RobôCIn Small Size League Extended Team Description Paper for RoboCup 2024

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Abstract. RobôCIn has participated in RoboCup Small Size League since 2019, won its first world title in 2022 and second in 2023 (Division B), and is currently a four-time Latin-American champion. This paper presents our improvements to find a great first campaign at Division A in RoboCup 2024 in Eindhoven, Netherlands. During 2023, our team has successfully published 3 articles related to SSL at two high-impact conferences: the 26th RoboCup International Symposium and the 20th IEEE Latin American Robotics Symposium (LARS 2023). Over the past year, we have sought to improve our system and robots structurally, simplifying processes, improving performance, and providing more reliability. Furthermore, we'll discuss the software improvements to increase the number of players as required in Division A.

Keywords: RobôCIn · RoboCup 2024 · Robotics · Small Size League

1 Hardware

RobôCIn's brief competition history has focused on refining methods to optimize and enhance the robot's systemic functionality. Alongside this progress, we have learned from various mistakes, yielding valuable insights that have significantly contributed to our ongoing development. This section centers on the v2024 generation, spotlighting its features and explaining the measures implemented for enhancement. Notably, the team endeavors have led to modifications in the drive set, aiming to guarantee robust and consistent performance in competitive environments.

In figure 1, the following main parts of the robot can be visualised:

1 - The base frame serves as the core structure of the robot, where all components (excluding the cover) are directly mounted. It is crucial to note that

the base itself requires careful consideration prior to undergoing the 3D printing process. High density should be incorporated into the fastening areas for the powertrain parts and fixation.

2 - A direct drive set with wheels and motor board is employed, featuring a specific motor axis configuration. The front angle aligns with the robot's X-axis (parallel to the front), and the wheel shaft is set at 30°, while the rear angle is configured at 45°.

3 - The dribbler mechanism comprises the dribbling motor, dribbling bar, a gear connection linking them, and electronics for the front brake beam to detect the ball.

4 - The kicker assembly consists of two cylindrical plungers – one for front kicks and one for chip kicks – along with two coils and two capacitors.

5 - The second floor encompasses a battery, a power board for kick discharge, a mainboard for control, and the dribbler board.

6 - The 3D printed cover completes the assembly.

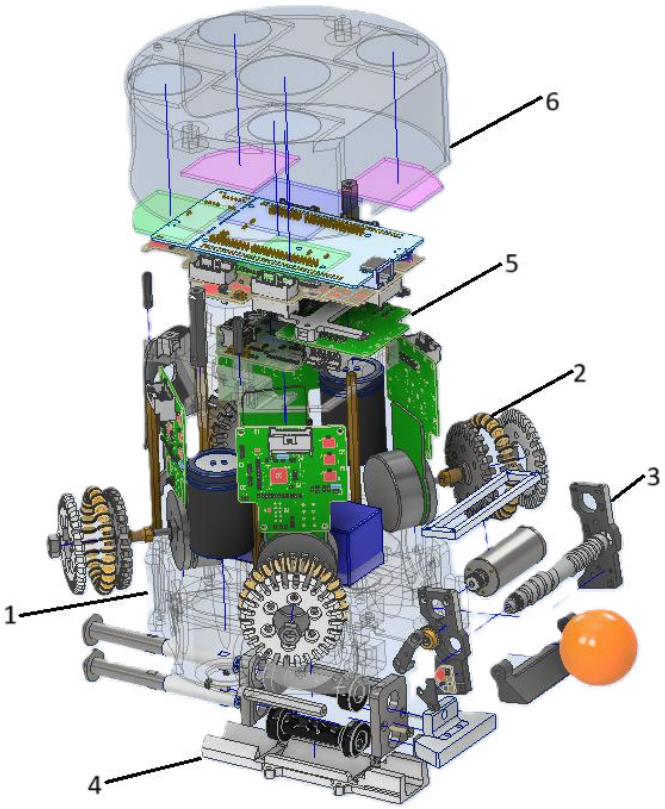


Fig. 1. Robot's exploded view, with all modules.

1.1 3D Printed parts

Over the past few years, the RobôCIn team has used 3D printing as the primary tool for manufacturing SSL robot parts. This is due to several factors, including ease of use, lower production costs, and the absence of members with expertise in areas such as machining.

