

**EUROCAST 2007**

**Computer Aided  
Systems  
Theory**

**EXTENDED ABSTRACTS**

11th Internacional Conference on Computer Aided Systems Theory  
Las Palmas de Gran Canaria, Spain, February 2007

## Preface

The concept of CAST as Computer Aided Systems Theory was introduced by F. Pichler in the late 80's to encompass those computer theoretical and practical developments as tools for problems in System Science. It was thought as the third component (the other two being CAD and CAM) that will provide for a complete picture of the path from Computer and Systems Sciences to practical developments in Science and Engineering.

Franz Pichler, of the University of Linz, organized the first CAST workshop in April 1988, which demonstrated the acceptance of the concepts by the scientific and technical community. Next, the University of Las Palmas de Gran Canaria joined the University of Linz to organize the first international meeting on CAST, (Las Palmas February 1989), under the name EUROCAST'89 and proved to be a very successful gathering of systems theorists, computer scientists and engineers from most of European countries, North America and Japan.

It was agreed that EUROCAST international conferences would be organized every two years, alternating between Las Palmas de Gran Canaria and a continental Europe location, being later decided to celebrate them in Las Palmas. Thus, successive EUROCAST meetings took place in Krems (1991), Las Palmas (1993), Innsbruck (1995), Las Palmas (1997), Vienna (1999), Las Palmas (2001), Las Palmas (2003) and Las Palmas (2005), in addition to an extra-European CAST Conference in Ottawa in 1994. Selected papers from those meetings were published by Springer-Verlag Lectures Notes in Computer Science nos. 410, 585, 763, 1030, 1333, 1798, 2178, 2809, and 3643 and in several special issues of Cybernetics and Systems: an International Journal. EUROCAST and CAST meetings are definitely consolidated, as it is shown by the number and quality of the contributions over the years.

EUROCAST 2007, to be held in the Eider Museum of Science and Technology of Las Palmas, February 12-16, continues with the approach tested in last Conferences as an International computer related Conference with a true interdisciplinary character. There are different specialized Workshops which, in this occasion, are devoted to 1.-Systems Theory and Simulation, chaired by Pichler (Linz) and Moreno Diaz (Las Palmas); 2.-Computation and Simulation in Modelling Biological Systems, chaired by Giocardi (Napoli); 3.-Intelligent Information Processing, chaired by Freire (A Coruña); 4.-Computers in Education, chaired by Martín-Rubio (Murcia); 5.-Grid Computing, chaired by Volkert (Linz); 6.-Applied Formal Verification, chaired by Biers (Linz); 7.-Cellular Automata, chaired by Vollmart (Karlsruhe); 8.-Computer Vision, chaired by Alvarez (Las Palmas); 9.-Heuristic Problem Solving, chaired by Affenzeller (Hagenberg); 10.-Signal Processing Architectures, chaired by Huemer (Erlangen) and Müller-Wipperfurth (Hagenberg); 11.-Robotics and Robotic Soccer, chaired by Kopacek (Vienna); 12.-Cybercars and Intelligent Vehicles, chaired by Parent (Paris) and García-Rosa (Madrid) and 13.-Artificial Intelligence Components, chaired by Chaczko (Sidney).

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# Real-Time Wide-Angle Stereo Visual SLAM using Adaptive Patches and SIFT features correction

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**Abstract.** One of the most important aspects in autonomous robotics is the Simultaneous Localization and Mapping problem. Although many efforts have been done to solve it in the last years, there are still certain aspects to solve mainly in large environments. This paper presents a new method for real-time SLAM calculation applied to autonomous robot navigation without restrictions. It is based exclusively on the information provided by a cheap wide-angle stereo camera. Our approach consists on the 3D sequential mapping of natural landmarks by means of a stereo camera, which also provides means to obtain the robot location/orientation. The dynamic behavior is modeled using a top-down Bayesian method. The introduction of a SIFT-based correction method helps to reduce the accumulated drift while keeping the real-time constraints.

**Keywords:** SLAM, wide-angle vision, stereo vision, real-time.

## 1 Introduction

Real-time Simultaneous Localization and Mapping (SLAM) is a key component in robotics. In last years several approaches have been used [1][2]. Recent researches have demonstrated that camera-based SLAM is very useful in domains where the goal is to recover 3D camera position in real-time moving rapidly in normal human environments, based on sparse visual features mappings, potentially with minimal information about motion dynamics [3]. In [4] a 3D visual SLAM method, based on a stereo camera and SIFT features, is presented. Currently, the main goal in SLAM research is to apply consistent, robust and efficient methods for large environments. One of the main milestones is to achieve large closing loops in robot paths.

This paper presents a real-time SLAM method based on stereo vision. The basis of this work is presented in [6]. It is based on a stereo wide-angle camera mounted on a mobile robot. Several visual landmarks are sequentially captured and introduced on an EKF filter in order to model the probabilistic behavior of the system. A measurement model is used for the error on the landmark captures and a motion model is implemented for the dynamic behavior of the robot. As it is well known, one of the major problems on the EKF implementation is the quadratic ( $n^2$ ) increase of computational cost as a function of the number of landmarks making it unsuitable for

large environments where this number can be potentially high. In order to solve the problem, this work presents a modified SLAM implementation which includes an additional detection level (high level SLAM) based on SIFT landmarks combined with the classical landmarks detector based on the Shi and Tomasi operator [6] (low level SLAM). The behavior consists in locally locate the robot within the environment based on the landmarks position estimation in real-time obtained from the low level SLAM. Then, under particular circumstances (total reference loose, too high number of landmarks, etc), a set of SIFT landmarks is extracted. Then, SIFT descriptors comparison is carried out between previously captured set and current one. The information extracted from the matched features is used to update the filter and correct the robot state. A similar method is carried out to identify previously visited places when closing large loops. These processes constitute the high level SLAM.

