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COMPUTER VISION AND ARTIFICIAL INTELLIGENCE TECHNIQUES APPLIED TO ROBOT SOCCER

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Abstract. *This work develops a computer system using computer vision techniques applied to robot soccer Very Small Size for disputes match at robotics competitions. This software is responsible for locating and identifying players from each team and the ball, allowing decisions to be taken on the basis of the positions acquired. Whole process should take place in real time to prevent prejudice in gameplay.*
Keywords: Artificial intelligence, Robot soccer, Robotics

1. **Introduction.** Computer vision is a subject of study in recent decades mainly in automation area. Computer vision allows building artificial systems capable of retrieving any possible information from an image previously obtained. Several branches use computer vision, such as the military, aerospace, industry and medicine. Some have a greater prominence, given that need this science to develop his work in a grandiose way [1].

Robot soccer was used to introduce computer vision study at university, encouraging research in autonomous multi-agent robotics and allowing deployment of experimental low-cost systems.

This objective of this work is to perform a study of artificial intelligence techniques and robot vision, in order to build robots capable of playing a real soccer game using techniques presented. Section 2 presents the necessary information to understand how computer vision works, divided in six steps: image acquisition, pre-processing, feature extraction, segmentation, high level processing and noise. In Section 3 some applications are exposed. In Section 4 robot soccer organizations and the category Very Small Size Soccer are explained. In Section 5 the software is elucidated, and the libraries used, the system structure, the vision system and the artificial intelligence are explained. Finally, the robots results in robotics competitions are mentioned in Section 6, and the conclusion in Section 7.

2. **Overview.** Computer vision is a branch of automation that allows the perception of machine vision and develops methods for creating systems that get information from images. Purpose of this science is to make useful decisions about physical objects and real scenes, based on acquired images [2].

Computer vision technology can be divided into six stages: image acquisition, pre-processing, feature extraction, segmentation, noise reduction techniques and high level processing.

A. Image Acquisition

Image acquisition is the first step of computer vision, which performs image capture through a device or sensor and transforms visual information on digital information [3].

Scanned image should be most consistent possible with real image, and at the same time appropriate to the following processing. To accomplish this task, two elements are indispensable: a physical device that is sensitive to a physical quantity and produces an electrical signal output proportional to a perceived energy level; and an analog-to-digital converter, able to convert electrical output of the sensor to digital form [3].

Some devices used to obtain images are: video cameras, scanners, satellites, medical CT scanners, x-ray sensors, color spectrum analysis and thermal sensor. These hardwares offer distinct properties such as, spatial resolution, operating speed, accuracy and cost. Sensor choice should be made according with desired information, under which conditions images will be obtained [3].

B. Pre-processing

After acquiring images, the second computational step to be performed is pre-processing. This procedure is responsible for preparing the image so next steps can handle contained elements.

Data converted by the sensor, in most case have a lot of noise and distortion. Data converted are analyzed to be performed geometric distortion correction, radiometric calibration and noise removal from obtained image. These problems are caused by lens distortion, inadequate or insufficient lighting, and improper captures sensor or of poor quality. Figure 1 shows a radiometric correction of image [3].

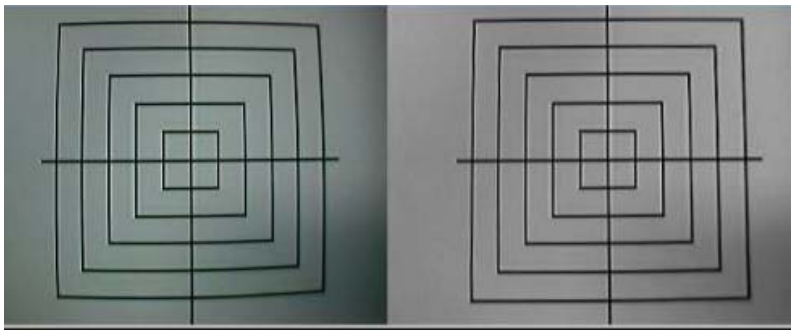

FIGURE 1. Radiometric correction of image [4]

During pre-processing can be performed an initial classification of contained objects, separating them into classes to be treated later.

C. Feature Extraction

First stage for detection of some objects is the features extraction contained in an image. During feature extraction is disregarded redundant information, decreasing the amount of data to be analyzed. Characteristics are chosen according to the set to be parsed [5].

The most used methods during this processing are edges detection, points, colors, histogram, shapes, and the movement. An example of a histogram is shown in Figure 2.

D. Segmentation

Segmentation is a separation of an image into cohesive regions using as criterion one or more image features. Quality of subdivision to be performed depends on the problem to be solved [7].