The critical factors that damages 3D printing process is the high maintenance costs of parts, printing failures leading to lost printer hours, lower durability, deformation occurring when motors heat up (causing PLA wheels, which starts deforming at 60°C, to alter the motor's rotation axis, pressing against the base and jamming, potentially damaging the motors), and reliance on 3D printers; considering the printing time, which can exceed 20 hours, and the high demand for parts, meticulous planning was necessary to ensure everything was ready on time.

However, the increased durability of machined parts allows them to be used for years without needing replacement, with much lower long-term maintenance costs and providing greater security during competitions by avoiding deformations, this is due to the higher melting temperature of aluminum compared to PLA, this change also reduces dependence on 3D printers.

With the possibility of using machined parts, we made improvements to the drive set, mainly in the wheels, which relied a better stress resistance than the printed parts could provide.

1.2 Direct Drive

The v2022 wheels were 3D printed with PLA material and had a diameter of 45mm. Due to the embedded gearing system (3.3:1), the motor system could provide more torque to the robot. However, there were significant losses in movement due to backlash from the gears' tangency [3], and the system couldn't ensure parallelism of the motor and wheel centerlines. To achieve a smoother solution, the way the wheels were attached was modified.

Most of the time, an SSL robot is accelerating, rarely moving at a constant speed. Therefore, optimizing the motor's operating point for acceleration makes sense, and becomes crucial for the motor's lifespan and maintaining a good energy balance. This is achieved when the motor system is designed to operate at maximum efficiency, given that at a constant applied voltage and due to the proportionality of torque and current, efficiency increases with increasing speed (decreasing torque). However, at low torques, the significance of friction losses becomes more pronounced, causing efficiency to rapidly approach zero.

The 50W Maxon motors through direct drive work at a maximum operating point around 10 percent of the stall torque, near maximum efficiency [7]. For this change to be possible, the wheel size increased compared to v2022, with a total diameter of 62mm. The ideal wheel size for an SSL robot is always a compromise between various factors, such as the robot's maximum speed, transmission ratio, and the efficiency. These factors culminate in the motor characteristic curve(Figure 2) [6].

As a result, it becomes possible to reduce the overall complexity of the power transmission, the v2024 robots now use this approach, meaning no gears are involved. The main disadvantage of this change is the increase in energy consumption. However, this increase was deemed acceptable due to the high losses from the gearing. The benefits include more responsive control and allowing higher maximum speeds due to the accentuation of power in the characteristic curve.

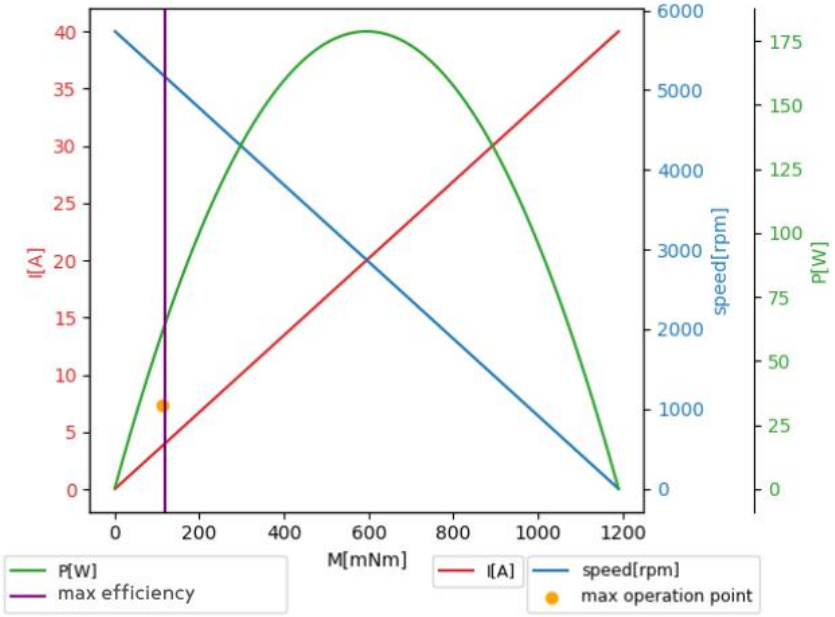


Fig. 2. Motor characteristic curve

2 Control

At the RoboCup 2023, we experienced some issues regarding the robot's motion control, primarily due to our transition from a geared system to a direct transmission, which reduced the encoder's counts per turn (CPT) available for measuring the wheel speed and changed the motor's operating range, causing a significant impact in the motors' behaviors during the robot's motion. These problems were related to the control stabilization time at the desired speed for the motor, generating errors in the final desired speed for each axis of the robot.

