RoboIME: From the top of the world to LARC 2018

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***Abstract*— This paper describes the electronic, mechanical and software designs developed by the RoboIME Team in order to join the LARC 2018. The overall concepts are in agreement with the rules of Small Size League 2018. This is the fifth time RoboIME participates in the LARC.**

I. Introduction

RoboIME is a Small-Size team from the Instituto Militar de Engenharia, IME, located in Rio de Janeiro, Brazil. This is the eleventh time the team takes part in competitions, being the best result second place in the RoboCup 2018 and first place in the Latin American Robotics' Competition 2017.

All students that work in the SSL project are members of the Laboratory of Robotics and Computational Intelligence at IME. Team's previous works were used as reference [2] [3] [4] [1], as well as the help from former members of the team as consultants and tutors.

This article describes the team's general information and improvement in the most recent semester, since our previous TDPs for LARC 2017 have detailed explanations on our previous changes. This article is organized as follows: software in section II, embedded electronics in section III and mechanical design in section IV. Conclusions and future works are discussed in section V.

II. Software Project

This paper reports the main improvements and changes since the 2017 LARC project.

A. Statistical Module

A module called the Statistical Operational Software (SOS) is being developed in the AI. The main idea is to process parallel information and give feedback to the AI with information that could help during or after the game. For example, it could detect that one robot is slower than the other and inform this information in order to have someone verify if there is a problem with that robot. This kind of data is not processed on the main AI and might help with certain in-game decisions.

The objective, in a long term, is to transform this module into a self-learning AI. A few features have been developed and integrated into our AI, such as:

1) Heat map: The heat map is inspired by those seen in soccer games. The field is divided into a grid and each cell is approximately the robot's size. A histogram of where each robot is located in the field is calculated in every iteration, generating a matrix. This matrix must be normalized in order to find the probability. Currently the heat map is just a visual tool, but in the future it will be very useful for self-learning methods.

The results look like this (see figure 1):

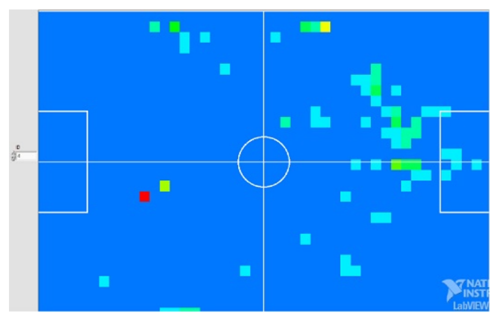


Fig. 1: Heatmap of an offensive robot. The different colors indicate the amount of time spent on each position.

2) Kick error histogram: This histogram calculates the distance between the point where the ball entered the goal and the point, on the goal line, that the attacker was aiming for. A test routine was projected to make the attacker kick as many times as desired and the result is plotted in a graph. One test is shown below (see figure 2) (y-axis: Number of kicks and x-axis: error(mm)):

This test provides a method of analyzing the difference of precision between two versions of a attacking robot.

3) Pass analysis: This test was originally made to verify the force of the robot's kick when passing the ball to some other robot, but it can also be useful to learn when the in-game pass is working, of our team or the enemy's team. Basically, it searches for a kick and for the robot of the same team that receives the ball and controls it for a certain time.

