MinhoTeam '2016: Team Description Paper

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Abstract. This paper describes MinhoTeam's Middle Size League robotic soccer team having the purpose of the qualification to RoboCup'2016, in Leipzig, Germany. Since 2011 the team and the robots stopped its course of evolution, restarting in the last year. The biggest changes done throughout the last year where the improvement of the older platform, making all the hardware stable, 3D ball detection, ball handling and kicking systems as developing the world modelling, communications and artificial intelligence. This improvements provided a stable platform for software development, allowing the basic set of operations like self-localization and information sharing to be done, making possible to make more complicated actions like passing and to implement coordinated behaviours a reality.

1 Introduction

MinhoTeam is a RoboCup team from University of Minho, Portugal. The team members are electronic and a mechanical engineers students, within the Master's Degree study plan, assisted by two doctored teachers providing advice and guidance. The team was founded in 1997 (MinhoTeam was the first Portuguese robotic soccer team), participating in several competitions including:

- 2004: GermanOpen (Padderborn, Germany) (3rd), Robótica 2004 (Porto, Portugal) (1st), RoboCup 2004 (Lisbon, Portugal) (5th).
- 2005: GermanOpen 2005 (Padderborn, Germany) (2nd), Robótica 2005 (Coimbra, Portugal) (1st), RoboCup 2005 (Osaka, Japan) (5th),Technical Challenge I (1st), Technical Challenge II (2nd).
- 2006: RoboLudens 2006 (Eindhovenm, Netherlands) (2nd), Robótica 2006 (Guimarães, Portugal) (1st), RoboCup 2006 (Bremen, Germany) (5th), Technical Challenge (3rd).
- 2007: GermanOpen 2007 (Hannover, Germany) (4th), Robótica 2007 (Paderne, Portugal) (2nd).
- 2011: Participation in RoboCup 2011(Istambul, Turkey).

Now, with a new generation of robots and fresh blood, the team is ready to compete in the upcoming competitions. The robots were completely built in University of Minho's Robotics Laboratory (LAR) and have been rebuilt from top to bottom, keeping the essence of the previous generation, but lighter, faster and improved, developing new algorithms and new technology. This paper describes the current development stage of the team and is organized as follows: Section 2 describes the improvements in the older platform's hardware and the developments of new systems. Section 3 addresses the improvements in the electrical system of the platform. Section 4 addresses the work done during the last year in omni-vision, self-localization and 3D ball detection using Kinect. Section 5 describes the basis of the motion control using Non-Linear Dynamical Systems. Section 6 describes the current development in world modelling. Section 7 presents the research focuses and short-term goals of the team, while Section 8 concludes the paper.

2 Platform Improvements

The platform developed in 2011 had many flaws, lack of stability and was very prone to failures, the team decided to fully rebuild and improve the platform. The overall structure has kept the same like the motors, wheels, motor controller, base plates, head, camera support and the catadioptric mirror. Everything was rewired and some major improvements were put into testing. The first big improvement was applying a set of four steel bars, to connect the centre structure to the base plate of the robot that was being held only by four long lead screws. Also, for aesthetics and security, a thick plastic cover will be added to the sided surface of the steel bars.

