SELF-LOCALIZATION OF A TEAM OF MOBILE ROBOTS BY MEANS OF COMMON COLORED TARGETS

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Abstract: Robot localization is one of the fundamental problems in mobile robotics. Using sensory information to localize the robot in its environment is the most fundamental problem that has to be solved in order to provide a mobile robot with autonomous capabilities, But, if robots can detect each other, there is the opportunity to do better. In this paper, it is explained how one robot, the leader, with a pan-tilt-zoom camera mounted on it can localize a team of robots. Camera images are used to detect other robots and to determine the relative position of the detected robot and its orientation with respect to the leader. Each robot carries a colored target that helps the leader to recognize it and calculate their position and orientation. Moreover, the zoom is used to enhance the perception and get a higher accuracy and a larger field of view.

1 INTRODUCTION

Cooperation among a group of robots has been a topic of very much study during the last years. To have a cooperative system it is necessary for more than one organism to have a relationship with another or anothers. So, to implement cooperation in a robotic system, it is necessary to have more than one robot working in the same environment, that is, a multirobot system.

There are several applications in which having more than one robot working in parallel has improved the system's fault tolerance, and has reduced the time required for executing the tasks. Some of these applications are autonomous cleaning, tour guiding in museums, art-galleries, or exhibitions, surveillance and patrolling, rescue in disasters such as fires, floods, earthquakes, landmine detection and autonomous exploration and mapping.

In more of these applications it is necessary the use of vision in order to implement or acomplish the tasks. Human and animal vision are the most powerful perception systems. Vision is a sense that consists of the ability to detect the light and interpret it, that is "see". Vision gets help from multiple information sources to interpret the world. The visual system allows to assimilate information from the environment to help guide the actions.

One of the most important task in computer vision is recognition, which consists of determining whether or not the image data contains some specific object, feature, or activity. One of the most characteristic task in recognition is "pose estimation", that estimates the position or orientation of a specific object relative to the camera.

In this paper, a similar task is implemented. In this case, one robot with a camera tries to estimate the pose of the rest of robot of the team, which don't have a camera available. In that way, the robot with the camera can help the rest of robots in case of lost of their possitions due to inaccurate odometric estimation pose.

To determine the relative location of other robots, the leader uses the visual information obtained from the pan-tilt-zoom on-board camera. Camera images are used to detect other robots and to determine the relative position of the detected robot and its orientation with respect to the leader. Each robot carries a colored target that helps the leader to recognize it and calculate their position and orientation. Moreover, the zoom is used to enhance the perception and get a higher accuracy and a larger field of view.

Robot localization has been recognized as one of the fundamental problems in mobile robotics (Fox et al., 2000). Using sensory information to localize the robot in its environment is the most fundamental problem that has to be solved in order to provide a mobile robot with autonomous capabilities (Cox and Wilfong, 1990). Most of the existing work in localization is addressed to the localization of a single robot by itself. However, if robots can detect each other,

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there is the opportunity to do better. When a robot determines the location of another robot relative to its own, both robots can improve the accuracy with which they localize each other.

Vision has been widely used to get exteroceptive information in order to detect and localize robots. Although omnidirectional cameras have been used in the detection and localization of robots (Das et al., 2002), directional cameras suppose a better option due to their much lower cost (Sarcinelli-Filho et al., 2003) and because they have complementary performances despite the visibility constraints (Michaud et al., 2002). Regarding the image processing, color has been widely used to achieve robot detection (Fredslund and Mataric, 2002; Michaud et al., 2002). However, the robustness of color detection with respect to light conditions can be a major source of failures (Cubber et al., 2003).

Also, the use of the zoom has been used in the context active vision (Atienza and Zelinsky, 2001) or visual servoing (Hosoda et al., 1995). For using the zoom, it is necessary the explicit knowledge of intrinsic parameters from the calibration of the camera (Clady et al., 2001).

The rest of the paper is organized as follows. Section 2 provides a description of the experimental setup. Section 3 explains the process to lozalize the different robots of the team. Finally, section 4 provides some general conclusions and lines of future work.