In general the autonomous segmentation is one of the most difficult tasks of digital image processing. A successful image segmentation procedure increases the chances of success in solving problems that require objects are individually identified [3].

Two most commonly used characteristics during process are: segmentation by regions (similarity) and by contours (discontinuity), as shown in Figure 3 [8].

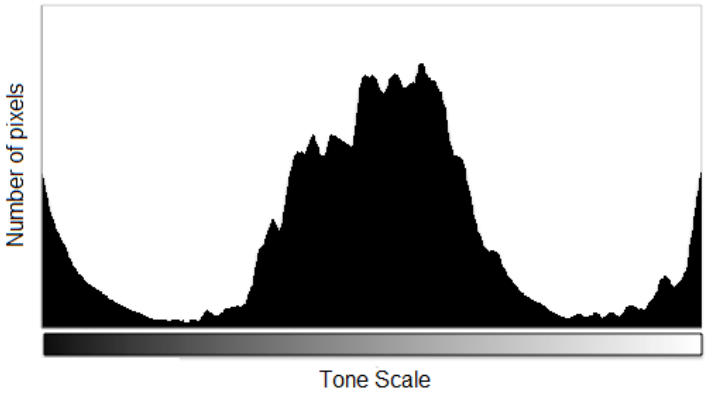

FIGURE 2. Example of a histogram [6]

FIGURE 3. Segmentation by contours [9]

E. High Level Processing

Computer vision aims to make decisions from the information extraction using acquired images. These decisions are made during the high-level processing, based on a set of knowledge about the objects to be detected [10].

All information obtained in previous processes is used to aid in decisions during high level processing. These decisions can be made only with the features found or using more complex techniques of artificial intelligence for an interpretation more effective [11].

F. Noise

Noises are present in almost all images obtained, varying mostly in its intensity. The origins are distinct, being the main: quality and sensitivity of used sensor, lens dirt, environmental conditions, local lighting, and image capture position [12].

In Figure 4 it is possible to see interferences capable of difficult or even making it impossible to interpretation or recognition of objects; these interferences are also considered as noise [13].

Filters are used to remove or attenuate noise in acquisition and software devices. Intention is to "clean" image, just like Figure 5, so it resembles as much as possible with desired image, losing least amount of information possible [14].

3. **Applications.** The computer vision is used in almost all fields, from industry, geography, aerospace until the medicine.

A. Industry

In the industry computer vision is used for detection and counting of objects, performing the differentiation by shapes or colors, in the assembly of products, and so many other processes [3].

FIGURE 4. Example of noise in the software developed

FIGURE 5. Frame after applying a filter in the software

B. Military and Security

The military sector is responsible for developing new applications in the field of computer vision. Some uses in this area are: identification of targets in satellite images, real-time tracking of targets, autonomous vehicle navigation, biometric recognition, and surveillance [15].

C. Aerospace and Astronomy

In astronomy the computer vision is widely used for analysis and the search for new planets and stars, and the chemical composition evaluation of the same [3].

In aviation its use is: UAV control, power lines inspections, rural areas analyses, and warehouses roofs and factory towers inspection [16].

D. Medicine and Biology

The diagnostic imaging is widely used in medicine. The x-ray is the main source of energy used in this field, being used for information of bone fractures, blood vessels and performs computerized axial tomography [3].

E. Geography and Archaeology

The applications in these areas are: use of satellite to study pollution standards, study of terrain relief in aerial images, climate prediction, and sound waves are used to perform

3D mapping of earth composition beneath the ocean floor and detection hydrocarbons pocket presence (oil and/or gas) [15].

Archaeology techniques are used for the restoration of damaged images of rare artefacts and records to aid restoration of rare objects [15].

4. **Robot Soccer.**

A. International Organizations

Currently, there are two organizations of robot soccer, the RoboCup and Fira. The RoboCup organizes championships in categories of Simulation 2D Soccer, Simulation 3D Soccer, Very Small Size Soccer, Small Size Soccer, Middle Size Soccer, Standard Soccer e Humanoid League, the last two categories being disputed by humanoid robots. The Fira is responsible for competitions in categories of AmireSot, MiroSot, NaroSot, AndroSot, RoboSot e SimuroSot.

B. Robot Soccer in Brazil

In Brazil, there are only the categories organized by RoboCup. They are usually held during the Brazilian Robotics Competition (CBR) and/or Latin America Robotics Competition (LARC) and at the INATEL (*National Telecommunications Institute*) Robotics Competition.

C. Very Small Size Soccer

The IEEE Very Small Size Soccer category is defined by two teams with players formed by three autonomous robots. A camera located at two meters of field captures images and sends them to be processed by computers, which take decisions and send the commands for players, and everything happens in real time. Figure 6 illustrates the match, two computers controlling each team by a camera and sending the commands for the robots [17].

