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Feature matching based positioning algorithm for swarm robotics☆

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ABSTRACT

In this study, a positioning algorithm which is inspired by model matching type positioning systems is presented for swarm robotics. Unlike the conventional model matching systems, the system is designed to be operated as distributed. The algorithm consists of online and offline stages. While specific data collection and positioning are computed in the offline stage, specific data exchange is performed in the online stage. In the positioning algorithm to be used, a swarm robot system where each robot receives an image from a camera located under itself and where the robots share these images with each other and perform positioning is taken as a basis. The positions computed are the positions of the robots with respect to each other. Position estimation is based on feature detection and description from images. To determine the optimal positioning algorithm, performance comparison is performed among different combinations of feature detection and description algorithms.

1. Introduction

Swarm intelligence is a new subject attracting scientists. This subject have found many application areas in engineering and mathematics due to its significant advantages such as robustness, flexibility and scalability [1]. The idea of using a system composed of multiple components which are simpler instead of a very complex, costly and cumbersome system has aroused a special interest in robotics, which is how swarm robotics has emerged. Swarm robotics is defined as the performance of certain tasks by multiple combined autonomous agents in cooperation [2]. The tasks for which swarm robotics is applied are aggregation, flocking, foraging, object clustering and sorting, navigation, path formation, deployment, collaborative manipulation and task allocation. During the performance of all these tasks, the robots must interact with each other. If the task contains the elements such as target, obstacle, friend or foe, road monitoring etc. the most important interaction problem is localization [3–5].

Location determination operations are divided into two categories: positioning and object detection. Positioning is to determine where the robot is, with respect to a point. Object detection is determination of the positions of the objects around the robots with respect to itself. There are many techniques such as distance sensor, radio frequency (RF) signal measurement, image/video processing, 3D scanners, radar and Global Positioning System (GPS) for positioning operations. Positioning is divided into two categories: relative and absolute [6]. Relative systems are easy to apply and cheap but they

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are error-cumulative. Therefore, it is not preferred in long-term jobs and sensitive studies. On the other hand, absolute systems are based on the principle of position computation with the data received from the reference points. These systems are divided into two categories, triangulation and triliteration methods and model matching methods. In triangulation and triliteration methods, the position is estimated with the angle and distance data received from at least three reference points whose positions are known. GPS is the best known among these systems. In the systems operated by triangulation, accuracy is high, but infrastructure installation is difficult, cost is high and portability is low. The common systems such as GPS, which works especially with radio frequency techniques, cannot be operated due to indoor signal attenuation and reflections. Model matching is the most advanced and complex one among the positioning systems. Model matching is called scene analysis or fingerprinting in some resources [7]. Model matching consists of two stages, offline and online. In the conventional model matching systems, data is collected from the environment in the Offline stage and this data is also called fingerprint. On the other hand, in the online stage, the Fingerprint data is transmitted to a center. During the procession of the Fingerprint data in the center, matching is performed in the database of the center with the help of pattern recognition techniques and the position data is generated. Finally, the position data generated is transferred to the robot. The current model matching systems are central and when the number of points to be computed increases, the computing power of the center should also increase. In addition, since the center is usually a big computer, portability is low; which requires media dependency.

Swarm robot studies are usually performed with the robots that can move two-dimensionally. The main ones of these studies are I-SWARM, Kilobots and WolfBot [8–10] . These systems are very efficient and their accuracy is high, they run with simple sensors since only two-dimensional positioning is required.

In the recent years, studies have also been performed with the robots which can move three-dimensionally. In the studies performed with GPS, coordinate data generated two dimensionally can be used. Three-dimensional positioning is possible when height data such as barometer is added to these data. In such applications done with GPS and auxiliary sensors, quadrotor and fixed-wing aircraft was used [11,12]. However, due to the reflection and signal attenuation problems, GPS cannot be used indoors. There are also studies on the systems with the ability of indoor positioning. In the study performed by GRASP laboratories with Quadrotors, VICON motion capture system was used for positioning [13,14]. VICON is a system consisting of infrared cameras mounted on the laboratory walls. Since this system is mounted on the fixed structures such as walls, it has no portability. Furthermore, the system produces precise and accurate results. The system prepared in the Swarmanoid study consists of hand, foot and eye robots [15]. This system consisting of different robots are heterogeneous. The Swarmanoid system uses the data received from the eye robot as positioning system. Actually, this system is for directing the movements of the hand and foot robots moving two-dimensionally, however it is not a positioning system designed for three-dimensional movements. Besides, when eye robot is removed from the Swarmanoid system, this robot cannot be replaced by hand robot or foot robot, which is why the system is not robust. In another study performed with this system, only eye robots were used, and Leica TS30 track system which is a similar system to VICON in the study of GRASP laboratories was used [16]. Since this system is also mounted on the fixed structures, it has no portability. Apart from the mentioned systems, the techniques such as LIDAR, stereo vision and omni-directional vision are used for 3D navigation, however these systems are rather used for obstacle detection purposes [17–19].

Feature detection and description algorithms are frequently used in image processing and used in robotics particularly for visual simultaneous localization and mapping (V-SLAM) purposes [20,21]. These systems require high computing power. V-SLAM systems are used in many robotic applications especially because they can be mounted on the robot and they can detect three-dimensional movements.

The specific patterns or key regions on this image are called feature, and the methods used to find these regions are called feature detection. Features From Accelerated Segment Test (FAST) Center Surround Extremas for Real-time Feature Detection and Matching (CENSURE), and Efficient Maximally Stable External Region (MSER) are the main feature detection algorithms [22–25]. In order to determine the similar regions in two images including the similar key points, it is necessary to find which feature in the source image corresponds to which feature in the target image. For this, feature description algorithms are used. The main feature description algorithms are Binary Robust Independent Elementary Features (BRIEF), Binary Robust Invariant Scalable Keypoints (BRISK) and Fast Retina Keypoint (FREAK) [26–28]. In the current algorithms, feature detection and description are sometimes performed together. Scale Invariant Feature Transform (SIFT), Speed Up Robust Features (SURF) and Oriented FAST and Rotated BRIEF (ORB) are the algorithms of this type [29–31]. SIFT and SURF are the patented algorithms which are frequently used in image-stitching algorithms. ORB can be used as detection or description as well as be used instead of both.

When feature detection and description algorithms complete their tasks, the number of the points detected, the coordinates of the points and a data set describing the points are obtained. The data set composed of point coordinates and point descriptions is used in regression with the Random Sample Consensus (RANSAC) algorithm, and a matrix called homography matrix is obtained. The structure of the Homography matrix is shown in the Eq.(1) [32].

$$H = \begin{pmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{pmatrix} \quad (1)$$