Our onboard control is implemented with individual PI controllers for each wheel; therefore, the PI gains must be readjusted to the new system accordingly. However, this procedure could not be done in time for RoboCup 2023, which led to difficulties tuning the robot's motion control. To solve that, we implemented a

robot-level velocity control on top of our existent controllers, i.e., a PID controller for each translation and rotation axis. This solution enabled our robots to move more accurately during matches, although it caused our motors to heat up, even leading to deformations in our 3D-printed base. Consequently, it caused permanent damage to some of our motors during the competition.

To address this problem adequately, we reproduced the experiments employed in the previous robot version for tuning the motors' PID controller, which uses the Multi-level PseudoRandom Sequence (MPRS) technique of control inputs for system identification [1]. This Section describes the approach we utilized and the experiments realized to identify the motor, tune the PID controller gains, and validate it with the robot motion.

2.1 System Identification and PID Tuning

The approach utilizes a transfer function to approximate motor behavior, implemented through MATLAB's System Identification Toolbox [4]. This toolbox facilitates the identification of a function that describes the specific motor behavior. To identify the transfer function, we need to extract samples from an actual motor that the toolbox can use.

The strategy for data collection uses MPRS to generate control inputs for the motors. This strategy consists of generating several values within the motor working range and applying them in a real scenario to capture all the external factors that influence the application [1]. The number of elements of the sequence should be large enough to get a good fit for the system identification. The number of samples is determined by the confidence interval we want to achieve during the system identification. Although it has recommended a sequence of around 400 samples, experiments with 30 to 50 samples showed similar results.

Briefly illustrated in Figure 3 is the data acquisition process for building the motor model. In this case, we send an input signal in MPRS format to the motor with parameters relevant to its application. The encoder then captures the motor response at a specific sampling rate, translating it into rotational speed in rad/s.

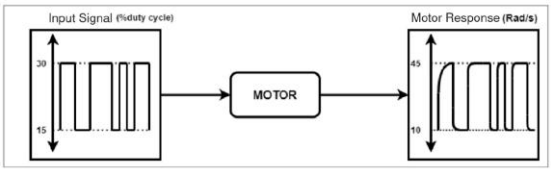
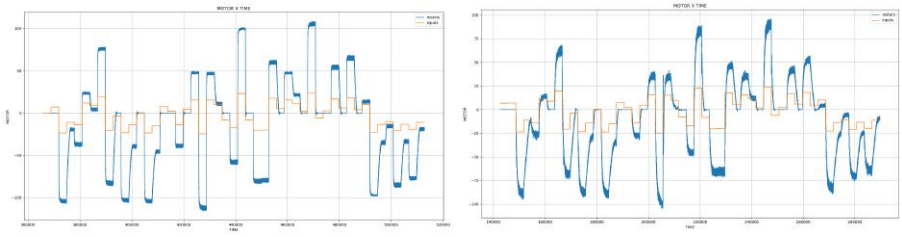


Fig. 3. Multi-level Pseudo-Random Sequence (MPRS).

Data collection This stage aims to acquire data on the motor's response in an open-loop environment, subsequently identifying the system (motor) using MATLAB. In other words, we will send PWM commands and record the motor speed,

timestamp, and input signal sent as reference, storing this data. Initially, we considered the possibility of collecting this data using a computer with the robot suspended. However, in recent experiments with the current robot (equipped with direct drive), we observed that the system's behavior is significantly altered when operating in the field. Therefore, we performed data collection using both scenarios. For the second scenario, we captured data using a Jetson Nano attached to our robot and communicating with our main board via Ethernet. The data collection process involved applying identical input values in two distinct situations: a) a suspended motor (without considering the robot's weight or floor contact) and b) a motor placed on the floor (factoring in the robot's weight). Figure 4 describes the behavior of the motors in the two scenarios evaluated.



(a) Suspended motor (b) Motor on the floor.

Fig. 4. Data collected from the robot motor(rad/s), in blue, and input in PWM(%) in orange.