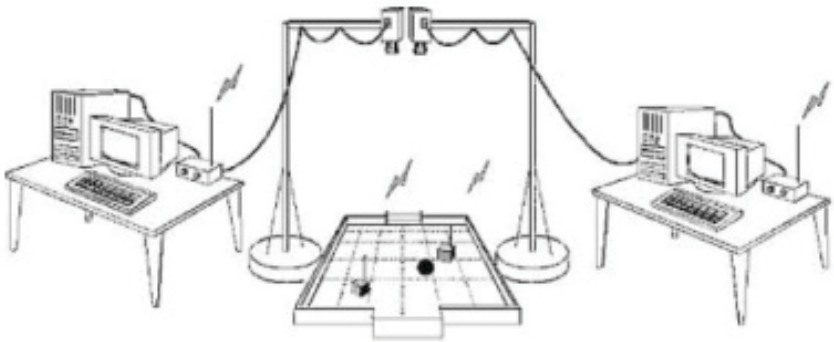

FIGURE 6. Very Small Size Soccer [18]

5. **Computer Application Robotbulls VSSS.** First software version (1.0) called RobotBulls was developed using two programs, one for computer vision and the other for Artificial Intelligence (AI) and sending commands. Computer vision software uses C++ language, and AI software uses C# language. Communication between software is accomplished through UDP Sockets (User Datagram Protocol), allowing both programs can run on one or two computers. In order to minimize cost just one computer was used.

In second version (2.0), artificial intelligence was integrated to program of computer vision (C++ language). However, commands sending continued being made by another program, which also communicates through UDP Sockets (C# language).

FIGURE 7. Software Robotbulls – Very Small Size Soccer 3.0, real image

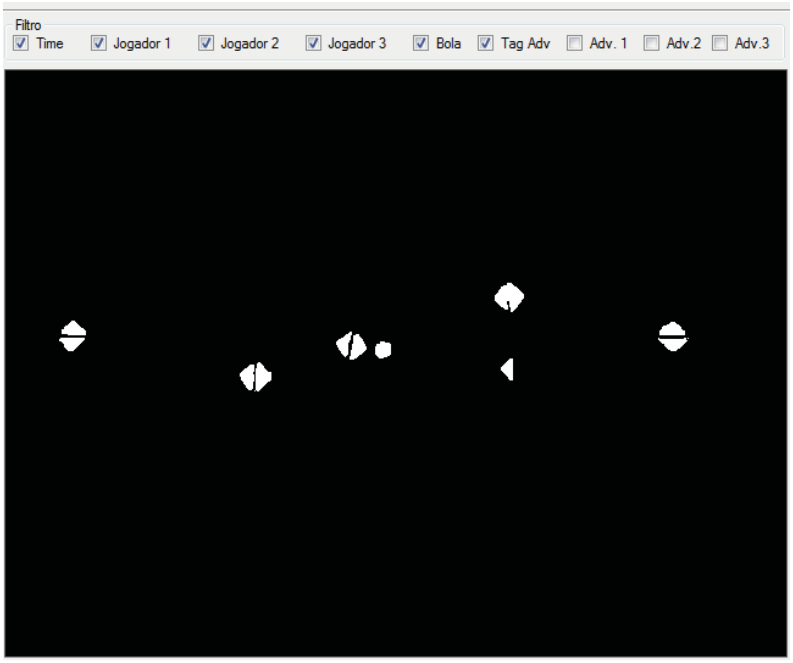

FIGURE 8. Software Robotbulls - Very Small Size Soccer 3.0, binary image

Newest version (3.0) joined the three programs, computer vision, AI, and sending commands in a single program. In this new version, all the code is built using the C# language. The real image obtained by computer vision system is shown in Figure 7 and the traded image in Figure 8.

A. OpenCV and EmguCV

All softwares developed in C++ (1.0 and 2.0) used the Open Source Computer Vision (OpenCV) library, developed to run on any operating system, using C and C++ languages. OpenCV is one of the most used libraries for this purpose, with a vast consultation material and examples facilitating the learning.

Software developed in C# (3.0) has no compatibility with the OpenCV library; so the choice was by EmguCV library. EmguCV was developed based on OpenCV, allowing OpenCV functions to be called from .NET compatible languages such as C#, VB, and VC++. C# language allows creating a good GUI (Graphical User Interface) for program integrating GUI with the code at an easy way; this is possible because C# is a high-level language.

