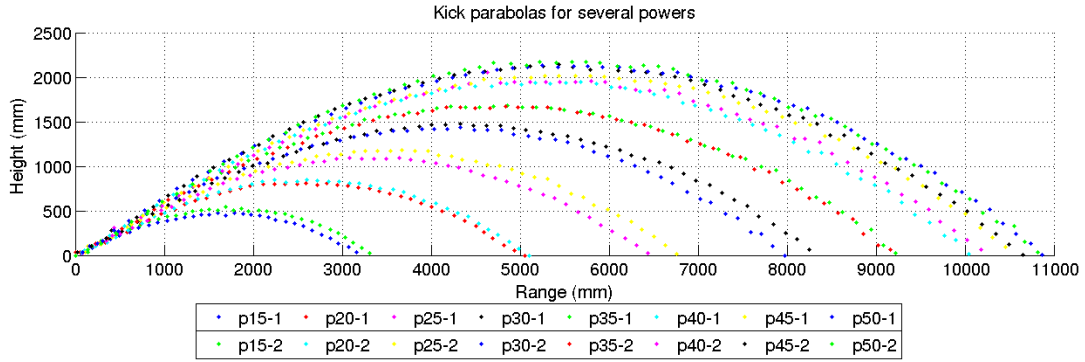


Figure 5: Representation of the kicking parabolas of a robot for different kicking powers and trials, represented as pNN-X where NN is the used kicking power and X is the trial.

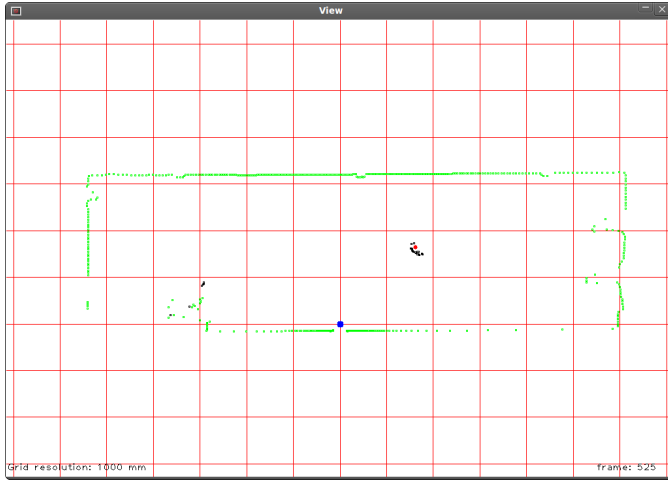


Figure 4: Screenshot of the laser range finder tool. The green dots are points detected as background, which are most of the points detected by the laser range finder. Black points are points that are part of moving objects, the bigger blue point centered horizontally is the laser range position and the red point among the black points isolated to the right of the laser range is the estimated center of the ball points.

with several powers at predefined distances until we visually obtained an acceptable height of the ball on the goal line. The main problem with this approach was that the kick configuration would work rather well when the robot was stopped but not so well when it had movement. Also, being the configuration dependent on a human observation of the ball height, the configuration could easily be very different depending on the observer, since the acceptable height was measured through instantly observing if the ball crossed the goal line at a good height, and “good height” have different meanings to different observers.

In this new approach, we analytically estimate a relation of initial speed with kick power. The advantage of this approach is that, when deciding to kick, we can directly affect the kick power with the current robot speed, since we are directly working on the same physical units.

Using the laser range data, we can easily estimate the

maximum distance and height of each parabola. The defined procedure implies that two kicks are performed and captured for each of the setpoint kick powers. With the maximum parabola distance, D , and the maximum parabola height, H , we extract the exit angle, θ , and the exit ball velocity, V_0 .

$$D = \frac{V_0^2 \times \sin(2\theta)}{g} \quad H = \frac{V_0^2 \times \sin^2(\theta)}{2g}$$

$$\frac{H}{D} = \frac{\sin^2(\theta)}{2 \times \sin(2\theta)} = \frac{\sin^2(\theta)}{4 \times \sin(\theta) \times \cos(\theta)} = \frac{\tan(\theta)}{4}$$

$$\theta = \tan^{-1} \left(\frac{4 \times H}{D} \right) \quad V_0 = \sqrt{\frac{D \times g}{\sin(2\theta)}}$$

Considering that the angle, θ , is constant because it is only related to the shape of the kicker and the point where it hits the ball, we consider a mean of the angles of the several parabolas of each robot as the value of θ . A kicking table is created with the exit velocities for each of the setpoint kick powers and those values are used as reference when the robot estimates the power of a kick.

For any given distance, we can estimate the exit velocity of the ball with $V_0 = \sqrt{\frac{D \times g}{\sin(2\theta)}}$, which is considered when the robot is stopped. However, the challenge is to keep kick accuracy when the kick is performed while the robot is moving, we have to consider that the robot frontal velocity component will affect the ball exit velocity on its XX component. Thus the velocity considered for the kicking order is $V_{kick} = V_0 - V_{robot} \times \cos(\theta)$. One of the configurations of this kicking power estimation method is a constant that affects how much of the robot velocity is transferred to the ball exit velocity, since we noticed that different floors affect this velocity differently. Particularly, as the floor becomes more slippery, the effect of the robot velocity on the ball exit velocity is more complete. The limit situation would be a floor with no friction, which would correspond to a 100% velocity transfer.