2 EXPERIMENTAL SETUP

- **Hardware Setup**
  The team for this application consists of a group of four Pioneer-2 mobile robots. These robots, though sharing the same platform, have different features, such as different accessories mounted on them, constituting therefore a heterogeneous group. In particular, only one robot is equipped with a camera and the rest of robots do not have any type of exteroceptive sensors. The robot with the camera is in charge of detecting the rest of the robots in the environment and indicates to them which is their current position in the environment.
- **Software Setup**
  The formation control is developed in Acromovi (Nebot and Cervera, 2005), a framework specially designed for the development of distributed applications for a team of heterogeneous mobile robots. The software architecture gives us the ease of development of cooperative tasks among robots, using an agent-based platform. In particular, communication between robots can be easily integrated to the control scheme.

3 LOCALIZATION OF THE ROBOTS IN THE ENVIRONMENT

This section describes how the robots can be localized. Having the robots distributed in an environment, the robot with the camera, from this point the *leader*, uses the camera that it carries to detect and localize the rest of the robots of the team and indicates to them which is their current. This process is explained below in more detail.

The first step is the detection of the robots in the environment, in order for this decision to be taken, the leader uses its camera to detect a series of color patterns which identify each one of the robots in an unequivocal way. To detect the colors, the Mezzanine program is used.

Mezzanine (Howard, 2002) is an 2D visual tracking package intended primarily for use as a mobile robot metrology system. It uses a camera to track objects marked with color-coded fiducials and infers the pose of these objects in world coordinates. Mezzanine works with most color cameras and can correct for the barrel distortion produced by wide-angle lenses.

Mezzanine is used only for the detection of the colors of the patterns that are used to recognize the robots. And with the information that is collected from the mezzanine system, it is possible to localize the robots in the environment and calculate their pose (position and orientation) with respect to the leader.

The color pattern that the leader has to search for is created with very common object, a beer can of half a liter covered with colored cards in a specific layout, because each ID is unique. In figure 1, it is possible to see the sizes and dimensions of the target and the color layout at the front and at the back.

As it can be seen in the ID, there are two different parts separated by a black zone. These two parts are formed with the same colors and the same cards, but there is a 90^o difference in orientation between the ID cards which means that thay are read as different cards. That is in this way to get two different readings of the orientation of the can and thus getting more accurate estimations.

Since each robot carries a different color target, the leader is able to recognise each one. Also, with this pattern it is possible to calculate the pose of the robot in relation to the leader. It is easy to recognize which robot the camera is seeing, it is simply neces-

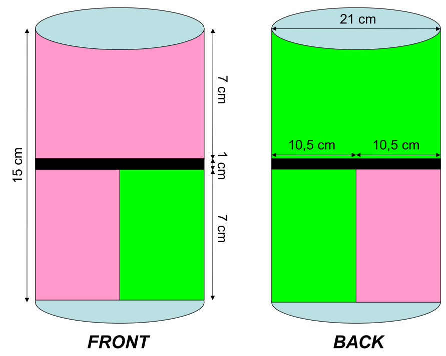

Figure 1: Dimensions and color layout of the IDs.

sary to pay attention to the layout of the colors. Mezzanine can detect several colors at the same time and group the different areas of the same color in blobs. With the information associated with these blobs it is possible to know which ID the camera is seeing at that moment.

The movement that the camera performs to find these IDs is firstly horizontal movement of 180^o from left to right. If nothing is found in this movement, the camera increases its vertical position in 5^o up to a maximum of 30^o. If when this process has finished, still any robot has not been identified, the leader executes a 180^o turn and repeats the same process until all the robots are found. In this way, the leader searches all the space around it for the other robots.

Throughout the searching process, mezzanine is monitoring all their channels where it has assigned a predefined color, and in the moment that it finds anyone of them, the camera is stopped. From this moment, a centering process begins. This new process tries to center the pattern found in the middle of the image. To this end, because the robots can be in movement, it is important to center the target in a minimum number of movements, and at the same time it is important to maximize the zoom of the camera to make a better identification in the following phases.

In order to center the target, when mezzanine detects one blob of any color bigger than a certain size, the robot stops the searching process previously described. The size has to be big enough to rule out possible errors of the program or reflections of the target. From this blob it is possible to know the position of its mass center in the image system, so the space between this and the center of the image can be calculated.

To translate this distance into a movement of the camera, it is necessary to know some intrinsic parameters of the camera, such as the focal length. These parameters can be obtained with a previous calibration of the camera.

As the camera includes a zoom, the focal length must be calculated for each of these values of the zoom. After several tests performed in the laboratory by an student, Vincent Robin, during a stay there, he managed to model the behaviour of the focal length depending on the zoom. The function that models these behaviours can be defined as:

$$f_v = (0.0368323 - 0.0000128323 * z)^{-2} * 1/2 \quad (1)$$

being z the value of the zoom that is desired. This function can be visualized in figure 2, and as it can be seen, the focal length does not follow a linear progression with the progression of the zoom.