B. System Structure

As previously mentioned, software 1.0 is divided into two programs, one called "Acquisition" and the other one "Receiver". This Division was required due to initial difficulty of performing sending commands through serial port for players. This communication is done through 2.4 GHz radio waves, using X-bee radio. Thus, serial communication was done in a simple way using C#.

Communication between programs is made through a UDP socket. After finding the players and ball coordinates by the software, they are converted to Hexadecimal and sent in a string to the Receiver. Receiver is responsible for dealing with all information (artificial intelligence) and finally sends the commands to each player.

Version 2.0 differs from first only in artificial intelligence. AI is done in C++, i.e., in acquisition program, leaving receiver just for sending the commands.

Version 3.0 has one software only. All three functions, computer vision, artificial intelligence, and sending commands are processed in the same program in parallel (asynchronous). Main gain was on friendliest GUI that allows external settings during the match, without the need for code modifications at break time. In addition, field calibration was introduced through the click on the screen, making this process easier.

C. Vision

Vision system of the three teams has the same operation. Each robot has two identification colors, one related to team and the other to its position.

Default color pattern used in digital images is RGB (Red, Green and Blue). This template is used by webcam, responsible for acquisition of images for the software. Color pattern can be understood as a colors cube where the red, green, and blue components, are corresponding to axes 'x', 'y', 'z'. The RGB cube can be seen in Figure 9.

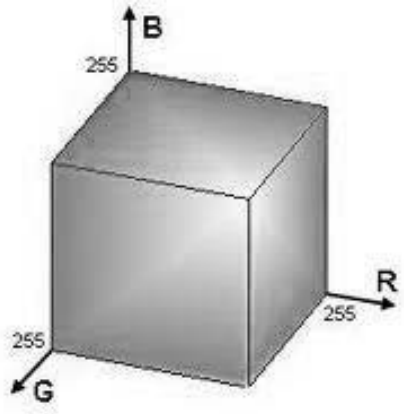

FIGURE 9. Color cube RGB [19]

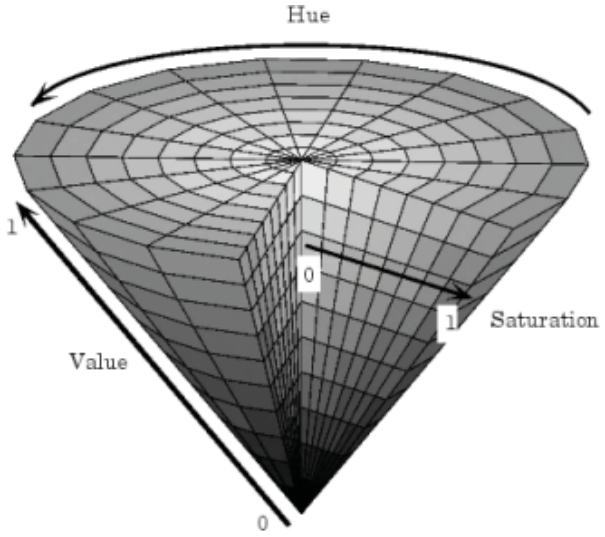

FIGURE 10. HSV pattern [20]

Despite this being a standard, RGB is not suitable for the application, due to the variation of ambient light during the game. During pre-processing the images to be analyzed are converted to HSV pattern (Hue, Saturation and Value). Figure 10 represents an HSV pattern, which is considered as an approximation of human perception.

After obtaining the images of the webcam, which is located two meters above the field, each frame is analyzed. This happens over a period of approximately 33 ms what amounts to 30 FPS (*Frames Per Second*). During pre-processing, the image is equalized, setting brightness, contrast, hue, saturation and gain. Brightness ranges from 0 (black) to 1 (white) along the axis of cone, where V is the gray scale. Contrast is a relationship of opposition or distinction between two objects. Hue, determines object color yellow, red, blue, etc, and this color is dependent on dominant wavelength. Saturation sets the purity or color depth. Gain is an adjustment of lens to capture images according to exposure to light, i.e., when there is little light increase the gain and opposite must be done too.

After performing image adjustment a subroutine is started which is repeated throughout the processing. All parallelism is done using the concept of Task. This task consists of an asynchronous operation, i.e., task is performed in parallel the main routine of the program, decreasing processing time, thereby creating a multitasking program.

Kernel (see Equation (1)) is the filter coefficient, kernel works as a window of coefficients sliding across of image. Normalized Box Filter is the filter used for this operation. Each output pixel is the mean of its kernel neighbors, and all of them contribute with equal weights. Kernel function is defined by [21]:

$$K = \frac{1}{K_{width} * K_{length}} * \begin{matrix} 1 & \cdots & 1 \\ \vdots & \ddots & \vdots \\ 1 & \cdots & 1 \end{matrix} \tag{1}$$

Second technique to filter out noise, Dilate, is a convolution of an image with a circular kernel with a predefined size. Size of kernel of ball is different from the rest, because its position is the most crucial [22].