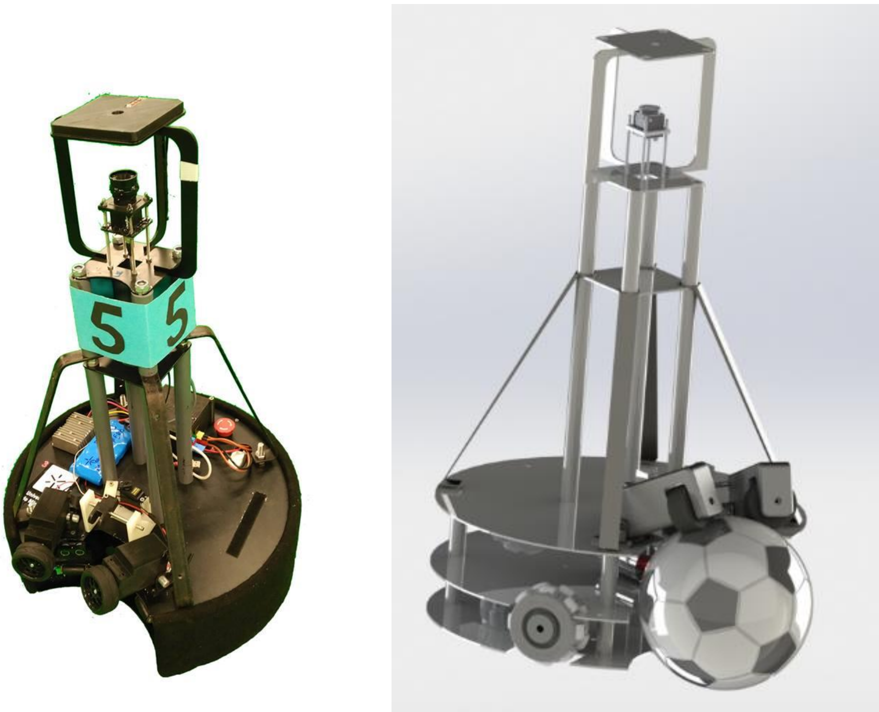


Fig.1. MinhoTeam's updated robotic platform, with the steel bars applied.

After the making the base hardware trustworthy and stable, the team decided to improve the ball handling and kicking system, having some other hardware improvements in progress.

2.1 Hardware Architecture

The hardware architecture was rebuilt completely to provide a more stable, efficient and reliable in relation to the previous versions of it.

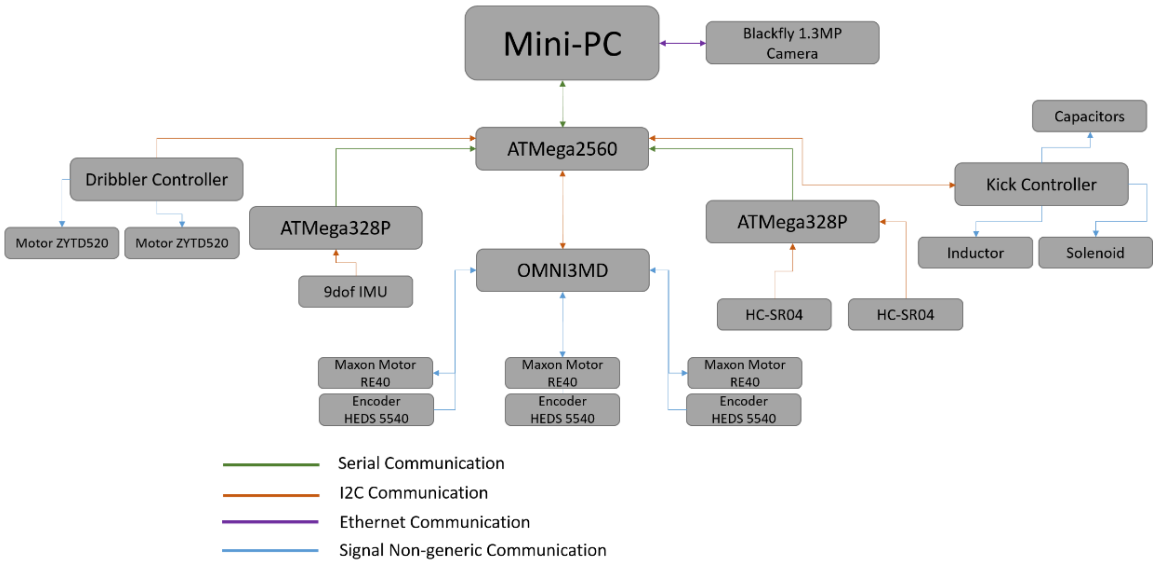


Fig.2. New hardware communications diagram, from higher to lower level.