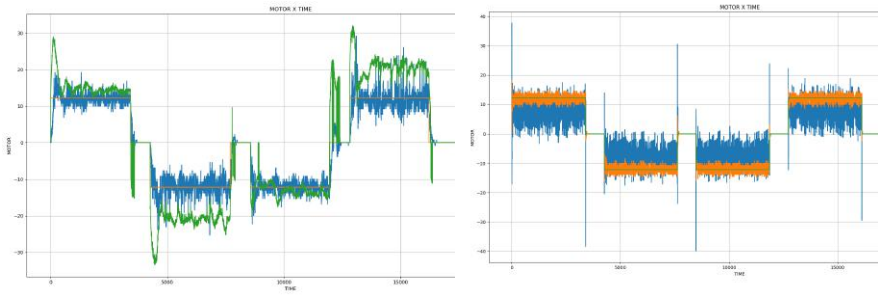
With this collected data, it is possible to obtain an approximate model of the motor in use for application-specific speed control based on observed data and a priori knowledge of the system. With the transfer function found, we can use the MATLAB PID Tuner toolbox to find the PID constants that match the system requirements.

2.2 Validation

This section describes the experiment used to validate the implementation of the PI controller. Analyzing whether the control constants obtained during tuning yield results consistent with the specified parameters is essential. The experiments were conducted in a real-world validation environment.

Motor response behavior The initial experiment involves analyzing the motor response at various reference speeds. Twenty arbitrary values will be selected and transmitted to each motor with a pre-defined time interval between each reference speed. Figure 5 illustrates the experiment applied to one of the motors using the control constants found in the tuning stage, demonstrating an interval of 3s between each speed. This phase aims to examine the motor's behavior

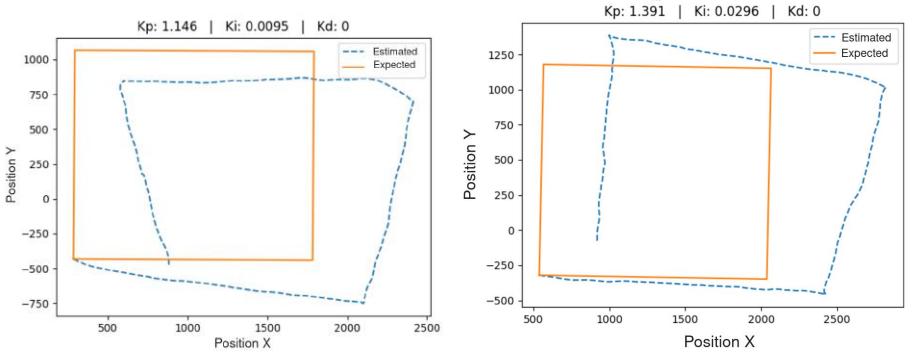
during speed transitions and verify its ability to stabilize the desired speed. The data collected shows that the error associated with controlling the motor speed decreases significantly, generating more stability in the control of the robot. This observation of the data allows us to assume that the motor's response to speed changes was satisfactory.



(a) Old control system: Current rad/s in blue, desired rad/s in orange and current PWM in green.

(b) New control system: Current rad/s in orange, desired rad/s in green and current PWM in blue.

Fig. 5. Motor Response Data.



(a) Constant Set 1.

(b) Constant Set 2.

Fig. 6. Robot tracking with a speed of 0.5m/s.

Linear Trajectory To see how this improved our motion control, we experimented with commanding the robot to perform a 1.5m square using the low-level PID controller. Figure 6 shows the performance of the new controller tuned with

two sets of values for a speed of 0.5m/s. This experiment was carried out in a real-world environment. After the experiment, we found that the motor drives were lighter and operated within the acceptable temperature range. During trajectory testing, we observed that the second set of constants matched the expected trajectory better. However, there were errors associated with the change in motion, resulting in a deviation from the y-axis.

After revisiting the entire system identification, adjustment, and validation process to address the implemented changes, we successfully mitigated the issues observed in our last RoboCup participation and mentioned at the beginning of the section.

3 Software

This year, our team concentrated on improving crucial elements of our in-game decision-making. A primary focus was refining the decision between passing and kicking, which was achieved by implementing a new heuristic based on the raycast algorithm. We also developed a dynamic positioning system for our robots, incorporating the algorithm and additional heuristics for a more robust approach.

