

Active markers for outdoor and indoor robot localization

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Abstract—Localization is one of the fundamental problems in mobile robot navigation. In this paper a study is presented on a new methodology aimed at localizing a mobile robot in indoor and outdoor environments using active markers and commercial off-the-shelf webcams. The localization system, which is currently under development, based on the difference of working frequencies of the shutter of a webcam and a signal from the marker, in a way similar to the beat created by two sound waves. This study is part of a more complex project for a patrolling robot and will be part of a message-oriented middleware called DCDT (Device Communities Development Toolkit) developed in the past few years at the University of Brescia.

Index Terms—Mobile Robot, localization, DCDT, distributed systems, active markers

I. INTRODUCTION

Localization is a key problem in making truly autonomous robots. Although many different methodologies have been developed in order to find the location of a robot relative to the environment in which it has to operate, most of them suffer from high costs, and many exhibit restrictions that limit their practical application to some environments and/or situations. In this paper a new system is presented, that relies on the recognition of an active marker by a vision system based on a webcam. Although it requires some structuring of the environment, this method is appealing because the tooling is simple and inexpensive, and in many cases already existing cameras can be used. The method, which is currently under development, is based on the difference of working frequencies of the shutter of a webcam and a signal from the marker, in a way similar to the beat created by two sound waves. Moreover, the system is structured to be a part of a message-oriented middleware called DCDT (Device Communities Development Toolkit) [Cassinis et al., 2001] [Cassinis et al., 2003], developed at the University of Brescia, with the purpose of taking advantage of already existing computing, sensing and communication resources, limiting the cost of additional equipment.

II. THE LOCALIZATION PROBLEM

Many different strategies have been applied to the localization problem. Tracking or local techniques, like dead reckoning methods and odometry readings, keep track of the position of a robot while it is navigating in the environment, but since the position estimates are based on earlier positions and due to the fact that this method accumulates sensor error and wheel slippage, the error in

the estimates increases over time, and at least periodical recalibration procedures that use other localization methods are required. Other techniques rely on the fact that a robot operates in a structured or semi-structured environment and use different types of environment features on different levels of perceptual abstraction as frequently and reliably recognizable objects. Some of them are map based positioning or model matching techniques, that use geometric features of the environment, like lines that describe walls in hallways or offices, to compute the location of the robot [Davison, 2003] [Borenstein et al., 1996] [Gutmann et al.,]. The matching of maps can come with a significant amount of uncertainty whether they are known in advance or not, so many solutions have been presented including approaches employing Kalman filtering [Georgiev and Allen, 2004] [Davison, 2003] [Arras and Tomatis, 1999], grid-based Markov localization, or Monte Carlo methods [Wolf and Pinz, 2003]. Other methods try to obtain absolute measurements through the use of beacons [Batalin and Sukhatme, 2003] or natural or artificial landmarks [Jang et al., 2002]. Many solutions adopt artificial landmarks [Batalin and Sukhatme, 2003] [Maeda et al., 2003] [Lamon et al., 2001] [Ma et al., 2002] [Parker et al., 2004] [Roh et al., 1997] [Fiala, 2004] because they can be designed for optimal detectability even under adverse environmental conditions. The system presented in this paper provides absolute localization from scratch to a robot in a dynamic environment, by means of a webcam and the use of an optical active marker. It is quite obvious that absolute positioning systems offer great advantages over relative methods, because their readings can be immediately used. In many cases great precision is also not an issue, specially when the system is used for "driving the robot around", as it happens for instance in surveillance robots. Furthermore, absolute systems do not suffer from "robot stealing" problems, since each reading is either independent from all the previous ones, or, if previous readings are used to quicken or to enhance the current one, a procedure exists that allows not to use them with little performance degradation.

III. DESCRIPTION OF THE SYSTEM

The localization system was designed to aid MORGUL, MOBILE Robot for Guarding University Laboratories, in its task of patrolling an area in the campus of the University of Brescia. MORGUL is a PIONEER 3 mobile autonomous robot equipped with an on-board PC, that is connected to the local area network and even to the internet via several

different channels, even if the most used one in indoor and short-range outdoor missions is a wi-fi communication link.

Unlike most absolute localization systems, that use robot-mounted sensors to gather information from fixed landmarks, the solution we adopted reverses this philosophy, using fixed sensors that "look" at the robot. This solution may seem complicated and non-economical, but it should be kept in mind that modern networking systems (specially wireless ones) make it usually very easy to place devices around the environment.



Fig. 1. MORGUL, MOBILE Robot for Guarding University Laboratories

In this approach a robot is a simple and therefore low-cost mobile device, that only take on board actuators and sensors that are needed for a reliable exploitation of their task, embedding the remaining portion of sensors and processing units into the environment, using whenever possible resources that are already available for other reason. In the patrolling area, for instance, the used cameras can be the same used for a fixed surveillance system.

This point of view in the recent years has led to the development of a message-oriented middleware called DCDT (Device Communities Development Toolkit) that implements a reliable and stable communication layer required by this approach.