As the main processing unit the MSI-Cubi-Pentium-3805U Mini-PC is used, being responsible for the higher lever programming, image processing, network communication and artificial intelligence. Using a Gigabit Ethernet bus, the connection is made to the omni vision camera, the BlackFly PGE 13S2C [1]. Using standard serial port communications (via USB) the higher level connects to the lower level using an ATMEGA2560 as a master for all the lower level communications. Using the I2C bus to communicate with the Dribbler Controller, the Kick Controller which communicate with its own peripherals using non-generic signals. The ATMEGA2560 also bridges communications with two separate ATMEGA328P. The first one acquires data from the IMU – Inertial Measurement Unit – with 9 degrees of freedom. The second one only polls an ultrasound sensor to detect ball possession, which was kept in a different microprocessor due to delays of the technology itself. Lastly, the ATMEGA2560 communicates with the motor control board, the OMNI 3-MD [2], again using I2C, allowing to send motor movement commands, read battery levels, temperatures and the encoders used in odometry.

2.2 Ball Handling System

The ball handling mechanism that was in the previous platforms was very weak and didn't allowed the robot to rotate around itself or go back without losing the ball. After watching the other teams' ball handling systems, with the resources and the constraints that the current platform yielded, a new and improved ball handling system was designed, built (using 3D printed material) and tested.

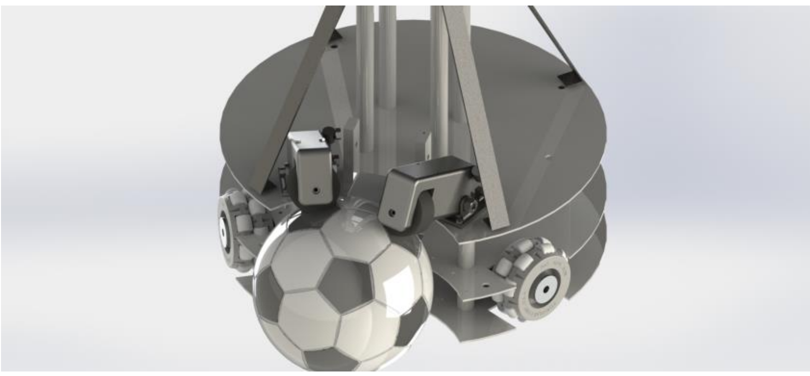


Fig.3. Improved ball handling system, having controlling arms with independent motors, allowing to control the ball and to keep it in possession for longer periods of time.

The controlling arms have wheels actuated by DC motors and its tension is regulated by a spring, allowing an optimal contact between the wheels and the ball. Furthermore, it is possible to apply electro actuators or oil-dampers instead of a spring. Rubber tyres were chosen as the material for the wheels, instead of mini omni-directional wheels, yielding bigger friction between the wheels and the ball, improving possession capabilities.

2.3 Kicking System

During the past years competitions that the team observed the other teams, we came to conclusion that our kicking system had flaws and was weak, only allowing a parabolic lob shot, instead of a more direct and strong lob shot. Based on other teams' platforms we thought of a system that could be actuated by a servo, being able to shoot more straight and strongly. Throughout its development, the team figured that this system was also able to do effect shots, when standing directly facing the middle of the goal, to shoot and hit the far left (or right) post.