Kernel has a defined anchor point, usually being the center of kernel. As kernel is scanned over the image, we compute the pixel maximal value overlapped by kernel and replace image pixel in the anchor point position with maximal value. This operation causes bright regions within an image to "grow" [22].

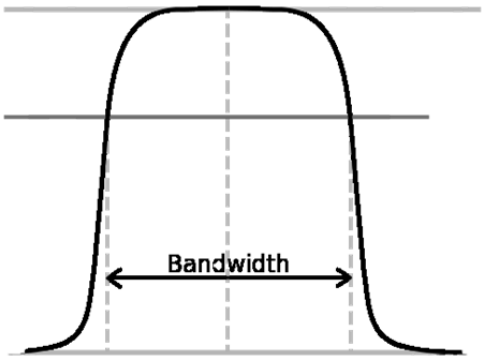

FIGURE 11. Band-pass filter [23]

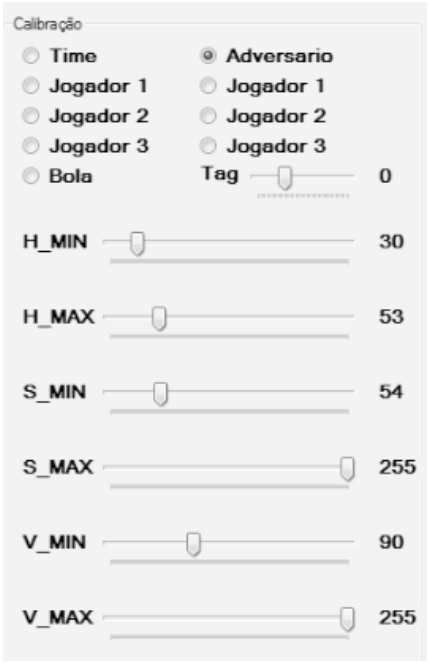

FIGURE 12. Tag chosen to identify the player, blue to identify the team and green the position (goalkeeper, forward or back)

Next step is to use frame that was converted from RGB to HSV. With converted image, three band-pass filters, just like Figure 11, are created. This type of filter accepts only a certain range of values (Bandwidth) and rejects the remainder. For the construction of the three band-pass filters, a range of values containing Hue, Saturation and Value of the desired color are used as upper and lower limits.

Each filter must be performed to result only the desired colors with the least amount of noise possible, thus reducing the processing time of next steps. This choice of values occurs during calibration of each color. Each Tag has a radio button that when selected stores the values contained in the calibration bars, shown at Figure 12. For every one filter is created a matrix where is stored the frame value which contains only the correct color desired. A total of seven matrixes are created (team identification, each one of three players, the opponent team and finally the ball).

In each matrix are analyzed sets of pixels contained in the image that have that particular color. These sets are considered to be a "contour" and for each one is calculated its area. Small areas are classified as noise, thus being ignored. For each object considered its moment is calculated, which gets the center of mass and, consequently, its 'x' and 'y'