The previous heuristic considered both kick-on-goal and pass probabilities as one, then decreased each probability based on factors like the presence of an enemy between the forward and the goal, reducing the kick probability. The need for a new heuristic comes from the old one lacking robustness, relying on arbitrary "magical numbers" that led to inconsistent decisions and suboptimal choices, such as passing when kicking was more viable. Moreover, the complexity of the old heuristic made it challenging to comprehend and modify efficiently, resulting in a time-consuming process for any necessary adjustments. The new heuristic aims to be more robust, providing more logical and understandable decision-making for the software.

The positioning system is another point that was addressed in 2023. Previously, the positions of our attacking robots were determined by a fixed correspondence between the ball's position and specific positions on the field. This static approach led to difficulties in evading enemy marking, especially in direct kick situations, making several plays impossible and reducing shooting opportunities on goal. In 2023, we developed a new positioning system that uses the new heuristic mentioned above to dynamically distribute our players on the field, actively trying to eliminate enemy marking, shifting from a fixed to a dynamic positioning system.

3.1 Shadow Heuristics

The recently developed and implemented heuristic is based on the Raycast algorithm. The Raycast is an algorithm used in computer graphics to calculate the illumination of a scene or an environment. In its 3D version, as seen in Figure

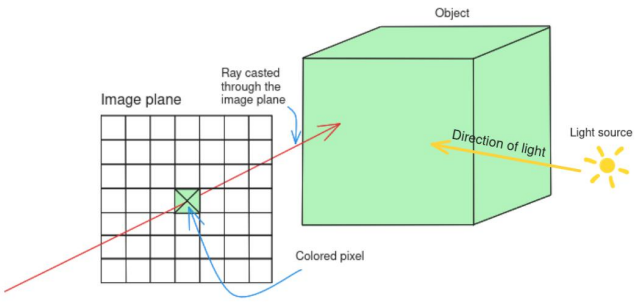


Fig. 7. Representation of the 3D raycast algorithm

7, it shoots rays from each screen pixel, determines the intercepted objects, and calculates pixel color based on these intercepted objects.

The 3D version of the algorithm is not useful for our purposes, as we are not aiming to illuminate a 3D scene. Instead, we opted for its 2D version, which casts virtual rays from a starting point in a specific direction, detecting intersections with objects or surfaces in the environment and determining which areas are visible from a given point [4]. To minimize computational intensity since we are only interested in the rays that get blocked by enemies, we implemented the optimization of the traditional 2D Raycast described in [4], projecting rays only at both ends of the segment. This approach minimizes the required number of rays to just 2 per enemy robot.

We used the Raycast to calculate the shadows cast by other robots on the enemy goal, enabling us to determine the amount of free space from a determined point to the enemy goal, which is used to calculate the probability of a shot from that point reaching the goal. To do this, we treat the ball as a light source and enemies as obstacles, producing shadows that cover parts of the goal segment, as shown in Figure 8. Uncovered areas represent free spaces, and more free space increases the chance of scoring from that point. This idea is similar to the one followed in the Score Chance by Tigers [5], but the implemented approach differs from it and aims to be more general.

The calculation is incomplete if we only consider the available free space. For instance, a shot from our defense may have ample free space, but it carries the risk of being an aimless kick. Additionally, it provides significant reaction time for the enemy goalkeeper, and the ball's deceleration affects its speed, potentially leading to a stop before reaching the goal. In order to address these situations, it is essential to consider the distance from the ball to the goal as a decisive factor in the final score probability.

Raycast Algorithm The goal of developing of this new heuristic is to use it both for kicks on goal and passes. In order to do that, we generalized some parts of the algorithm. The generalization is straightforward: any point on the field can function as the light source, any segment on the field can cast shadows, and