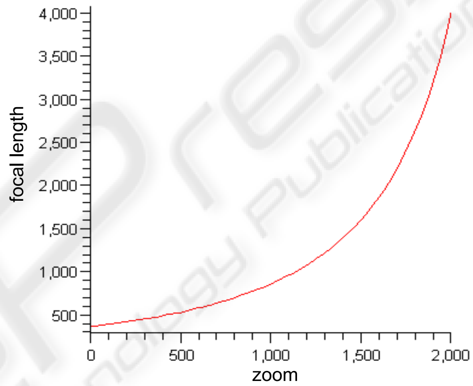

Figure 2: Relation among the necessary parameters to calculate the distance to the ID.

Knowing the value of the focal length for the actual zoom of the camera, it is simple to calculate the movements that the camera must perform in order to center the blob in the image. There are two movements that have to be made, in the pan (∇p), that is, in horizontal, and in the tilt or vertical (∇t). These values can be calculated as:

$$\begin{aligned} \nabla p &= \arctan\left(\frac{(x-x_i)}{f}\right) \\ \nabla t &= -\arctan\left(\frac{(y-y_i)}{f}\right) \end{aligned} \quad (2)$$

where x and y correspond to the coordinates of the mass center of the blob in the image, and x_i and y_i correspond to the center of the image. With these values the first blob that the robot finds can be centered.

Once the first blob of the target is centered, it is possible to calculate the optimal value of the zoom in order to reduce the detection failures of the targets of the robots and making sure of a better approximation in the calculation of the position of the robot. These calculations are based on the previous work of Pierre Renaud (Renaud et al., 2004) during a stay in this laboratory.

Prior to calculating the optimal zoom, it is necessary to calculate the optimal focal length, and with this value is possible to calculate the optimal zoom. In order to calculate the optimal focal length, it is necessary to know the actual distance (Z) to the target.

$$Z = f_v * \frac{h}{\Delta v} \quad (3)$$

With this distance, and knowing which is the desired height (h_{des}) of the blob that the program needs to get the optimal configuration, and knowing the height of the blob in the image, the optical focal length can be calculated.

$$f_{op} = h_{des} * \frac{Z}{h} \quad (4)$$

Finally, as deduced by Renaud in his work, the optimal zoom can be calculated merely by knowing the optimal focal length.

$$z_{op} = 77928.35 * \left(3.6833e^{-2} - (2 * f_{op})^{-0.5}\right) \quad (5)$$

Once this calculation is made, the zoom is applied to the camera, and as the rest of the blobs or colors of the target are now visible, it is possible to identify the robot. This process is simple and merely perceiving the distribution of the different colors in the target, the different robots can be identified.

Next, in order to make the calculation of the position more precise, a new centering process is carried out, but this time taking into account the blobs of the other colors present in the image. The biggest blob of the other color in the image provides the system with enough information to center the target in the image. The new equations to calculate the movements of the camera to center the target are:

$$\begin{aligned} \nabla p &= \arctan\left(\frac{((x_1+x_2/2)-x_i)}{f}\right) \\ \nabla t &= \arctan\left(\frac{((y_1+y_2/2)-y_i)}{f}\right) \end{aligned} \quad (6)$$

Once the ID is centered on the image and with the maximum size possible, its position and orientation with respect to the camera, or the leader, can be calculated. To know its pose $(x, y, angle)$, it is necessary to perform some calculations with the image.

In order to calculate (x,y), the system needs to know the distance and the angle of the ID with respect to the leader, and from these values, calculates the position.

To calculate the distance from the ID to the image, it is necessary firstly to know some parameters. These parameters are the real height of the ID (h), the height in pixels of the ID in the image (∇h), and the focal length of the camera (f_v). With these values, the distance to the ID (Z) can be calculated as:

$$Z = f_v \frac{h}{\Delta v} \quad (7)$$

The height of the ID is fixed, and the height in pixels of the ID in the image can be obtained from the blob information from mezzanine. The focal length of the camera can be obtained as explained before, merely by knowing which is the actual value for the zoom of the camera.