B. Passing State

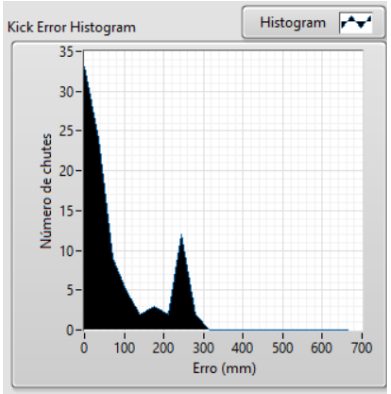


Fig. 2: Histogram of 100 kicks to the goal

1) Receiving the pass: In order to increase the amount of correct passes, an analysis of what is the best algorithm of receiving a pass was made. After selecting the position of the striker using the Inverse Best-Y(see reference[2]), it is necessary to have it wait for the ball and re-position itself if necessary. Two approaches were analyzed for when the striker is waiting for the ball: allowing it to move only parallel to the x-axis and allowing it to move only perpendicularly to the vector that represents the velocity of the ball. This restriction of movement only happens during the pass state, guaranteeing that the striker will not present this behavior in other conditions. Using the new statistical module with the pass analysis feature, (see section II-A.3) it was possible to analyze which algorithm presented the biggest quantity of successful passes. The result was that the perpendicular approach was the better, possibly due to the fact that the striker had a shorter distance to move (see figure 3).

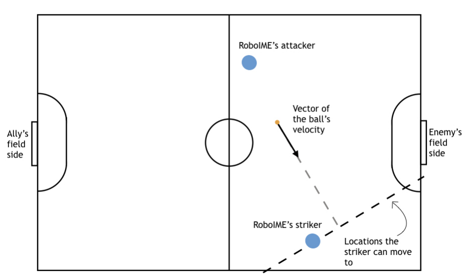


Fig. 3: The movement of the striker when receiving the pass

C. Personalities

For the advancement of the AI, some changes were made to the personalities (see Personalities in [4] in order to have a better understanding on how other personalities work).

- *Defender:* The main change implemented in the defender was the ManMarker behavior, that were based on ER-Force's TDP (see in [5]). This behavior's function is to mark enemies without ball possession but which may receive the ball, through a pass, for example. The defender robot that exercises this conduction stands itself separately from the wall of robots, in front of the enemy robot chosen. Based on the distance to goal and on the distance to ally robot with ball possession, the code calculates the most dangerous and the second most dangerous enemies. Hence, the ManMarker has the option to mark any of these enemies robots.
  It is important to highlight that the code allows to choose between two formations:
  1) All defenders in the wall of robots.
  2) Defense with ManMarker (one e only one).

  The choice between formations 1 and 2 and the selection between two options of enemies to mark can be made manually through a button before the match or during breaks. It is considered for further improvements an integration with the coaching parallel system to decide whether formation is more adequate. The former is thought to be more effective against teams with low passing rates, whereas the latter is thought to be good against teams with high passing rates.
  Now, when an enemy robot with ball possession approaches the wall of robots, one of the defenders also assumes the offensive behavior as described in the RoboCup TDP (see reference [2]). The chosen defender may throw the ball away or to block an enemy's shot, depending on the situation.
- *Goalie:* The general behaviour of the goalie was modified, working now as a state machine, where the actual state is determined by the distance between the enemy attacker and the ball.
  First, the closest enemy to the ball is defined as the enemy attacker. Then, the goalie will choose one of the following states based on the enemy attacker distance d (in mm) from the ball. Let d_{inf} be the behaviour distance lower bound and d_{sup} the upper bound.
  1) $d > d_{sup}$: The trajectory line of the ball is determined by the ball's current location and its velocity slope.
  2) $d > d_{inf}$ and $d \leq d_{sup}$: The trajectory line will be the one connecting the enemy attacker and the ball.
  3) $d \geq d_{inf}$: The trajectory line will be the line that passes through the ball and which slope is given by the orientation of the enemy attacker.

  In each state, a trajectory line is calculated and the goalie behaviour determined. The goalie will intercept the line if it meets the goal and kick the ball out of the goal area. If the line does not meet the goal at any point the goalie will then go to one of the posts or the goal center, depending on the slope of the line that passes through the ball and center of the goal, waiting in a good position for a change in the ball trajectory.
- *Striker:* The striker now assumes a man-marking behavior when an enemy robot has the ball possession, which is determined by whether the ball is closest to an ally or enemy. First, it is calculated for each enemy robot its distance from the ally's goal and from the

robot which has ball control. The one which presents the smallest addition of these two results is considered the most dangerous enemy. Then, it is applied the GoTo method to position the striker properly between the enemy which has the ball and the most dangerous one. This position is set next to this last robot mentioned, along the vector that links these two enemies. The striker is oriented in order to kick the ball away from the man-marked robot, in case the most dangerous one receives a pass from the other.