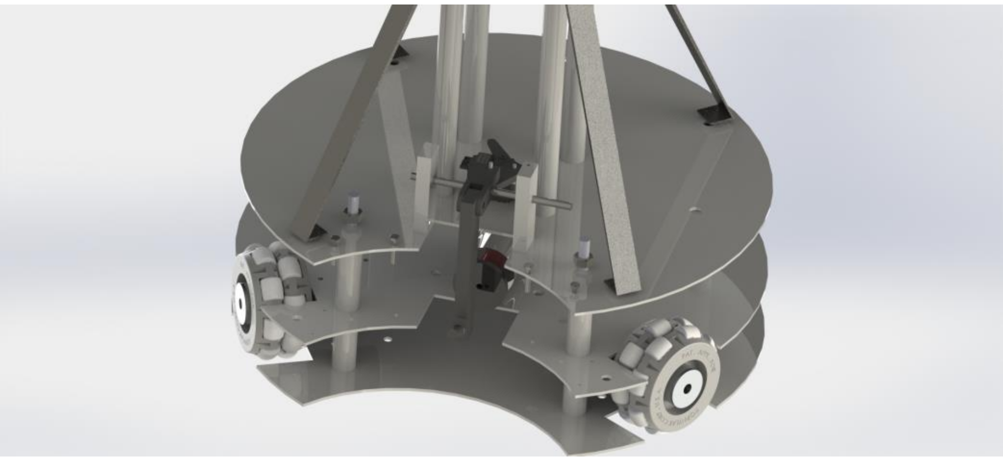


Fig.4. Improved ball kicking mechanism, actuated by a servo-motor, making possible to shoot along the surface of the ball, shooting with effect and more straight.

The mechanism implemented it's similar to the ones used in "piston-connecting rod" movement in car engines. To achieve optimum movement of the kicking rod in relation to the ball, the distance between centres in the "connecting rods" had to be optimized also.

2.4 Further Improvements

One of the biggest improvements is the development of a board to charge and monitor the batteries, the consumption of power and prevent problems. It will be powered straight from 230V, immediately disconnecting the batteries, keeping the robot's power supply up through a secondary circuit. The board allows to monitor the batteries voltage level, current and temperature, allowing also user programming for charging and discharging of the batteries. Furthermore, it will contain the kicking system electronics to improve the older one that is still used in the current platform, becoming smaller, more energy-efficient, powerful and user-friendly.

3 Electrical Design

The electrical design was again redesigned and improved to make it safer to use, using switches to power on or off the different power components of the platform.

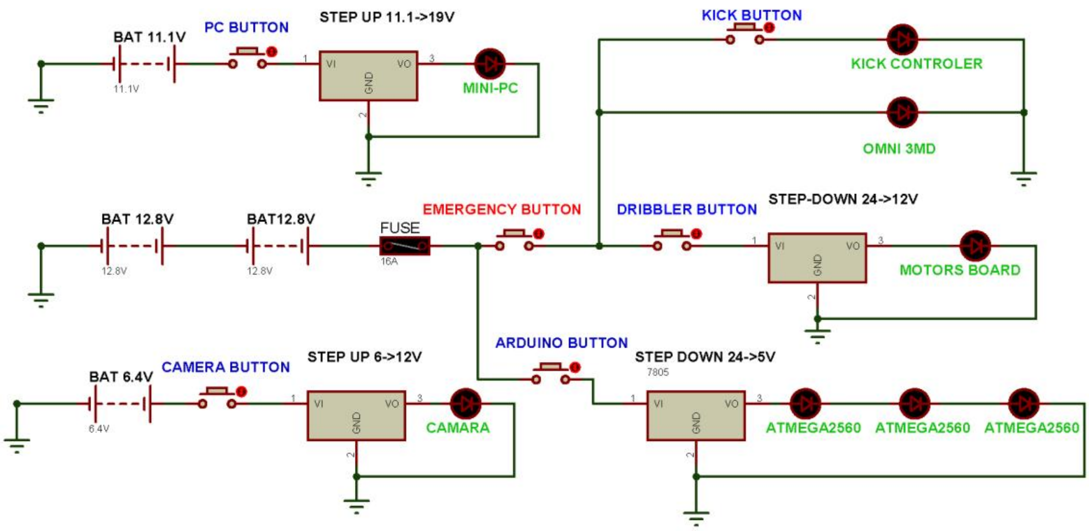


Fig.5. Current electrical design of the power distribution.

In total the robot uses now 4 batteries. Two of them are 12.8V LiFePo 4400mAh running in series, supplying the Kick Controller, the Dribbler Controller, the Controller Box and the Motor Controller. The power and controller systems are running separately to avoid problems, using voltage regulators in some sub-systems. All sub-systems can be disabled through a switch to allow better control of the robot's power supply. A separate LiPo 3S 11.1V battery, with 5000mAh of capacity is used to supply the Mini-Pc, stepping it up to 19V using a Step-Up Voltage Converter. Lastly, a LiFePo battery of 6.4V 4400mAh is used to run the camera, again using a Step-Up to provide 12V.