The precision of the approximated distance depends on the capacity of the system to recognize the specific colors of the cylinders, which is influenced by the prevailing lighting conditions. When the cylinder is lit from the side, their colors are preceived no longer uniform, making only part of the width of the cylinders visible to the leader. For an optimal approximation, good uniform lighting is necessary.

The calculation of the orientation (α) at which the robot is depending on the leader is easier, since the camera indicates the orientation that it has (α) at that moment. In figure 3, the relation between orientation and distance for the calculation of the ID position (x,y) can be observed.

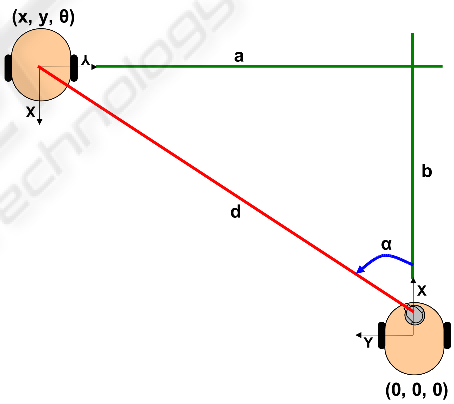

Figure 3: Relation among orientation and distance with the calculation of the ID position.

When the distance and the orientation have been calculated, it is possible to calculate the position (x,y) as:

$$\begin{array}{ccc} d = \sqrt{a^2+b^2} & & x = b = d \cdot \sin\alpha \\ & \Longrightarrow & \\ \alpha = \arctan b/a & & y = a = d \cdot \cos\alpha \end{array} \quad (8)$$

Once the position has been calculated, it only remains to calculate the orientation of the robot with respect to the leader. For this calculation, the two horizontal parts or colors of the ID are used, or rather, the relation between these two parts.

Based on the existing relation between the horizontal sizes of the two colored parts, the orientation of the robot can be calculated. It can be observed that the upper layer and the lower layer have the same colors, but the lower layer has them with a specific turn in relation with the configuration of the upper layer. This is done to have two differentiated parts and to calculate the orientation of the upper and lower layer separately, and thus, making the calculation more precise. Moreover, as it will be seen below, in that way it is possible to avoid some positions that are not accurate enough in the calculation of the orientation.

In the calculation of the orientation using the target selected, it is very important to take into account the order of the colors. Regarding this, from the 0^o position of the can to 180^o position, the pink color is in the upper left position and grows until covers the complete side of the can. If the green color is in the upper left, the orientation will be from -180^o to 0^o, depending on the portion of the can occupied by this color. In the two cases, it corresponds the 90^o or -90^o when the two colors occupy the same portion of the can, but depending on the color in the upper left side, the orientation will be positive or negative.

From the relation of the left part (X) and right part (Y), the orientation of the robot can be calculated. The relation among the left and right parts and the entire width of the cylinder can be seen in figure 4.

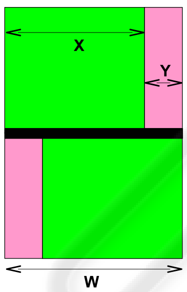

Figure 4: Relation among the parts to calculate the orientation of the robot.

From the figure, it can be deducted when the left and right parts are equal that

$$\frac{2X}{W} = \frac{2X}{X+Y} \qquad (9)$$

The behaviour of the cylinder when it is turning can be modeled as $\sin(\alpha - 90) + 1$. Joining this with the previous equation,

$$\frac{2X}{W} = \sin(\alpha - 90) + 1 \qquad (10)$$

from which it can be infered the value of α as,

$$\alpha = 90 + \arcsin(\frac{2X}{W} - 1) \qquad (11)$$

In the case of the negative orientation, the equation is similar,

$$\alpha = -90 + \arcsin(\frac{2X}{W} - 1) \qquad (12)$$

In figure 5, it can be seen the graphics in radians that model these to functions.

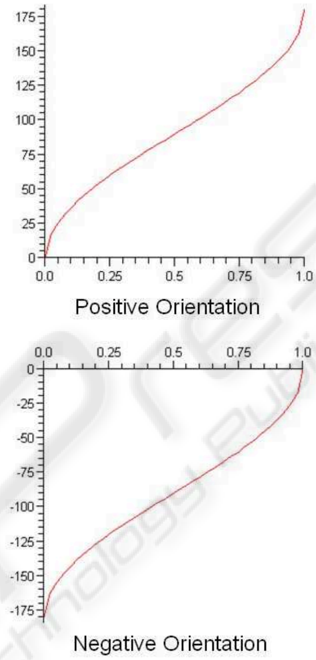

Figure 5: Functions that model the orientation of the robot.