On the other hand, when estimating the necessary kick power to achieve a given distance, we estimate the exit velocity using the previous equations and then use a piecewise

linear approximation of the relation between kick power and exit velocity to estimate the necessary kick power for that particular velocity.

Thus, the kicking power for any given distance and robot velocity is given by the linear equation between the kicking velocity setpoint immediately lower than V_{kick} and the one immediately higher than V_{kick} .

3. ROBOT MOTION EFFECT

To achieve a successful and accurate kick, the previous calibration is taken into account in realtime to determine the kick power to apply to make the ball pass the goal-line at a certain height. Moreover, the kicking order must be sent at the right moment - the one that will lead the ball to be released in the direction of the target. This means that the actual movement of the robot has to be taken into account, since the outcome will be different from the situation of when it is stopped.

For example, if the robot is moving forward, part of the velocity of the robot will be added to the ball velocity in the kicking process, as was already explained in the previous section. Additionally, there will always exist some delay between the instant of the kicking order and the physical release of the ball.

An efficient kick algorithm should send a kicking order even if the robot is not physically aligned with the target, but its motion (composition of instantaneous angular and linear velocities) would result in the ball being released to the target direction.

3.1 Alignment Condition

In the scope of the following description, the robot is considered to be aligned with the kicking target when two line segments intersect. One of the line segments represents the expected ball output angle (when the robot is stopped, this angle is equal to the robot's front direction) and the other passes through the target and is perpendicular to the line between the robot and the target. The latter has a certain length representing the allowed error for the intersection.

Figure 6 shows a situation where the robot is aligned with the target (marked with "X") within the allowed error. If no intersection between the line-segments occurs, then the robot is considered to be **not aligned with the target**.



Figure 6: Robot aligned with the target (within the error).

3.2 Linear Velocity Effect

Figure 7 shows the relative coordinate system used by the CAMBADA robots.

The component of the robot's linear velocity in the y-axis is compensated based on the offline calibration explained in section 2, since it only affects the maximum height and distance of the trajectory, not the direction of the kick.

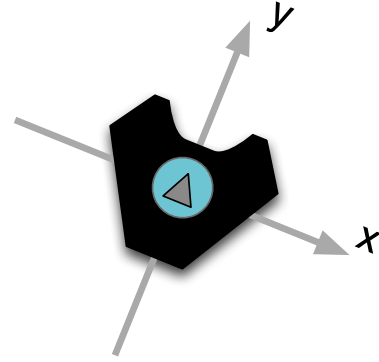


Figure 7: The robots relative coordinate system

On the other hand, both the x-velocity and angular velocity of the robot can change the direction in which the ball is released from the robot and, therefore, each has been separately evaluated. In order to accomplish this, two special routines have been developed to estimate the effect of these velocities.

Figure 8 illustrates the test conducted to measure the influence of the robot's x-velocity on the kicking direction. The robot made a path parallel to the goal line, from one field side-line to the other and kicks the ball as soon as it crosses the middle of the field. Then, the displacement to the center of the goal was measured to extract α angle. This was repeated for different x-velocities, both positive and negative velocities with the conclusion that the outcome was symmetrical, and all the values are present in Table 1.

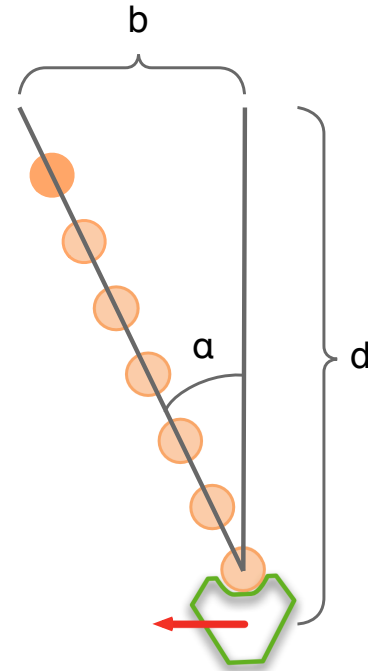


Figure 8: Influence of robot's x-velocity in kicking direction.

More tests could not be made, because of the lack of precision on the measurement of b (thus influencing

the accuracy of α) and also because, for higher velocities, the robot is unable to hold the ball while moving sideways.

Vel_x [m/s]	d [m]	b [m]	α [°]
0.5	6.0	0.5	4.76
1.0	6.0	1.0	9.46
2.0	6.0	1.8	16.70

Table 1: Measurements on the output angle for robots with different x-velocities.

Finally, a linearization was made to come up with a function that outputs the α angle based on Vel_x .