D. *Test Module*

In order to help test infield and during the timeouts, the test module was developed. There are three major testing modules, as described as follows:

- Kick Test: The Kick Test is used to test the kick with controlled magnitude. It is possible to generate a log with kicking performance data (such as ball positions and the kick's magnitude in each observable moment of the test), which is useful for calibrating the kick for passing.
- Dribbler Test: Used for turning the dribbler on.
- Control Test: The Control Test works by setting a sequence of waypoint coordinates, creating a circuit and making a robot perform it.

E. *Path Planning*

1) Obstacle Avoidance: This year RoboIME changed its path planning algorithm. In order to achieve an optimized trajectory and to avoid problems that may occur with the Potential Field approach, an extended rapidly exploring random tree (ERRT)(see reference [6]) based algorithm was developed for critical roles, such as the attacker and the striker.

This new approach builds a tree from an initial point until it reaches the goal point. The trajectory generated, for example as depicted on Figure 4, is guaranteed to be free of obstacles: on the other hand, in some situations it may not be the optimal path, since it can still be smoothed. For this implementation, the team was mainly inspired by an article about path planning, which describes with many details how both algorithms work.

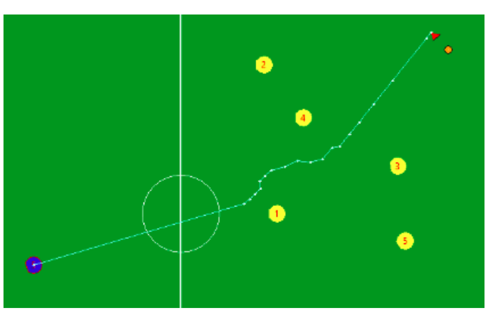


Fig. 4: Example of trajectory generated by RRT algorithm. In this representation, ally robot is blue, enemy robots are yellow, the ball is orange and waypoints are white.

III. Electronics Project

Since the LARC 2017, a lot of effort has been put into making the electronic project more robust. Standardizing the production of the boards proved to be an improvement in the board's reliability. Also, the modularization of the project proved, once again, to be useful, enabling removing a defective robot mid-game, debug it, and placing it back in action in a span of a few minutes. The modifications made in both the main board and in the kicker board also made the robot much more reliable. The RoboCup 2018 competition was very useful to test the changes in the project.

A. *Firmware*

The firmware was improved from a bare metal code that ran with hardware interruptions to execute the communication and the wheel controls, to a real time operating system. FreeRTOS was chosen due to its ample support in online community and its robustness.

Previously, the firmware in the transmitter was the same as the one in the robots, being the connection to a serial port the trigger to call some functions instead of others. This was also changed with the addition of the FreeRTOS tasks, in order to make the code clearer and more readable.

With such architecture, new additions to the code are easier to make, not having to know the whole flow of the code, just the particular module being modified.

The transmitter's firmware consists of two main tasks, responsible for reading the USB COM port and transmitting its commands through the NRF24l01P and the other responsible for reading and writing in the command line for debugging purposes.

The robot's firmware has a task for receiving the commands from the transmitter, another for controlling the four wheels' speeds, a third for activating the kicks and check for the ball sensor and a fourth for transmitting back data for the software.

The changes in the firmware LARC 2017 to 2018 are the following: both kicker boards (models 2014 and 2018) work with the same code, even though they have different signal inputs, this is good for the modularity of the project, a firmware test mode was made for the new motherboard to inform problems in the robot through the 7-segment display and now the AI will receive some data like battery power. Also, a micro SD card was inserted into the design for future implementation of writings logs for debug. Besides, there were two new additions that are presented below.

1) Kick Strength: One major contribution of the LARC 2017 was the kick strength modelling. After several tests using the camera system and controlling the time the capacitor discharges in the coil, the data was collected and it was possible to develop a simple equation that, with the time the capacitor discharges, estimates the ball's speed.