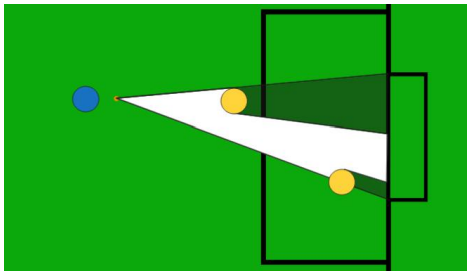
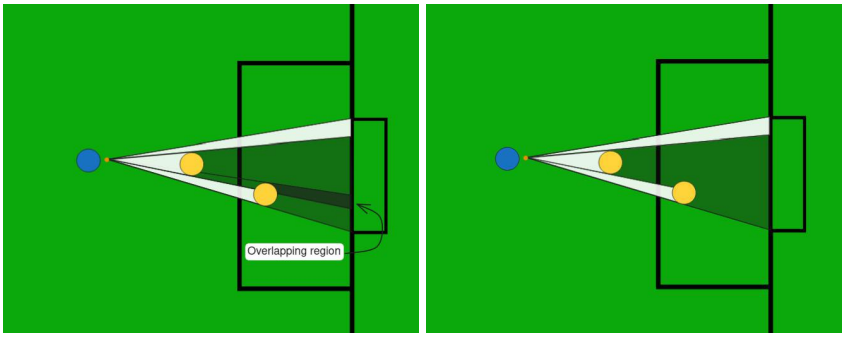


Fig. 8. Representation of the shadow heuristic. The light comes from the ball and the enemies are obstacles that block it.

any segment on the field can be the target segment, as exemplified in the context above where the ball is the light source, enemy robots cast shadows and the goal is the target segment.

The algorithm is initiated by projecting rays toward each enemy and determining their intersection with the four boundary lines of the field. The intersections not occurring on the goal line are repositioned to the nearest enemy goal post (Figure 8), focusing only on the shadow part covering the goal. The shadow calculation is performed for each robot, potentially resulting in overlapping shadows over the goal, such as when one robot is positioned behind another. The implemented algorithm includes a step to merge overlapping shadows to prevent discounting the overlapping area twice. Figure 9 shows the before and after of this step. Additionally, to optimize the algorithm, we excluded the enemies behind the ball concerning the kick target point from the calculation of shadows, as they do not cast shadows on the target segment.



(a) Unmerged raycast lines with overlapping regions.

(b) Merged raycast lines without overlapping regions.

Fig. 9. Raycast lines

Implementation details Although the implementation of the algorithm is described above, there are still some details that should be explained.

1. We exclusively consider enemy robots as shadow producers. This decision works because we implemented mechanisms ensuring our robots do not intercept shots, even if an ally robot kicks toward another ally. Also, considering just enemies reduces the number of shadows to consider, making the algorithm faster.
2. The algorithm does not consider robot movement for shots on goal but accounts for it in passes. In pass situations, shadows are extended by anticipating the position of the enemy robot in the next few milliseconds. This variation is justified for several reasons:
   - The target segment on passes are ally robots, which are smaller than the goal, and thus, it is harder for an enemy to make a shadow on an ally.
   - We consider that a pass interception is worse than an interception of a shot to the goal, so by extending the shadows and considering the movement of the robots, we can anticipate if a pass has a high chance of being intercepted.
   - Through empirical tests, we acknowledged that considering the movement of robots to a shot on goal would leave just little free space, decreasing the scoring probability and, consequently, decreasing the number of kicks on goal.

Pass or Kick Our team's playstyle is based on passing the ball to advance on the field and create goal opportunities. Consequently, the decision of whether a robot should attempt a shot on goal or make a pass to an ally is crucial. Additionally, choosing the optimal pass destination can significantly impact our goal-scoring opportunities. Historically, our decision-making relied on a complex and less reality-based heuristic, leading to missed goal opportunities or quickly interceptable passes.

The shadow heuristic was developed to overcome this problem and improve this decision, evaluating both the scoring probability of a shot on goal and the optimal pass destination. However, there are differences between the factors considered between a kick on goal and a pass. Passes have a higher chance of failure due to potential interceptions, so it is necessary to incorporate additional factors to minimize failure probability. Currently, we consider seven factors to determine the final probability of a pass:

- **Kick on goal probability:** the shadow heuristic considers the goal as the target segment. This feature already takes into account the 'decreasing probabilities' part of the old heuristic;
- **Pass chance of interception:** uses the allies as the target segment;
- **Ability to chip over enemy:** In this case, this enemy is not considered a possible pass interceptor;
- **Facility to receive the ball:** if there is any ally that can receive the ball at the desired pass destination in order to avoid useless passes;

- **Closest enemy distance to pass target:** is used to determine how difficult it is going to be for the receiver to kick on goal after receiving the pass;
- **Angle difference to goal:** how much the receiver will need to rotate in order to kick on goal because a big rotation would take more time and, consequently, give time for an enemy approach;
- **Closest enemy distance to forward:** Ignores the pass targets behind the ally to avoid losing the ball while trying to pass.