## 2 Low level SLAM

In order to solve the low level SLAM process an EKF filter is applied. A state vector  $X$  and its covariance matrix  $P$  are defined, where  $Y_i$  are the features global position state vectors representing the map and  $X_v$  is the camera state vector representing its linear/angular position and speed respectively.

$$X = (X_v \ Y_1 \ Y_2 \ \dots)^T, \quad X_v = (X_{rob} \ q_{rob} \ v_{rob} \ \omega)^T \quad (1)$$

Regarding the motion model, the so-called *impulse model* has been used. This allows a freely but smoothly camera movement. It is based on the assumption of constant speed during each time step while having random speed changes on the transitions. Prediction of the next state of the robot is defined by the function showed in (2), where  $q_{rob}$  represents the rotation vector in *quaternion* format.

$$f_v = (X_{rob} + v_{rob} \cdot \Delta t \quad q_{rob} \times q[\omega \cdot \Delta t] \quad v_{rob} \quad \omega)^T \quad (2)$$

To calculate the *process noise*  $Q$ , a noise vector  $n = (v \ \Omega)^T$  is defined, which represents the random linear and angular speed changes mentioned before.

Respecting the measurement model, visual measurements are obtained from the "visible" features positions. We define each individual measurement prediction vector  $h_i = (h_{ix} \ h_{iy} \ h_{iz})^T$  as the corresponding 3D feature position relative to the camera frame. As long as the robot moves around the environment it detects and initializes new landmarks calculating its 3D position relative to the global frame. In the other hand, the already initialized landmark positions are measured again, in case they pass a visibility test. The measurement process consists of two phases. First, a search area on the projection images is calculated as a function of the covariance matrix  $P$ . Then, a correlation process, using the stored appearance of the landmark patch, across the search area is performed, obtaining the updated projection coordinates of the landmark. Using epipolar equations, the related 3D position is obtained. This information is used to perform the global EKF update process.

### 3 High level SLAM

As it was stated before, in large environments, as the number of landmarks grows the covariance matrix size increases until the processing time exceeds real time constraints. In order to avoid this, only a local visible *window* of landmarks is introduced into the EKF.

One of the main issues on SLAM in large environments is the *loop-closing* problem. The first issue to solve is the recognition of previously visited places. To do that, a solution based on SIFT features (see [5]) is carried out. The procedure extracts all SIFT features at certain robot locations. Then, their descriptors are compared with all previously extracted within an uncertainty region of places. The matching method is based on the euclidean distance between descriptors and the position of the features in the images. If a positive match is found, the location is marked as recognized. The new descriptors associated to this location and the next update step are accomplished.

The second step, in case of positive matching, is to update the robot state and all landmark positions involved in the loop. First, the new robot location has to be calculated. This is achieved by obtaining the 3D positions of the SIFT features calculated both the first time and at the current step. Once obtained the transformation between both positions, the new location is transformed into the new locations as well. After the robot pose has been updated, all landmark positions have to be updated as well. To do that, the transformation applied to the robot location is applied to the whole landmarks. However, in order to keep the map global consistency, this update process is corrected by the robot global covariance matrix along the robot path. That means that the landmark positions will be modified according to the uncertainty of the robot location at the moment of being initialized.

### Results

The system was tested over a large closed loop path. This path is a corridor located on the 3th floor of our Polytechnic School building. The robot covered a distance of 320m right before closing the loop (see Fig1.). The robot recognized the start location and corrected its position. Regarding the map correction, we still don't have it implemented, so there are no results shown. Respecting the processing time, the system was implemented on an AMD Turion processor at 2.0 GHz. The mean value on processing low level SLAM was 28 ms, spending 3 ms on measurement process, 5 ms on filter update and 20 ms on feature initializations. It allows a real-time behavior, always below 33 ms (30 fps). Regarding the high level SLAM, results are shown to spend a mean time of 531 ms on the SIFT features extraction, matching and recognition of previously visited places.

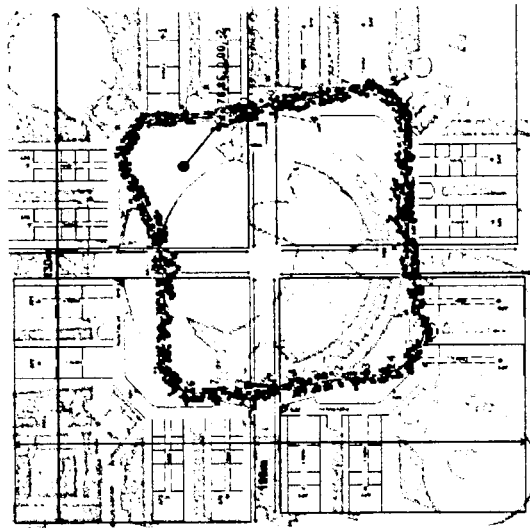


Fig. 1. Path covered by the robot right at the moment of recognizing the start position (red arrow). The blue points represent all of the landmarks captured by the system. The numbers indicate the positions where a SIFT search has been performed.

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