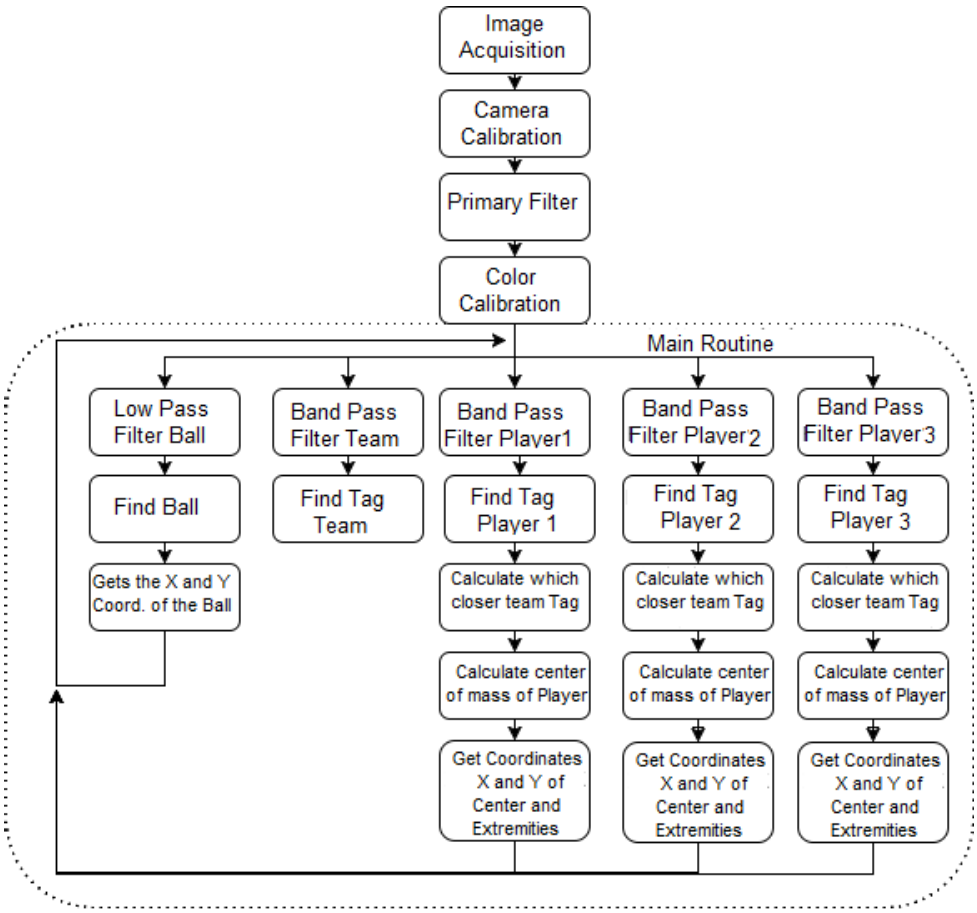

FIGURE 13. Software operating flowchart

position in the plan, with references (0.0) the center point of the field. From this step each version of code handles the information in different ways.

Versions 1.0 and 2.0 store all objects with the colors of the team and the player in two vectors. These vectors are passed to a second function that calculates the distance between set of pixels of the team and the player identification pixels. When this distance is less than the determined value these two sets are considered as the player. The values of the center of mass of each color are assigned as robot guidance positions. The midpoint between them is defined as central point of the same.

In the 3.0 version for each pair of objects of team and player color found is initiated a parallel function. Distances between each pixels set of the team and player are calculated at the same time (in parallel). If this distance is less than a certain value, that pair is defined as a player. After that the function converges to the function of team 1.0. The entire process is shown in the flow chart in Figure 13.

D. Artificial Intelligence

Interpretation of information contained in each image is made by Artificial Intelligence (AI) software developed.

Artificial intelligence is an interdisciplinary field of study that emerged from computing, engineering, psychology, mathematics and cybernetics. The main goal of AI is to build systems that exhibit intelligent behaviour and perform complex tasks with a level of competence that is equivalent or superior to the level currently exhibited by human experts [24].

Each player can receive a function, being: goalkeeper, back and forward. This function is attached to the Tag of each player, and the player 1 goalkeeper, 2 forward and back 3.

Goalkeeper role is to prevent ball from into the goal. Only goalkeeper can be in the area when the ball is in dispute with the opposing team; otherwise it is marked a penalty. Goalkeeper logic consists of analysing ball position, and using a Kalman filter to predict the future position of the ball. Thus, it is possible to anticipate goalkeeper to place it in correct location for defending the goal.

Back, or defender, must block the ball in backfield before it gets to the area, and if possible return the ball for attack. The biggest challenge is to avoid that the same makes goals against, something very recurrent in this modality. To resolve this issue every time defender is in a position to score against it recoils and goes around the ball. If some opponent is around, defender only stops between the ball and opponent preventing the opponent from making goals.

Forward has as sole purpose to score goals. For this, forward must avoid the defender and goalkeeper opponent. Only the fact of conducting the ball correctly to the goal is already a challenge, diverting from the opponents eventually becomes a differential. Using potential fields concept, where the opponents players are repulsive vectors, represented in Figure 14, and the ball an attraction vector, represented in Figure 15, was created a navigation system, which avoids shock with opponents. To determine conditions wherein forward can be able to score goal, the angle formed between the ball and the goal inner corners is analyzed. With this information is created an area where the forward must position itself for ball conduction and make the goal.

In order to comply with the objectives of each function, each robot has a default behaviour that consists of a set of functions called from in the software by "Behaviour".

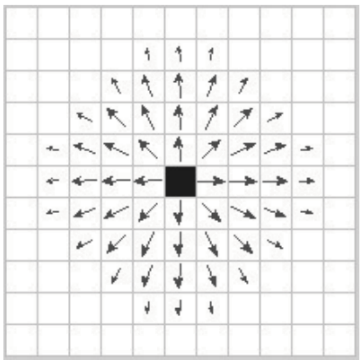

FIGURE 14. Repulsive vectors formed by each opponent player [25]

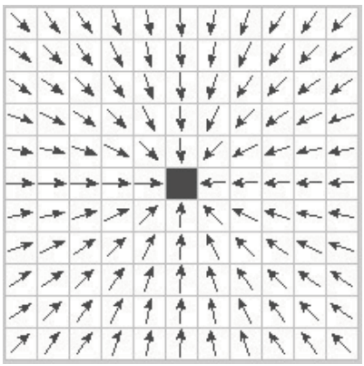

FIGURE 15. Attraction vectors formed by ball [25]

These functions incorporate mostly the logic of movement of each player and strategies. In order to improve the first, a controller in "second layer" using fuzzy logic was used.

