Robofoot ÉPM Team Description Paper 2008

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Abstract. This paper presents the main research and development aspects on which Robofoot ÉPM team concentrates for the current RoboCup season. Major improvements have been made to the vision system, such as an automatic camera calibration, a new mathematical model of the mirror, and a novel localization algorithm. Also, the team presents an enhanced motor speed control system, in addition to a superior kicking system. These enhancements prove Robofoot ÉPM being an interesting candidate at the RoboCup 2008 competition.

1. Introduction

After two competition years, Robofoot ÉPM has gained valuable experience and has proven that it masters most of the scientific and technical elements needed for a MiddleSize League RoboCup to play autonomously against other competitive teams.

Since the corner cylinders are now removed for the RoboCup rules, a new vision system has been developed using an auto-calibrated camera, a new mathematical model for the mirror, and a new Line-objects based auto-localization algorithm. Moreover, a redesigned microcontroller speed control system has been implemented. Finally, a new on-board self-regulated kicking mechanism is now used.

Artificial intelligence has not been a serious subject yet but the architecture recently developed is offering powerful capabilities and has shown its robustness and efficiency.

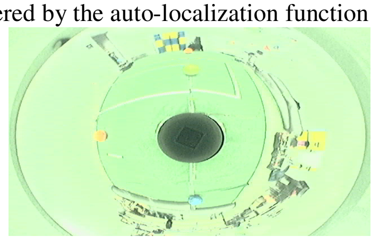
2. The new vision system

With the corner cylinders gone, a new vision system was conceived. This system is far more efficient, less time consuming and robust than any other system design by Robofoot ÉPM before. This new system is based on many innovations as an automatic color calibration, a new mirror mathematical model and a line-objects based auto-localization algorithm that has lead us to a different image analysis routine.

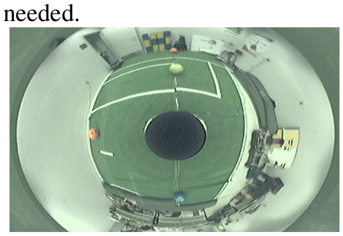
The new line-objects based auto-localization algorithm uses field lines to find the robot position. It starts by scanning the robot's view to build a cloud of points. These points are part of the field lines and are called line-objects. The robot then uses a mirror model to determine the line-object's position from its Cartesian system and searches for its best position in the field model. This last operation is the new line-objects based auto-localization algorithm and it finds the robot's position by minimizing the summation of distance of the line-objects and the modelled lines.

2.1. Automatic camera calibration

In order to reach the maximum success rate in vision algorithms, Robofoot ÉPM has developed a set of algorithms to calibrate a camera automatically. In some competitions, Robofoot ÉPM had experienced hostile lighting environments that lead to poor performances in auto-localization, ball finding and obstacle detections. First, an algorithm that adjusts the luminosity sense by the camera is applied. This algorithm computes various parameters of an image to determine if the luminosity is too high or too low. The algorithm can then modify the camera parameters to adjust the brightness. When the auto-localization algorithm does not detect the line correctly, another algorithm can be applied to adjust the contrast of the image. This is possible by changing the exposure time and the automatic gain control parameter of the camera. When the luminosity of the image is correct, an algorithm can perform a white-balance by calculating the color of the lines on the field of play. Then, the algorithm can adjust the camera parameters to make sure the white lines are really white. This is useful when the lighting environment is variable. This set of algorithms can be triggered by the auto-localization function when needed.



a) The initial environment view



b) The result view

Figure 1: An example of the camera calibration processes

2.2. The new mirror mathematical model

The previous vision system was very accurate to find angular position relative to the robot but used a linear approximation to find distance of seen objects. In order to find precisely the positions of line points on the field we first had to do a mathematical model of the mirror deformation.

The model chosen is made with a single effective viewpoint catadioptric system and a pinhole camera. In order to process math, we used the reflective ray theorems and we decided to develop it under its vector form to avoid trigonometry. This has proven to be very useful, because the result from the calibration can directly be applied to distorted points, and also because doing this mathematical computation was found faster than accessing a pre-computed value from memory. In order to further simplify the problem, we assumed a rotational symmetry of the distortion around an arbitrary point (cx,cy) near the center of the image.

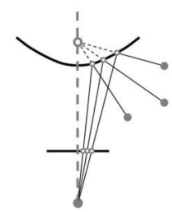


Figure 2: pinhole projection model

Given the rotational symmetry, we can pose the problem on a radial plane:

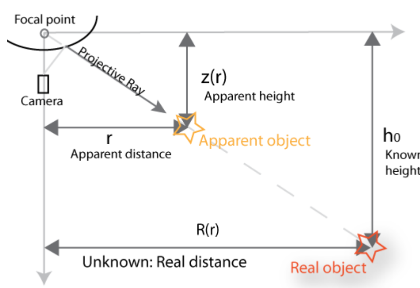


Figure 3: Using projective ray to find real object coordinates.