4 Omni Vision and Self-Localization

In this section will be presented the hardware and the software used to provide a self-localization mechanism to each robot.

4.1 Camera

As far as main vision system configuration concerns, the team follows the standard setup, having a camera pointed up to a catadioptric mirror, allowing a 360º degrees floor-plane vision perspective. MinhoTeam's omni-vision camera is the BlackFly GigaBit PGE-13S2C from Point Grey, with a resolution 1288x964 at 30 FPS, using Sony ICX445 as the sensor (CCD) with 1.3MegaPixels. The catadioptric mirror was developed in University of Minho using a simulator to achieve best performance possible.

Fig.6. Camera being used in the current MinhoTeam's platform, the BlackFly PGE-13S2C.

4.2 Omni Vision Setup

The omni-directional vision system lies in the well-tested setup by all teams and used for many years in older platforms. The current setup allows the robot to "see" up to 5 meters in every direction, having some distortion in some points of the image, due to imperfections of the current Camera Lens-Mirror setup.

a) b)

Fig.7. (a) Current Omni Vision setup with a BlackFly PGE 13S2C camera and a catadioptric mirror. (b) Image captured by the Omni Vision system.

The field in which the image was taken has 7x5 meters, a reduced version of the official MSL RoboCup field allowing the robot to see more lines than it will be able in an official sized field.

4.3 Vision Algorithm

One of the most important aspects of the artificial intelligence to be developed is the self-localization algorithm. The first step is to extract field features based on the white line markings in the field using scan lines. After the V MSL Workshop and some knowledge exchange, the scan lines concept was extended, not to use just radial scan lines but also spiral scan lines. This idea was presented and explained by ASML Falcons and bring the advantage of covering a larger area of the field with less points than the axial scan lines, being able to detect more line points in less time. The features extracted in the image as line, ball, and obstacle points are gathered using the scan lines. Color segmentation is performed using YUV color space [3][4] which allows to enhance of the chrominance component and a fast conversion in real-time.

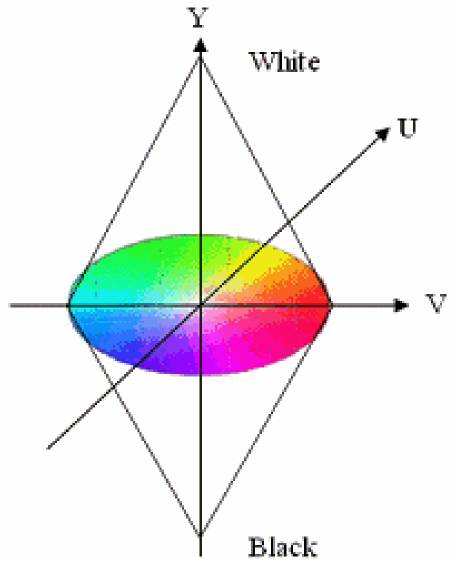
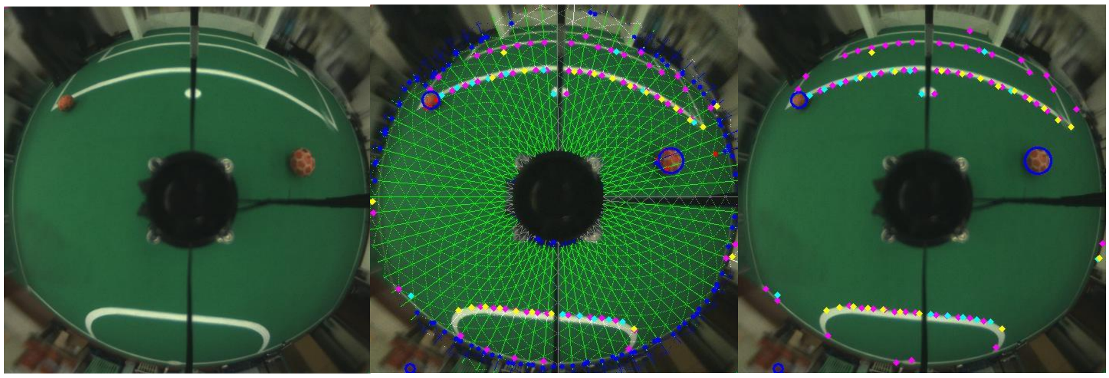