Every device outside the robot can exploit autonomously its task, offering its services only when and where required in this sort of distributed sensing and processing system, in which the DCDT takes responsibility of the delivery of messages throughout the system, managing each single active and independent software agents, called *member*.

In our project, the robot's localization is conceived as an autonomous task provided by a member of the DCDT system that so could interact with the community of interconnected device in a transparent way, regardless of the physical communication means used.

The localization is exploited by of visual-based system that recognize an active marker when the robot get lost in his environment. The visual system consists of a commercial off-the-shelf webcam, namely a Philips ToUCam Pro II PCVC840K, with a resolution of 640x480 pixels connected via USB link to a PC. As far as the active marker is concerned, several tests have demonstrated that in outdoor environment the best results can be obtained with a series

of high brightness LED's, while for indoor use infra-red LED's could be used with good results, even if the sensor of the webcam is not very sensitive in the infrared region. The LED clusters are controlled by a microcontroller unit connected via a serial line to the robot PC that could run a suitable autonomous DCDT member.

IV. RECOGNITION ALGORITHM

The recognition algorithm is inspired by the beats created when two sound waves of very similar frequencies interfere with one another. This interference creates a beat pattern, characterized by a wave whose amplitude is changing at a regular rate. In a similar way, we can obtain a periodic signal with a sort of "beat frequency" from the product of two square waves of similar frequencies. A marker can be seen in an image only if the shutter of the webcam is open when it transmit its signal and only if this signal is enough to be captured by CCD sensor. If we consider the square waves as the exposing time of the webcam and the signal of the active marker, the product signal represent the time in which the light of the marker can be captured by the sensor of the webcam. If we assume a threshold for the marker to be isolated from the environment in an image, we can see a periodic behavior of the marker in the sequence of images. This behavior depends on the difference of frequencies of the marker and the shutter and can be used as a pattern to localize the marker. The recognition algorithm consist in several step:

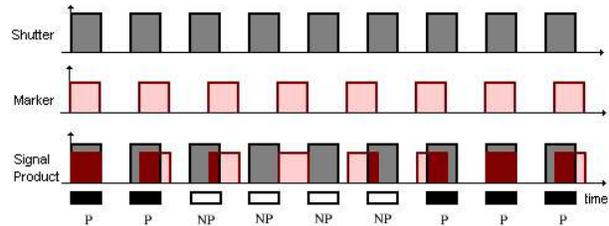


Fig. 2. The marker signal and the shutter of the webcam

acquisition, thresholding, blobs identification, blob pattern recognition and finally marker localization.

A. Acquisition

During this step the images are acquired from the webcam in a VGA resolution and saved in a suitable memory area.

In indoor environment some experiments have shown that we can calibrate some of the camera parameters, basically the gain and the shutter speed, to obtain an image quite clean from noise, in which the only relevant features are the sources of light and the infrared emitters.

In the outdoor environment, the sun reflection don't permit to have an image clean from the noises of the environment even calibrating the camera parameters. Actually some studies are in progress in order to reduce the vision-computation.



Fig. 3. Indoor image - Marker off



Fig. 5. Outdoor image - Marker off



Fig. 4. Indoor image - Marker on



Fig. 6. Outdoor image - Marker on

B. Threshold

After the acquisition, the whole image is thresholded, leaving only two colors: black for the environment and white for the rest. It's a rough segmentation, but the aim of this operation is only to deliver an image where it is easy (i.e. fast) to detect blobs, while the true localization of the marker is done through its pattern recognition.

C. Blobs identification

The next step is the identification of blobs in an image. A blob can be either the marker or a "noise" like a neon, a window or a sun reflection, so at the end of this phase we obtain a list with informations about the barycenter and the number of pixels of every blob.

D. Blob pattern recognition

The next phase is to identify the pattern of every blob in the sequence of the k images collected. When two blobs in different images have similar characteristics (barycenter and number of pixels), we can assume that they represent the same object (i.e. the marker or noise). If we confront every blob of an image with those of the other frames, we obtain the behaviour of the object. A neon or a constant sun reflection will be always present in the video streaming, so in all the image we will have a blob with approximatively the same characteristics. Random lights will be present only in

some frame while the marker or fixed signals will have a periodical pattern. At the end of this phase, the behaviour of every blob will be described by a sequence of k elements of values of 1 or 0, according to the presence of the blob in the images $i(i \in [0, k])$.

E. Marker localization

In this phase, in order to localize the robot, we have to find a blob whose behaviour matches the pattern expected from the marker, basically a periodical repetition of n frame in which it is present and m in which it is not visible.