These factors can encapsulate, improve, and expand the idea behind the old heuristic while keeping it easy to understand, as they are logical and intuitive from both the robot's and human's perspectives.

3.2 Support Positioning

Over the years, the team's positioning system has stayed relatively untouched while we developed other software parts. It was based on fixed positions on the field according to the ball's position, but it did not react to enemy marking, meaning that the robot handling the ball had no good passing option if all supports were marked, blocking our playstyle.

To address this issue, we developed a dynamic positioning system capable of reacting to enemy defense marking, adjusting to eliminate it, and creating new situations that keep the opposing defense in a reactive state, always behind our team's movements. The positions assigned to supports cannot be fixed for dynamism and should vary over time. Our chosen approach involves sampling points on the field at specific time steps and evaluating them using indicators, similar to what SRC described in [9]. As our goal is to choose optimal points to receive the ball, these indicators are the factors for the final probability of a pass.

Pipeline for dynamic positioning The decision module handles point selection calculations to coordinate multiple players [8]. To organize the implementation, we have divided it into a series of steps, forming the pipeline illustrated in Figure 10.

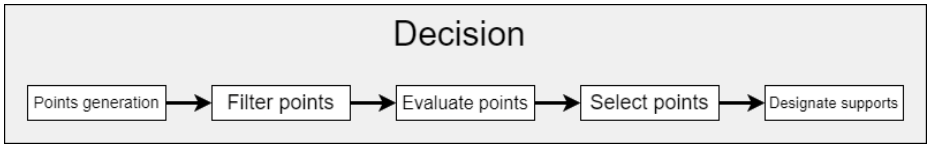


Fig. 10. Pipeline of the support positioning system

We start by generating several points on the field, as seen in Figure 11. In order to force forward passes and to prevent the risk of exchanging passes near

our goal, no point is generated too deep into our defensive side of the field. These points are fixed throughout the game, and the dynamism comes from the number of possible positions to choose.

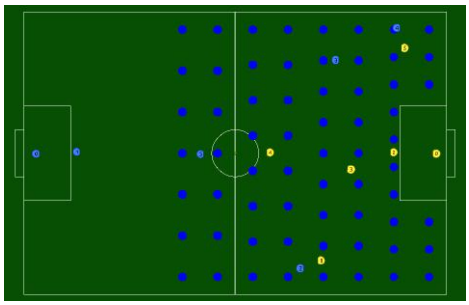


Fig. 11. Field with all points that were generated by the first step of the positioning system's pipeline

The initial step generates points without considering feasibility, and filtering them to remove the bad ones is necessary. Bad points are defined as the ones that could cause trouble to our strategy, such as points too close to the robot in possession of the ball and those inconsistent with our plays. We divided the field into sectors and defined a link between the ball's sector and the desired sectors to place supports. The region right in front of the goalkeeper area is considered highly important as it can lead to better-scoring chances. Therefore, we broke it down into smaller sub-sectors that allow more specific filtering of the points. The filtering process keeps only the points in the desired sectors. The result can be seen in Figure 12. The correspondence is manually made, which could open the opportunity to have different kinds of positioning based on the opponent's team.

The evaluation step applies the shadow heuristic calculation to each filtered point and sorts them in descending order, which helps the selection step. The color of each point in Figure 13 indicates its score.

After evaluation, there may be regions of points that have reasonable probability. The selection happens sequentially and prioritizes points that are distant from each other to avoid aiding enemy marking. If a point is too close to a selected one, it is moved to the end of the list to ensure that it will be selected if there are not enough far points. This process continues until enough points are selected to place the supports.

After all these steps, we designate one support to each point using our role-assignment algorithm.

Challenge of the dynamic positioning While this approach to dynamic positioning seems reasonable, it poses some challenges, especially at the moment of

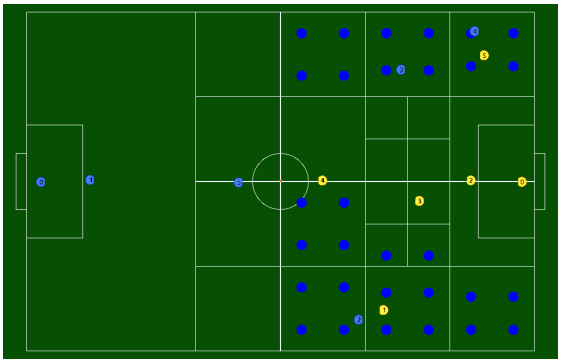


Fig. 12. Field sector and filtered points. Only the points in the desired sectors are kept to the next step of the pipeline.