2) Robot Communication: One big improvement from LARC 2017's project to LARC 2018's is the addition of communication from the robots to the AI software. Previously, due to difficulties in the firmware configuration and hardware limitations, information from the robots could not

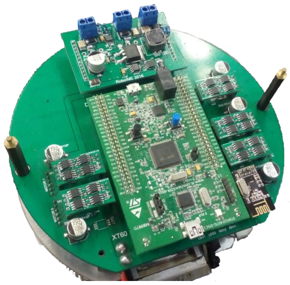


Fig. 5: Picture showing all boards: the kicker module at the top, the stamp module at the center, five motor modules at the sides and one communication module at the corner. Beneath all, the main board.

be transmitted to the AI. For example, if the ball sensor is activated or not or even if it is working. With such limitation fixed, this forward-backward communication becomes possible, enabling more possibilities for the IA system.

B. Control

Maintaining the robot at the expected speed or position is very important so that the software is able to work properly. To try to keep the robots moving as expected, there are several routines to check or filter the results obtained from the vision system and the robots themselves.

1) Dealing with a non-ideal movement: In cooperation with the each wheel's speed being controlled, it is important to control the overall direction that the robot follows. Wheels accelerate differently from each other. One wheel achieving the final speed before the others can compromise the entire movement of the robot, changing its direction due to the robot's rotation. Incremental acceleration of the robot with the slower one acting as the leader is a possible solution to this problem, therefore acceleration should be sacrificed over overall trajectory precision.

To aid in this problem, current sensors were implemented on the board. By reading the current passing through each motor, it is possible to not only control its speed, but also its torque. Inertial sensors were also implemented to improve reliability of the robot's own readings and as an additional control parameter.

C. Board Designs

RoboIME's hardware platform kept its same structure, as seen in figure 5.

The motor module remained unchanged since the last competition, proving itself to be very reliable, with only few remaining problems during the games, either in the RoboCup or LARC.

1) Stamp module: This module is responsible for performing all the logical functions, serving as a brain for the electronic system. The module is a commercially available board - the STM32F4-Discovery; it is a development kit that aggregates an Arm Cortex M4 microcontroller with a series of peripherals like a debugger, a motion sensor, two push buttons and two USB plugs.

2) Main Board: The Main Board, figure 6, provides physical support to the other modules and connection between them and the robot's actuators, sensors and battery. Most of the main board is composed of simple routes and planes making these connections. But it also implements some important circuits, such as the currents flowing to each motor and the battery voltage.

Further adaptations were made aiming the for at RoboCup 2018. An important one was the thickening of the tracks, which was implemented after a power loss test. This allowed more current be available for the motors as the track's resistance is decreased. Another one was the exchange of the current shunt monitors INA220 to INA169, once they are analog, which caused the data reading to become considerably faster. Also, a MPU-9250 was added in order to improve the control system by providing more stability to the robot. In addition, there was a migration from the use of an ID selector to the use of a 7 segment LED display controlled via STMPE, an I2C input/output (I/O) expander. More LED's for debugging were added as well. A mini SD Card slot was also included and it communicates via the same SPI as the MPU-9250. The top 3D view of the new board is available in figure 6

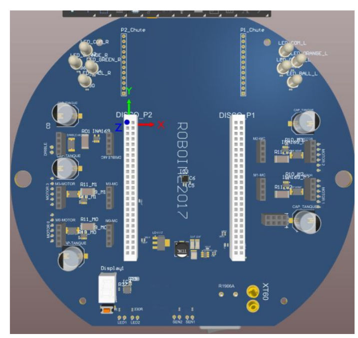
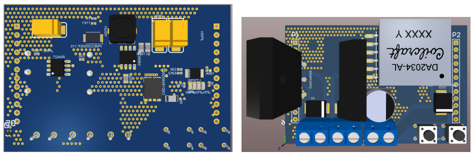


Fig. 6: Main board 3D top view

3) Kicker module: The flyback topology was chosen due to its faster charging time, making the kick ready with full strength in less than four seconds, instead of 10, using the old topology.