Fig.8. YUV Color space representation, having one luminance component (Y) and two chrominance components (U and V).

All the RGB cube is then labelled related to the YUV parameters being field, line, ball, obstacle or unknown. The feature extraction algorithm looks for changes in color classification along the scan line, classifying them as line, ball or obstacle points.



a) b) c)

Fig.9. (a) Original image taken by the camera in the omni vision setup with a 480x480 resolution. (b) Detected line points (magenta, cyan blue and yellow squares) by the radial and spiral scan lines. (c) Image with extracted features, the detected line points and two footballs that were on the field.

The algorithm for feature extraction takes no longer than 3ms to run through every pixel. When it comes to ball detection, a few more operations have to be done, like defining a ROI – Region of Interest – and performing color segmentation, extracting the features of the blob, having then a set of ball candidates. After the self-localization algorithm, false positives in ball candidates are discarded, using the last known robot position and morphological operations, as the same happens for obstacles. False positives in line points are discarded using previous robot position and a hysteresis range.

4.4 Self-Localization

MinhoTeam developed a proprietary algorithm for self-localization, not directly following the algorithm described in “Calculating the Perfect Match: an Efficient and Accurate Approach for Robot Self-Localization” by Brainstormers Tribots [5]. Instead, a world model is built in which in every possible position of the field, with a 0.1x0.1meters resolution, the optimum number and value of line points (using the radial and spiral scan lines presented before) within the defined range. After the feature extraction algorithm, using the heading angle provided by the IMU, the position with the least error is taken as the world position of the robot, in a global or local fashion. Furthermore, Kalman Filtering is applied merging the data from the odometry setup and the self-localization algorithm, preventing “jumps” and improving smoothness. The self-localization algorithm, when running in a local basis, comprising an area of $4m^2$, takes 4-5ms to obtain the new robot position, taking approximately 300ms to do it globally. The vision to self-localization pipeline is as follows:

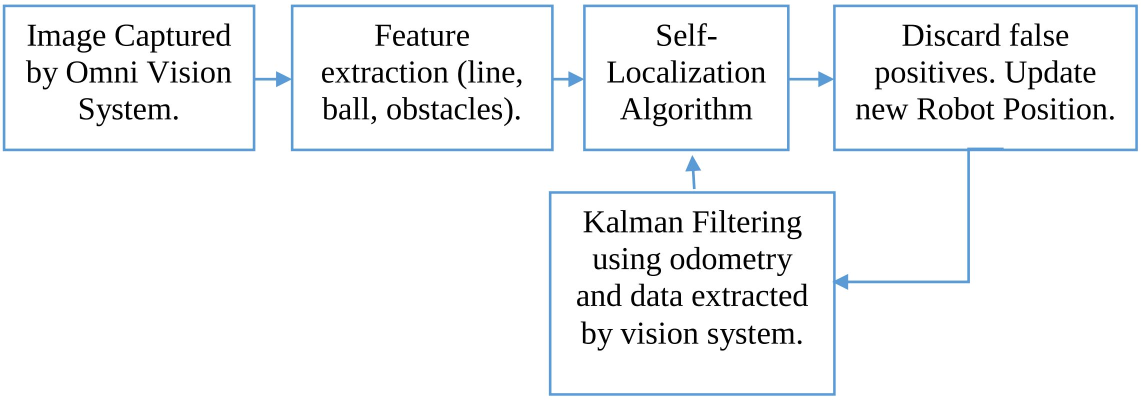


Fig.10. Data pipeline from image camera to world state definition using image features and the self-localization algorithm.