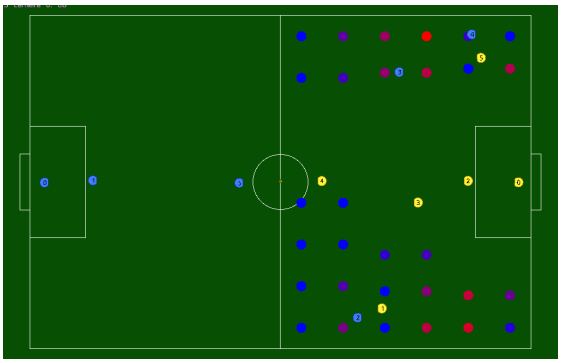


Fig. 13. Points with colors based on their score. Totally blue means a score of 0 and totally red indicates a score of 1.

recalculation of the probabilities. The calculation is very computationally heavy and would slow down our processing if performed every frame. Also, recalculating every frame is unnecessary and may introduce instability to the selected points. Therefore, we developed a solution to address these issues.

The games in SSL are very dynamic, with the robots moving a lot on the field in a concise time frame. This feature implies that the probabilities change quickly and the selected support positions may also change frequently. These frequent changes are undesirable as they cause instability in the robots' movements and increase the crash risk due to frequent alterations in path planning.

We combined two approaches to overcome this challenge: the first uses a timer to limit when the calculation occurs, and the second checks if the ball has changed position such that the probabilities may have been significantly altered. The timer's time step is calibrated to be large enough to ensure stability by avoiding frequent point changes but not so large that we lose the team's

reactivity to changes on the field. Furthermore, the change in ball position needs to be calibrated in the same way as the period was.

The current approach for determining when to recalculate probabilities may not be optimal as there might be better heuristics. Improving this aspect is part of our future plans.

4 Migration to division A

Given the success and performance in the last campaigns in Division B, RobôCIn is structuring itself to participate in Division A in 2024. We see this as a new level of challenge and possibilities for the project; playing in Division A means evolving and maturing the project at several points. To keep more robots up and running efficiently and without the overhead of the mechanical team for maintenance between games, we are looking to improve reliability and optimize the robot, as explained in Section 1. Furthermore, as we will have more robots, we seek to expand our decision heuristics and the level of multi-agent cooperation, such as structuring complex plays that involve more than two players together, based on the plays described in the STP [2].

4.1 Ball Placement Strategy

Ball placement is a requirement to be able to participate in Division A and Division B. It appears to be a technical challenge; given the performance obtained in this challenge during RoboCup 2023, RobôCIn decided to extend its use to games, an effective strategy that extensively validated our ball placement behavior.

In our high-level software, when the ball placement command is received from the referee, the team divides into two groups, one to execute the action and the other to avoid the exclusion zone.

The following behaviors or a combination of them will be performed, depending on the context, to get the ball to the defined location:

1. If the ball is out of bounds or close to a wall: As our robot's dribbler mechanism is still in development and currently not used by the software stack, we kick the ball diagonally against the wall so that it returns to the pitch and preferably closer to the target position.
2. If the ball is far from the target: We use two robots to quickly take the ball to the goal with one pass, where, ideally, the second robot already receives the ball at the expected destination.
3. If the ball is close to the destination: The robot will push the ball to the determined destination, stopping a little before estimating how far it will roll after the robot stops.

While the ball placement occurs, the other robots must avoid interfering with the process by avoiding the exclusion zone created, but simply collecting the team to a position as far away as possible is ineffective.

In our approach, we place the other robots in a line along the x-axis of the field, with a displacement in the y-axis to be on the opposite side of the ball's position. As the ball placement progresses, the teams gradually move from the position they assumed in the referee's stop command to the ball's destination position.

With this, the team will be positioned to quickly return to the game without invading the ball placement exclusion zone, especially without being unprotected from a quick return from the other team.

5 Acknowledgement

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