Fuzzy logic is an extension to the binary logic that allows you to create infinity of values between conventional 0 and 1. With this new concept it is possible to generate grades of uncertainty for a given situation or a system variable. A simple example would be to classify a person as high or low using binary logic; however, if there was a person of average stature, as he would be classified? This logic could not associate it to one of these two groups correctly. At this point, the fuzzy logic fills this gap, because it associates a fractional number or degree of relevance, indicating how this person is low or high, approaching the human way of thinking [26].

To use fuzzy logic is necessary to have knowledge about the problem to be able to plan all the possibilities. Pertinence functions rank the numeric value of entries through linguistic terms and do the reverse to determine numeric value of the corresponding output to activated regions by the function. The functions are: Trapezoid used when you are sure of a range of values; Triangular, used when you are sure of just a single value; Gaussian, used when you have statistical data on the variables; Singleton, used in fuzzy system outputs. They are used in the Fuzzification (input) and Defuzzification (output) process. Fuzzy sets identify triggered rules and activated output regions by the system. The rules set represents relationships between input and output variables. The steps that illustrate all fuzzy logic operation can be seen in Figure 16 [24].

In the software was used as input the α angle formed between player and destination point, and this angle can be seen in Figure 17. The engine is able to move only in two directions (front and back), whenever the angle is less than 90° and greater than 270° engines rotate to front. If the angle is greater than 90° and less than 270° engines turn backwards. For the angle equal to 90° or 270°, a motor turns in one direction and the

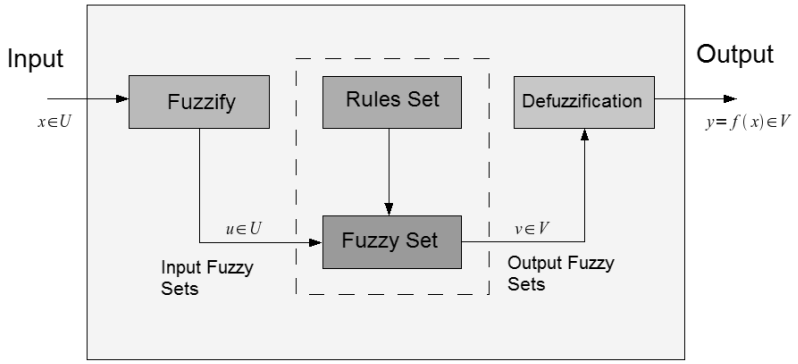

FIGURE 16. Operation of fuzzy logic [27]