4.5 3D Vision using Kinect

Using the RGBD capabilities of the Kinect camera one can extract various rich information from it, being able to build a prediction model for ball movement and goal-line crossing point. Using the color image and performing color segmentation, the algorithm can select regions of interest within the image (where ball color pixels are found) and perform feature extraction of the blob(s) in the ROI. Then, candidate list’s false positives are firstly discarded through morphological comparisons. Once a candidate is validated, it is necessary to access its 3D information, using the depth image mapped to the color image. Using the camera’s horizontal and vertical field of view, height from the ground and the mean depth value of ball’s centroid, one can estimate the 3D coordinates of the ball in relation to the robot. This technique allows to see lob shots which are often used by teams to attempt a goal scoring situation. Once a valid first position of the ball is gathered by the 3D vision system, a Kalman Filter steps in, merging the physical model of the projectile (the well-known parabolic trajectory) with the 3D vision system estimate, yielding a smoother tracking of the detected flying ball. With the Kalman Filtering applied, one no longer have the necessity to see the ball in every frame as it is possible to predict the next positions of the ball using only the Kalman Filter and the physical model, allowing a lob shot trajectory to be estimated, corrected and predicted, and ultimately, saved.

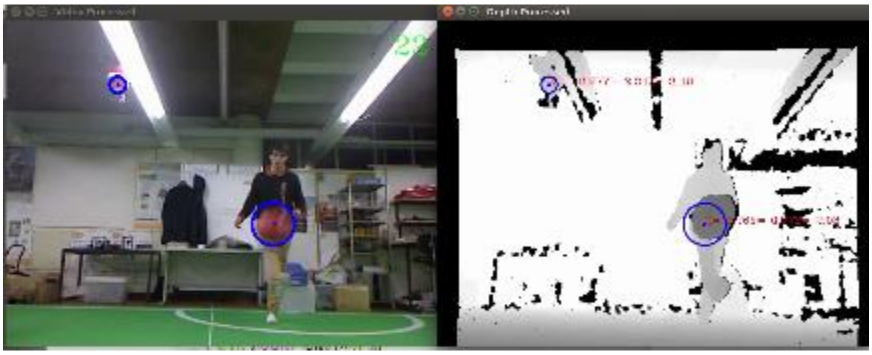


Fig.11. Color and depth image of Kinect, with ball detection and depth mapping, and 3D coordinates estimation. Also, a detected false positive is present that would have been discarded after the ball's dimension-distance model filtering.

5 Control using Non-Linear Dynamical Systems

The robot control motion uses a non-linear dynamical systems [6] that calculates the navigation direction and velocity. This navigation method uses non-linear differential equations to model the evolution of the state variables that define the robot's behavior. The method provides two behaviors: obstacles (opponents) in the environment exert a repulsive effect and the target (ball or target location) has an attractive effect. To achieve the desired position, the movement of the robot at each instant results from the contribution of these two behaviors.

5.1 Navigation Direction Control

To control the robot's movement is used as state variables the direction of navigation, Φ_{robot}, and the linear velocity, v. The temporal evolution of the variables is formulated by equations differential (1) and (2):

$$\frac{d\Phi_{robot}}{dt} = f(\Phi_{robot}) \quad (1) \qquad\qquad \frac{dx_{robot}}{dt} = g(x_{robot}) \quad (2)$$

The differential equation that defines the dynamic system of the angular velocity control is:

$$\mathcal{W}(t) = \frac{d\Phi_{robot}}{dt} = -\lambda_{target}\ \sin(\Phi_{robot} - \Psi_{target}) \quad (3)$$

Where:

- $\mathcal{W}(t)$ – Robot rotation angular velocity
- Φ_{robot} – Robot navigation direction (is relative external world axis and robot front)
- λ_{target} – Magnitude of the "force of attraction" that the target has on the robot
- Ψ_{target} – Target direction