Moreover, it is necessary to take into account four exceptions to the general rule. If there is only one color in one of the parts of the ID (upper or lower), then there is one of these special cases. Simply, distinguishing the order of the colors in the remaining layer, it is possible to recognize the spacial case in question.

Also, as it can be seen in the graphs in figure 5, there are two zones in each graph in which the value of the orientation changes too fast and it may cause the estimation to be less accurate than desired. These zones are at the extremes with a width of 30^o. When the calculation in one of the layers returns a value within one of these zones, the values that are taken for the orientation of the robot is the value that returns the calculation in the other layer. Due to the fact that the layers have different turns, the values that appeared in one layer when the other is in one of these situations are correct.

This calculation of the orientation of the robot can be easily extended to any of the IDs. It is only necessary to take into account which is the pattern of the colors. Furthermore, this identification system can be

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extended to any number of different IDs, the only limitation is the number of different colors that mezzanine is able to detect.

Once the robot's orientation is calculated, all the values necessary for determining its pose $(x, y, angle)$ in the environment with respect to the leader are available. This pose then is translated to the environment system. This process is obvliuos. Then, this pose is then sent to the corresponding robot so that it knows its position.

4 CONCLUSIONS

A new method for the visual localization of robots has been implemented. Using a very common and simple target it is possible to localize one robot and determine its position and orientation with regard to the robot with the camera and of course in the environment.

The main advantage consists on having a very simple object, by means of the corresponding geometric constrints, it is possible to stablish not only the distance to the target robot, but also the orientation. Regarding to the orientacion, by means of a two simultaneous readings process, it is possible to eliminate the accuracy errors produced by the specific features of the object used as target.

The localization of the robots by means of the colored targets has been a hazardous work due to the sensitivity of the vision system to the lighting conditions.

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REFERENCES

Atienza, R. and Zelinsky, A. (2001). A practical zoom camera calibration technique: an application of active vision for human-robot interaction. In *Proceedings of the Australian Conference on Robotics and Automation*, pages 85–90.

Clady, X., Collange, F., Jurie, F., and Martinet, P. (2001). Objet tracking with a pan tilt zoom camera, application to car driving assistance. In *Proceedings of the International Conference on Advanced Robotics*, pages 1653–1658.

Cox, I. and Wilfong, G. (1990). *Autonomous Robot Vehicles*. Springer Verlag.

Cubber, G., Berrabah, S., and Sahli, H. (2003). A bayesian approach for color consistency based visual servoing. In *Proceedings of the International Conference on Advanced Robotics*, pages 983–990.

Das, K., Fierro, R., Kumar, V., Ostrowski, J. P., Spletzer, J., and Taylor, C. (2002). A vision-based formation control framework. *IEEE Transactions on Robotics and Automation*, 18(5):813–825.

Fox, D., Burgard, W., Kruppa, H., and Thrun, S. (2000). A probabilistic approach to collaborative multi-robot localization. *Autonomous Robots*, 8(3).

Fredslund, J. and Mataric, M. (2002). A general, local algorithm for robot formationss. *IEEE Transactions on Robotics and Automation (Special Issue on Advances in Multi-Robot Systems)*, 18(5):837–846.

Hosoda, K., Moriyama, H., and Asada, M. (1995). Visual servoing utilizing zoom mechanism. In *Proceedings of the International Conference on Advanced Robotics*, pages 178–183.

Howard, A. (2002). Mezzanine user manual; version 0.00. Technical Report IRIS-01-416, USC Robotics Laboratory, University of Sourthern California.

Michaud, F., Letourneau, D., Guilbert, M., and Valin, J. (2002). Dynamic robot formations using directional visual perception. In *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems*, pages 2740–2745.

Nebot, P. and Cervera, E. (2005). A framework for the development of cooperative robotic applications. In *Proceedings of the 12th International Conference on Advanced Robotics*, pages 901–906.

Renaud, P., Cervera, E., and Martinet, P. (2004). Towards a reliable vision-based mobile robot formation control. In *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems*, pages 3176–3181.

Sarcinelli-Filho, M., Bastos-Filho, T., and Freitas, R. (2003). Mobile robot navigation via reference recognition based on ultrasonic sensing and monocular vision. In *Proceedings of the International Conference on Advanced Robotics*, pages 204–209.