This module stores power an electrolytic capacitor of 2200μF, 250V using a DC-DC step-up circuit controlled by the LT3750 IC, that transforms the 7/8V DC of the battery supply into a 180V DC power supply to charge the capacitors. It also uses two IRG4PC50FD Power MOSFETs driven by an IR4427 Mosfet driver to close the high voltage circuit, that releases the power stored in the capacitors to one of the coils. The stamp board can also control the kick speed, controlling the signal duration sent to the mosfet driver.

The board has a two new circuits, one for charging and one for discharging the capacitor. The discharging circuit uses a MC34063 as a DC to DC converter to the voltage Step-Up to 15V and a IR4427 Mosfet. As for the charging circuit is used a LT3750 to control the charging of the capacitor. It was also added a DA2034 transformer to the circuit making the charging faster. The LT3750 needs to receive a rising edge on one of the pins to enable the charge of the capacitor, this new implementation allows the test of the module with no necessity to use the main board. The kicker board returns a voltage of 7.4V to the mais board which causes the to Discovery to burn, so there was added a diode to protect it. The figure 7 show the 3D model of the board, from the top and the bottom view.



(a) Bottom view of the board. (b) Top view of the board.

Fig. 7: 3D model of the kicker board

IV. Mechanical Project

The mechanical project still is developed using CAD (Computer Aided Design) and CAM (Computer Aided Manufacturing) softwares. Therefore, the team members are involved on the conception but also on the machining itself. CNC milling, CNC lathe and 3D printing were used for the manufacturing of the new parts.

The participation in the LARC 2017 made it possible to notice many opportunities of improvements of the mechanical project, not only because of the real experience of the matches but also because of the exchange of information with other teams. Next, it will be described the improvements made since the competition at Curitiba and also the planning for the LARC 2018.

A. The Cover:

The current cover has undergone some changes compared to what was used at LARC 2017.

1) The decreasing of polycarbonate thickness: The current cover is made of 1mm thick polycarbonate (the former was 2mm thick). Some factors were determinant for this change to be made, among them, we can mention:

-the decrease of the robot's diameter: a greater gap is created in relation to the allowed limit;

-the strength of the polycarbonate: Due to the high resistance of this material, the 1mm thick polycarbonate is enough to withstand the game conditions;

2) The creating of two openings in the fairing: In order to facilitate the visualization of the electronics, two windows were created in the cover that are located at the same height of the robot motherboard and have a length of 69.5 mm and a width of 12 mm.

3) The cover's easy removal device: The current cover has a device created to make it easily removed from a rotation around the center of the cover and in order to prevent it from rotating during the game, having created a fixed latch for the cover. However, when tested, it was realized that this system was not more effective than the previous one because, among other factors, the cover's lid was made with polycarbonate of 1 mm of thickness which made it more malleable than it should. Because of this, the possibility of returning to the mechanism referenced in our TDP for RoboCup 2018 is being evaluated.

B. Development of a new dribbler

From the experiences obtained during the competitions in which the team participated, it was noticed the need to have a better system that would help the robot to have a greater ball control.

1) CAD modeling: To model the dribbler, SolidWorks was used, always having in mind the best geometry to have a good efficiency and suitability for the project.

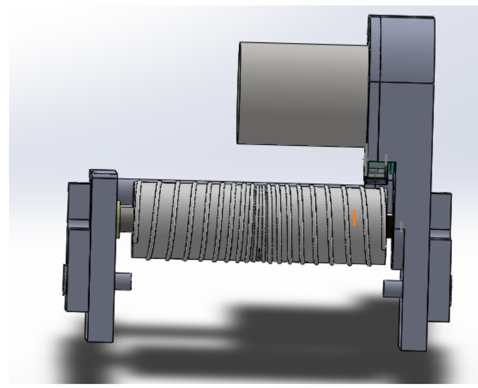


Fig. 8: Dribbler CAD model

2) Transmission system: In the previous version an o-ring was used to transmit shaft movement connected to the motor to the roller shaft. However, this did not prove to be an adequate solution for the project, failing to dribble the ball efficiently. So a new dribbler that uses gear transmission instead of the o-ring was designed.