The differential equation that defines the dynamic system of the linear velocity control is:

$$v(t) = \frac{dx_{robot}}{dt} = -v_{max}\ \tanh(\left(\left(x_{robot} - x_{target}\right) - \sigma\right)\ \lambda) \quad (4)$$

Where:

- $v(t)$ – Robot linear velocity
- x_{robot} – Robot position in a straight line to the target
- v_{max} – Robot maximum linear velocity
- x_{target} – Target position in a straight line to the robot
- σ – Security distance to the target
- λ – Attraction intensity to the target

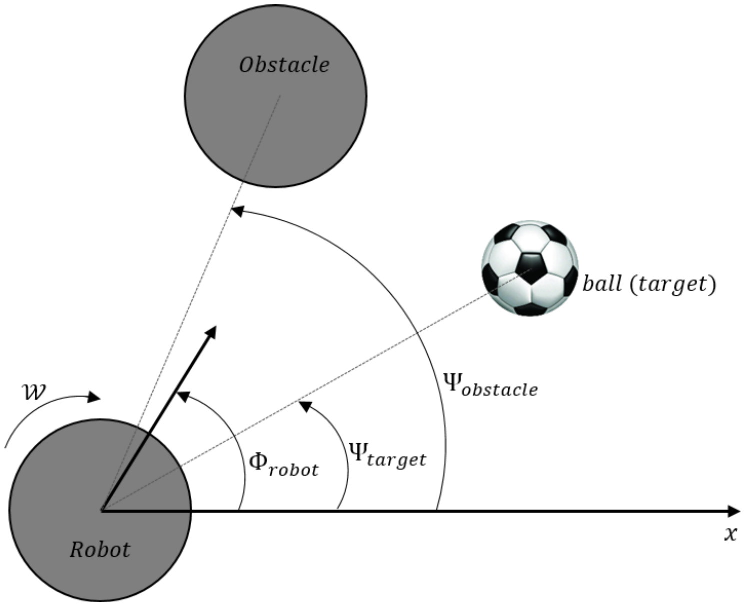


Fig.12. Graphical example of the placement of the agents and the variables involved in the control theory of the motion control system using non-linear dynamical systems.

6 World Modelling and Communications

Using an adaptation of CAMBADA's RTDB [7] for the real-time database, the robot-to-robot communication has been implemented. Information gathered by each robot as its pose, obstacles, best ball candidate, intentions and actions etc, are shared through this real-time database, being merged by MinhoTeam's base station and shared with every robot, being this information the best information possible, yielding the best perception of the world. The information gathered by every robot has the biggest local importance (inside an area around the robot, in the world model[8]) and the merged information provides data that the robot couldn't know about without information sharing, making possible to make long passes, ball interceptions and other difficult actions, that would be hard with little information. The identification of "friend-or-foe" is only possible with the information sharing, were one can know which obstacles are teammates, which obstacles are not. This is one of the most important parts of the robot intelligence, allowing information sharing, building the best world model possible, therefore, providing a superior level of robot intelligence.

7 Research Focuses

For future developments in a short-term the team aims to use the accomplishments made until this date to be able to perform high level coordination between agents and building more complex behaviours and tactical comprehension of the game. Furthermore, and active goalkeeping agent will be designed, to try to take a big impact along the game. Having the base operations like self-localization, positioning, ball detection and searching, world state modelling and sharing, the research focuses are now in agent coordination and interaction, artificial intelligence and "robot game sense".

8 Conclusions

This paper introduced the changes made in the robots platform and the re-adaptation of the platform itself, along with all the high to low level communications, electrical re-design and power control. Were also presented the core robot actions as self-localization, 3D ball tracking and world state modelling and sharing. As far as research focuses go, the control system for the robots is yet to be fully developed, but a greater part of it was presented here, being the non-linear dynamical systems, and lastly, the multi-agent coordination, more complex behaviours building and artificial intelligence. We aim to be ready to compete in a full competition alongside the other teams throughout the competitions in the current year of 2016.

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