3.3 Angular Velocity Effect

The influence of the angular velocity was also evaluated and measured, using a special test behavior that makes the robot turn around its center with the ball at a set of fixed speeds, as depicted on Figure 9. The robot was placed 8 meters away from the goal (d) aligned with the goal's center and the kicking order was sent as soon as there was an intersection between the two line segments. The allowed error (length of line segment above the target point, b) was manually adjusted in order for the ball to hit the center of the goal (the fixed target, in this particular testbed). These two values allowed the extraction of the β .

The graph in Figure 10 shows a linear relation between the allowed angular error (in degrees) versus the robot's angular velocity (in degrees per second).

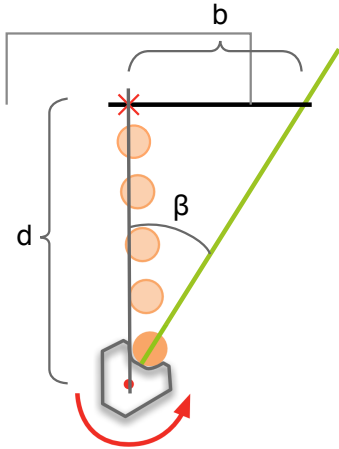


Figure 9: Influence of robot's angular velocity in kicking direction.

3.4 Real-time Compensation

In run-time, mainly during the matches, the robot uses the odometry information to get a better approximation of the robot's angular velocity and then makes the appropriate calculations with the alignment algorithm, making use of two different line segments. The first line segment represents the robot's front direction and is deflected by α (based on the robot's instantaneous x-velocity), while the second is centered on the target and is orthogonal to the line segment between the robot and the target, with 10 cm to each side (the minimum allowed intersection error), by default. Then,

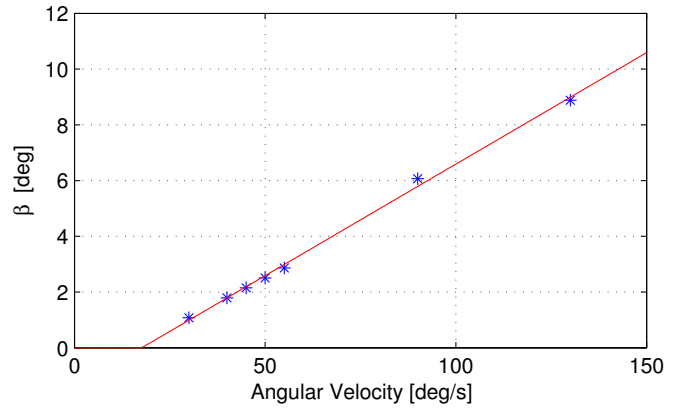


Figure 10: Allowed error vs Angular Velocity.

using the β angle, it calculates the length of the second line segment. If the robot is rotating with a positive (CCW) angular velocity, the line will grow to the right and vice-versa.

The alignment condition is triggered each time an intersection between those line segments is found. If the agent decides to send a kicking order, the robot releases the ball in the direction of the target, even if it is not physically aligned with it.

4. RESULTS AND CONCLUSION

The developed algorithm has been integrated and used for the first time in the **Robotica2014** competition. A thorough analysis was performed over the global accuracy of the kick. With both the alignment and the realtime height compensation in mind, the kicks in all the games were compared (Table 2) with the ones from **IranOpen2014** competition, where the old method was used (the robot kicked the ball only when it was stopped).

	Inside Goal	Outside Goal	Efficiency
IranOpen2014	34	31	52%
Robotica2014	100	32	76%

Table 2: Comparison of number of shots in goal (i.e. between the posts and below the bar) and shots out the goal with the previous approach and the new proposed approach.

Firstly, the total number of kicks is much higher in **Robotica2014**, because of the added ability to kick the ball while still in movement. The increase in the number of kicks towards the goal leads to a directly related increase in the probability of winning a match also. Furthermore, the difference in the number of kicks out of the goal is negligible.

Before the developed work, an average of **52%** of the kicks would never translate into valid direct goals, since the ball was kicked outside of the field or to a post or a bar. However, in the **Robotica2014** competition, in average, **76%** kicks were in goal (between the posts and below the bar), proving that the developed work resulted in an efficiency improvement of **46%**.

Furthermore, a significant improvement on the accuracy of the estimation of the necessary kick power to shoot the

ball at a useful height, as well as on the robot alignment, was also achieved. Comparing the overall efficiency of 50% obtained at the IranOpen with the overall efficiency of 83% in the Robotica Portuguese Open, an increase of over 60% in the CAMBADA kicking efficiency can be computed.

The real benefits of the proposed algorithm regarding the previous one can only be evaluated when playing against an opponent team, in a dynamic and almost unpredictable environment. With the previous algorithm (like the majority of the other teams on the Middle Size League seem to be doing), the robot performs a two-step behaviour: firstly, it moves to a calculated point and then rotates to the target. When it was aligned, a kicking order was sent. With this new approach, we increased the number of kicks by evaluating the alignment in parallel with the motion of the robot. No controlled experiment could be done on the lab, since the efficiency really depends on the behaviour of the opponent team.

For future work, a comparison with a Machine Learning optimization technique could be made to evaluate how this simple approach compares with more advanced approaches.

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