3) The roller: To make the roller of the dribbler, a 3D printed mold was used and put a mixture of silicon and catalyst in it. However, more than just one mold was made. While performing this task, reshaping the roller was necessary by not guiding the ball properly to its center, although the new one has not yet succeeded in this regard. In addition, the current roller still does not maintain satisfactorily the possession of the ball during rotational movements of the robot. To perform the tests, a Dremel was used to simulate the torque generated by the dribbler's motor.

C. The modeling of the new low kick system

Although the low kick worked well during LARC 2017, it was realized that we the low kick system could be optimized not only in terms its geometry but also the accuracy of the equation of the trajectory previously made.

1) The decreasing of piston diameter: We thought about make the prototype with a smaller piston diameter because the reduction becomes advantageous both by reducing the inertia of the piston and allowing more space for the solenoid, allowing more turns of wire with the same size of external diameter. That way, we have a more powerful kick and more free internal space that can be used for the high kick solenoid we're developing.

2) Evaluation of the gauge of the solenoid wire: No advantages could be seen in using a wire that would leave the kick plate closer to firing, since the permitted speed limit for kicking would be achieved by any of the gauges evaluated (awg 20,21,22 or 23). From the theoretical modeling, it was noticed that awg 23 is the safest, however, with a small difference for awg 21. From tests performed on the robot, it was noticed that awg 21 was the most appropriate considering the speed of the kick and the current that ran through it.

3) System of guide for the low kick: During the tests, a problem was encountered: the kick plate was no longer parallel to the horizontal during the kick. To correct this situation, a system of guides was developed for the low kick as shown below:

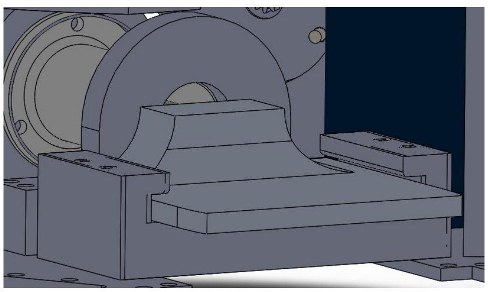


Fig. 9: The guide

This system was already efficient during RoboCup 2018, when it was noticed a satisfactory improvement in the passes made from the implementation of the guide.

4) Behavior of 1020 steel: One of the observations that are important to be made is that a misconception was made during the execution of the project. For the system where high magnetic fields are generated in the solenoid it is not a good approximation to assert that the magnetic permeability of the 1020 steel is constant. This occurs due to the phenomenon of magnetic saturation, where the piston reaches the state that almost all the magnetic spins of the steel are already aligned and the steel fails to potentiate further the incident field (see reference [7]).

D. Planning for LARC 2018

Until the LARC 2018, the mechanical project might face some more modifications. Three improvements are already being elaborated in order to make the functioning of the robots more stable and reliable.

1) Development of robots high kick system: After participating in RoboCup 2018, the need for a reliable high kick system was realized in order to a better development of game dynamics. Thus, it will be modeled the equation that describes the movement of the ball after kicking and the new shape of the kick system (both the solenoid used and the geometry of the kick pieces)

2) Development of a new roller for the dribbler: After many tests and changes in the roller, it was realize that the ideal roller was not yet modeled, since the current one still has difficulties guiding the ball to its center and still does not maintain satisfactorily the possession of the ball during rotational movements of the robot.

3) The low kick system improvement: Since a reduction of the mass seems to be a good improvement for the kick system, a new model will be formulated taking this into account.

V. Conclusions and Future Works

For this competition, we are aiming into continuing the progress established last year: experimenting a new approach to the software project, modularizing the electrical project and producing more reliable CADs and CAMs in the mechanical project.

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