We have the distorted coordinate (x,y) on the image and we seek the real coordinate (X,Y). On the radial plane: we have the apparent distance $r = \sqrt{x^2 + y^2}$ and we seek the real distance R.

Given the fact we know the height between the mirror and the object we are looking for (the lines lie on the ground), the real distance is given by $R(r) = r * h_0 / z(r)$

Thus the problem is all about finding an appropriate Z(r). This step has been done by fitting data points into a 4rth order polynomial. The whole process of removing deformation is a multiplication by a forth order polynomial, which represents the speed. In order to get that polynomial and determine the center of the mirror (cx,cy), we used the work of David Scaramuzza.

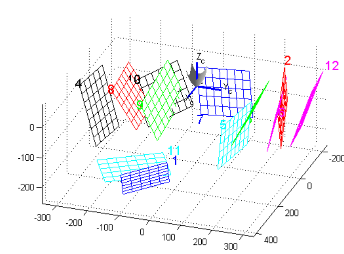
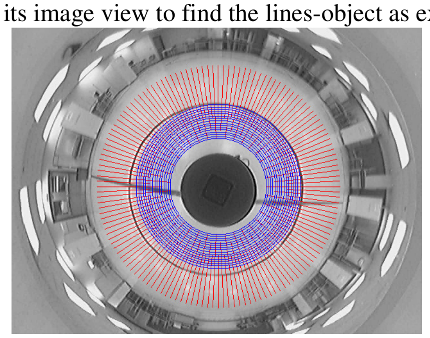


Figure 4: 3D coordinates of calibration grids

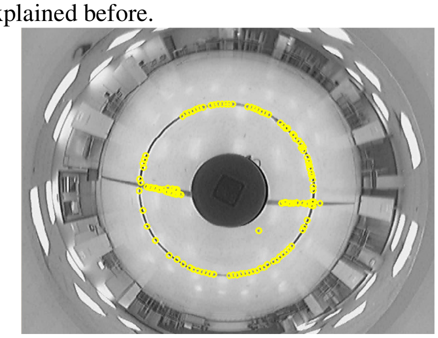
That technique uses structures from motion algorithm, which means that no prior knowledge on the position of calibration points is needed. Also, no prior assumption on the shape and size of the mirror is made. This technique uses multiples images of a calibration grid so no special calibration field needs to be build. This allows precise calibration even if only a compact space is given.

2.3. Line-objects based auto-localization algorithm

By an image scanning process and a set of lines' visual properties, the robot scan its image view to find the lines-object as explained before.



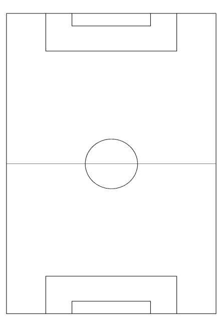
a) Scanning Process



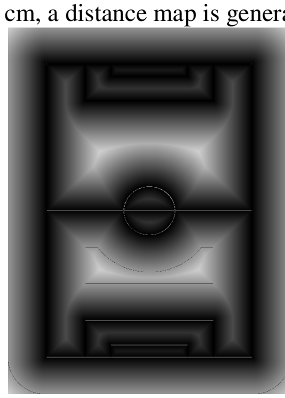
b) Lines-object found

Figure 5: From a field model to a distance map model.

Using the mirror mathematical model, it then obtains the line-object's position from its Cartesian system. At that point, the robot knows the position of a set of points in its own Cartesian system and tries to minimize the summation of distance of the line-objects and the novelized lines. This is done by the use of field model shown in the figures above. From a field model, scale 1px:1 cm, a distance map is generated.



a) Field model

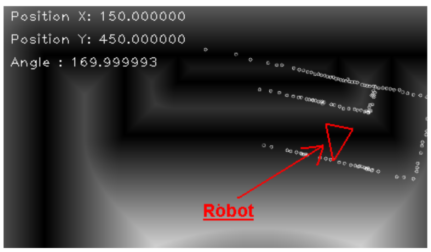


b) Field distance map

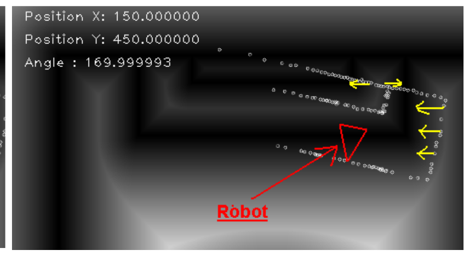
Figure 6: From a field model to a distance map model.

The field distance model shown above uses gray levels as distance value: the lighting of the pixels is proportional with the distance.

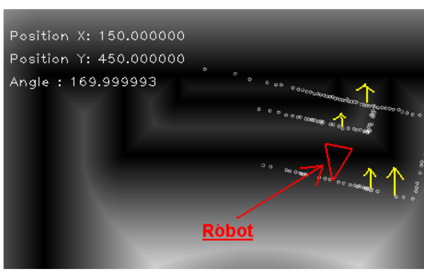
In order to reduce the computation time needed to minimize the distance function, the robot uses an initial guessed position. Then, by using the gradient of the distance map, it computes a displacement force and momentum for each line-object in the field model. These forces allow the estimation of the robot's position to the nearest minimum of the distance field map.