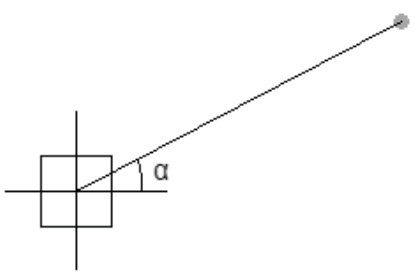

FIGURE 17. Angle formed between the robot and the destination point

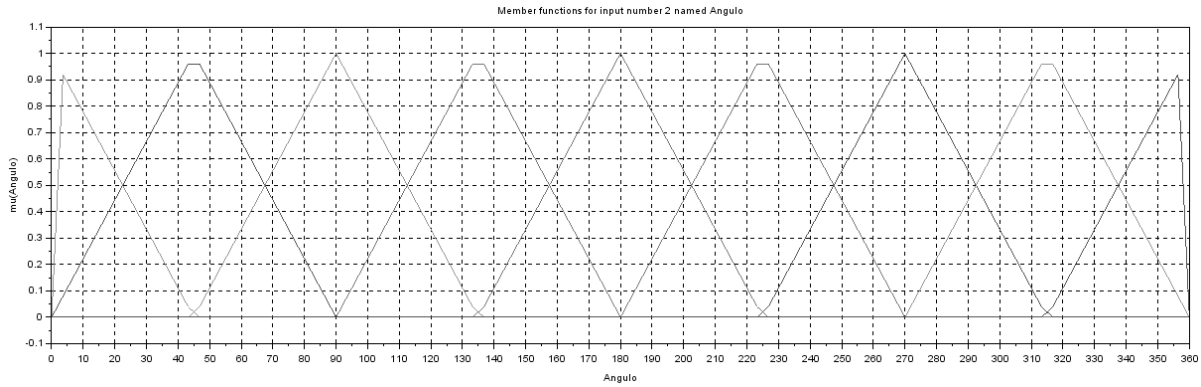

FIGURE 18. Pertinence functions of the input angle

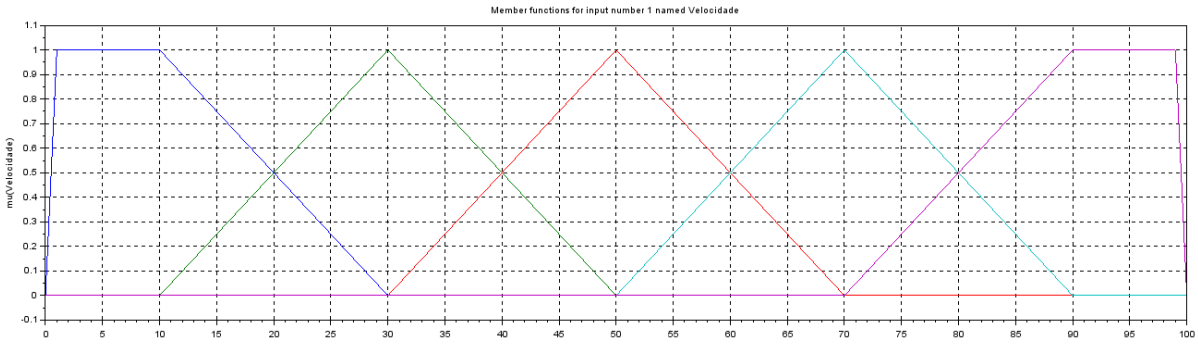

FIGURE 19. Pertinence functions of output of the speed

other one in another direction. This is done to ensure that the robot is aligned with your goal (destiny point), which in most cases is the ball.

Figure 18 shows the input pertinence functions were divided into nine triangular regions ranging from 0° to 360°, in order to map out all values that may arise. The regions were divided into equal intervals, with the exception of the first and last which has half the size. These regions were chosen so that they can know when the robot must turn to left, right, forward, backward or turn on its own axis.

The output pertinence functions are used the power of each engine, and can be seen in Figure 19. As the robot has only two engines and two-wheel drive only, its movements resemble a tank, in order to make a curve to the right the right engine should have an output lower power than the left engine and the reverse to turn left. To rotate on own axis, simply reverse the rotating direction of only one engine, as it is capable to move in both ways forward and backward, the rotation direction is irrelevant. The pertinence functions, shown at Figure 19, were divided into five regions, ranging from 0 to 100%.

The rule base has been adjusted to the movement of the robot to become smooth and steady, making easier the ball conduction when it is in possession of a player.

Considering each motor a fuzzy system separately, the model formed is a SISO system (Single Input Single Output) responsible for determining the robot's movement.

6. **Results.**

A. CBR/LARC 2015

The RobotBulls team, at their first participation, was among the 16 better teams. Results:

- RobotBulls 1 × 0 Rodetas (Federal University of Ouro Preto).

- RobotBulls 1 × 5 Pequi (Federal University of Goiás).
- RobotBulls 2 × 0 Bahia RT (University of the State of Bahia).
- RobotBulls 1 × 4 Erus (Federal University of Espirito Santo).

B. 2° Inatel Robotics Competition

The team obtained the second and third place at the competition.

C. CBR/LARC 2016

RobotBulls team, on his second participation, got the second place, being runner-up. Results:

- RobotBulls 10 × 0 MiniTratores (Rural Federal University of Pernambuco).
- RobotBulls 3 × 1 RinoBots (Federal University of Juiz de Fora).
- RobotBulls 4 × 3 ITAndroids (Technological Institute of Aeronautics).
- RobotBulls 1 × 0 UnBall (University of Brasilia) – Round of 16.
- RobotBulls 10 × 0 BDP (Federal University of Viçosa) – Quarter-finals.
- RobotBulls 4 × 1 ITAndroids (Technological Institute of Aeronautics). – Semi-finals.
- RobotBulls 2 × 3 Caboclinhos (Federal University of Sergipe) – Finals.

7. **Conclusion.** Robotic systems are a major evolution of the application of artificial intelligence for the most varied tasks. Therefore, the work showed the implementation and design of complete development of robot soccer, containing the image recognition, artificial intelligence and electronic design of robot.

Through the results obtained from the competitions it is possible to visualize the real application of the techniques developed, applied to the robots designed. It is considered that there is a big evolution still working in that field and on the robots developed, mainly concerning artificial intelligence.

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