This comparison can't be simply made by a sort of XOR operation because it's difficult that a blob can have a sequence equal to the theoretical expected. First of all the threshold in certain situation could be too restrictive and in some image could cut off the pixels representing the marker, for example if the robot is quite distant from the webcam. Moreover, as the recognition is based on the difference between the frequency of the marker and the frame rate of the visual system, error in this quantity lead the have a longer or shorter beat frequency. This error affects the pattern of the marker, that wouldn't be characterized by the repetition of the couple n (present P) and m (not present NP), but will have a sequence of different couples (P, NP). As we can see in Figure 7, this

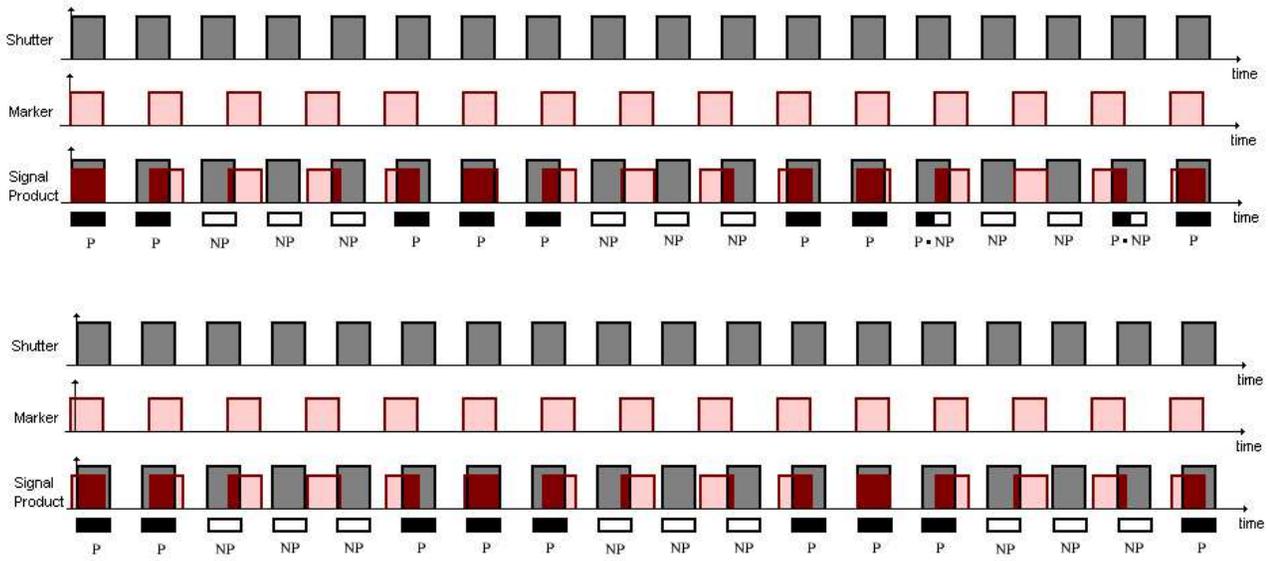


Fig. 7. The marker signal and the shutter of the webcam whit an error in the thoretical values

sequence will consist in couple (P, NP) of values (n, m) with some values of $(n \pm 1, m \pm 1)$.

Following this idea, we don't have to search a sequence that match perfectly a pattern, but the blob that has a sequence of couples (P, NP) nearest the theoretical sequence of points (n, m) . The marker localization is so exploited transforming every blob pattern in a sequence of points (P, NP) and giving a values at each sequence depending on the distance of every of its points form the couple of the expected period (n, m) .

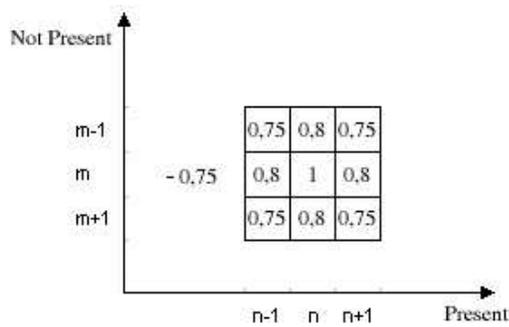


Fig. 8. The values of every possible point in the sequence

The weights of every point is showed in figure 8. Points with an error in only one of the axis will have a better coefficient than those who fails by one in both presence and not presence in the images. Naturally points that have a major error in one or both axis suggest that the blob doesn't represent the marker, so will have a negative value. At the end of this phase, we can assume that coordinates

of the marker is the barycenter of the blob whose pattern has the best values.

V. CONCLUSION AND FUTURE RESEARCH

In this paper we presented a new simple and low-cost localization system based on the difference of working frequencies of the shutter of a webcam and a signal form the marker, in a way similar to the beat created by two sound waves. This system can localize a mobile robot in indoor and outdoor environment using a commercial off-the-shelf webcam and an simple active marker, aiding a robot in a patrolling task. The system has to be integrated in the DCDT middleware and can be improved by the use of more than one camera. Also another future research can be the use of industrial camera to take advantage of an existing surveillance system.

The time required by this operation lead to execute these comparison only at the end of the acquisition phase. The blob identification instead can be done by the PC connected with the webcam in the slot time between two consequent acquisition or by another PC. "identification" member, while the webcam member only transmit the images. The DCTD system in fact permit the execution of two different member on the same PC or in two different station. In this approach we can see two members of the DCDT system:

- a identification member responsible of the recognition of the blobs
- a webcam member responsible of the acquisition and the deliver of the images

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