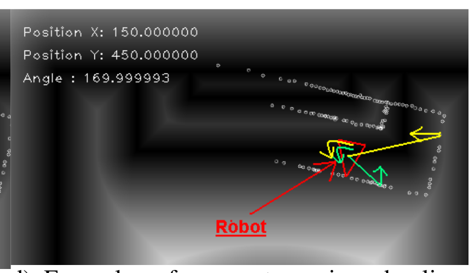
a) Robot and set of line-objects in the field distance map



b) Examples of forces along the X axis given by line-objects. With those forces the robot will be placed more to the left.



c) Examples of forces along the Y axis given by line-objects. With those forces the robot will be placed higher.



d) Examples of momentum given by line-objects.

Figure 7: Estimation of the robot position from a field distance map

When the entirely algorithm is used in real time condition, it has shown very good performance in regards of time consumption, precision and robustness. In facts, processing a new frame take about 3 milliseconds on a Pentium 3 LP 850 MHz, and gives a position with approximately 5 cm of error on a 12x8 RoboCup field. Since the automatic camera calibration is not used for each frame, it has not been timed in the 3 ms.

3. The new speed control system

In order to improve the robot reaction to the movements it has to perform, Robofoot ÉPM decided to control the DC motor speed with a microcontroller, which is linked to the PC by a USB link: the microcontroller receives a speed command for each of the motors from the PC. This command is handled by the main microcontroller and sent to the motors, through four *Ocarina* servo drives. The current loop bandwidth of the drives is more than 4 kHz. The signals of the optical encoders are read by four dedicated microcontrollers and sent to the motor controller.

With this configuration, due to the great performance of the DACs and the drives, it is possible to have a retroaction loop that lasts less than 1ms. For comparison, the frequency of the retroaction loop of the former configuration, which went through the embedded PC via a multifunction I/O card was at most 200 Hz. Furthermore, this time was not precise because it depended of whether the PC was busy treating other information or not.

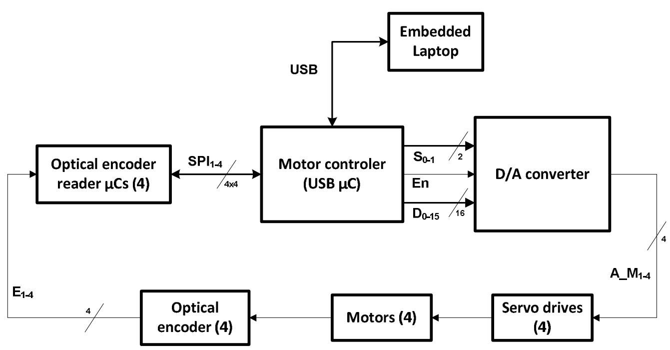


Figure 8: The new speed control system

4. New kicking mechanism

The kicking mechanism feeds on a self regulating air tank. A switch controlled pressure compressor keeps this tank at a constant pressure of 100 psi. As soon as this pressure is reached, the compressor stops and reactivates once the pressure drops below 90 psi. This system allows for up to 10 piston activations with decent force, which we consider more than enough.

Since the tank is refilled automatically during matches, we are no longer required to find a store to fill uselessly high pressure tanks, and the system will always have available compressed air for the three pistons. The center piston is used for ground passes and simply pushes forward on the ball. The two side ones are used for areal passes and pushes on flipping plates, enabling us to lift the ball. These pistons are controlled independently by three solenoids valves.

This system configuration enables us to perform several types of shots by planning which piston is activated and when. For example, activating one of the side pistons and the central piston will result in a diagonal ground pass, activating both side pistons at the same time will make the robot perform a straight aerial shot, etc. This ability gives us an advantage over some teams who can only perform forward shots.

4. Future work

In the future, Robofoot ÉPM plans to work on several aspects of the robots. First of all, although there have been many recent improvements concerning the vision system, the team wants to increase both the perceived image quality and the sight range, in order to successfully apply self-localization on larger fields. To achieve this goal, the mirrors have to be improved; in fact, many tests have been done with different cameras. These tests suggest that the camera resolution doesn't change significantly the ability of the robot to localize itself – this also shows the robustness of the new vision system.

Finally, the offensive strategies have to be improved, considering the robots have proven their defensive abilities in past competitions. Indeed, to be able to reach further steps in tournaments, they have to score goals. For example, Robofoot ÉPM can optimize the ball handling of the robots: the wheel configuration and the control system of the new prototype allow a large number of movements. This advantage has to be used at its maximum in all of its applications, like passing, carrying, and protecting the ball.

In conclusion, Robofoot ÉPM has made many important improvements on the robots during the past year. With those improvements, the robot team proves to be more competitive and shows a noticeable potential for great results in the middle size league tournaments.

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