Robotics and Autonomous Systems 63 (2015) 10–21

Contents lists available at ScienceDirect

Robotics and Autonomous Systems

journal homepage: www.elsevier.com/locate/robot

A novel pose estimation algorithm for robotic navigation

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HIGHLIGHTS

- A new pose estimation algorithm is proposed.
- The difference between the mobile robot desired and current pose is computed.
- The mobile robot sensor readings and the virtual sensor readings are employed.
- The algorithm is tested by simulation and real-world experimental results.

ARTICLE INFO

Article history:
Received 13 June 2014
Received in revised form
15 September 2014
Accepted 22 September 2014
Available online 13 October 2014

Keywords:
Mobile robot
Pose estimation algorithm
Relative rotation angle
Relative translation
Robotic navigation
Virtual sensor

ABSTRACT

This paper proposes a new pose estimation algorithm in the framework of robotic navigation problems. The algorithm gives the mobile robot (MR) pose on the basis of the difference between the MR desired pose and the MR current pose. In this regard the MR sensor readings and the readings of a virtual sensor are employed. The algorithm is advantageous in comparison with other pose estimation algorithms including those based on classical filter approaches because of the small computation time. Simulation and real-world experimental results are included to illustrate the effectiveness of the pose estimation algorithm and its potential for integration in MR control structures and algorithms.

1. Introduction

The localization is a key challenge in the fields of mobile robotics and of autonomous driving. The importance of this topic results from the fact that the model-based approaches are based on robotic platforms that navigate using mathematical models. For a given robot, its models are updated through environment measurements or observations which describe, to a certain degree, the robot position and orientation, referred to as pose or as posture, namely, the localization of the robot is carried out. The observations, most likely affected by different disturbances, are used to correct the mobile robot (MR) model. Once the MR pose is known, it is further used in navigation problems.

The navigation strategy implied in our paper involves two major steps:

(i) the MR first acquires the environmental data for map reconstruction,
(ii) the MR next navigates to specific locations combining the map produced at step (i) with the localization.

Many solutions to the localization problem have been reported in the literature. These solutions can be divided in two categories, choosing an appropriate sensor and the data processing by specific filters. Several approaches have been given in this regard by means of appropriate sensors as video cameras, infrared sensors, ultrasonic sensors and laser scanners. The step (ii) in the navigation strategy is associated with filtering techniques such as Kalman filters [1–3], Bayesian filters [4–6], or particle filters (PFs) [4,5,7].

Since our paper uses the concept of virtual sensor that is inspired from the PF approach, the analysis of the state-of-the-art on sensor fusion techniques in MR localization problems is focused as

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http://dx.doi.org/10.1016/j.robot.2014.09.034
0921-8890/

follows on laser scanners combined with PFs, but other sensors and sensor fusion techniques will be considered as well. The occupancy grid concept is applied in [8] to perception; a sensor-based map is derived using a probabilistic sensor model. The recognition of land marks using a laser scanner is given in [9]; the MR pose is estimated by detecting the break points in the acquired data set. A three layers (modules) MR navigation system is proposed in [10]; the layers perform the localization by the Iterative Closest Points using a 3D laser scanner, the obstacle avoiding behavior and the target point navigation control loop, and they solve the Simultaneous Localization And Mapping (SLAM) problem. The localization of dynamic targets is treated in [11] by a 2D laser scanner, which is proved to be more robust in comparison with computer vision techniques. The tracking of moving objects is carried out in [12] by movement detections algorithms that employ Kalman filters and laser scanners. Several experiments are conducted in [13] in order to explore the links between the laser sensor accuracy and the SLAM. Map designs with segment lines constructed on laser scanner measured points are suggested in [14] to model the objects including obstacles with a minimum number of lines using density based clustering. Laser scanner and wireless channel measurements are used in [15] to achieve map building and obstacles recognition; a probabilistic approach to wireless-based mapping is formulated. The analysis of PF approaches carried out in [16] outlines that assumptions on the state-space and on the noise distribution are not required. The PFs have proved to be successful in MR localization as shown in [17], where the FastSLAM algorithm is proposed; the algorithm employs the PF approach to perform a logarithmic scale with the number of the map landmarks, and less demanding computation time is obtained. A simultaneous mobile robot localization and people tracking approach is presented in [18]; the approach is based on a conditional PF that uses a high distribution for people locations, which is conditioned by a small distribution of the MR pose. PF approaches are involved in [19] in the localization and mapping of multiple robots. Dynamical environments are mapped in [20] using a combination of PFs and hidden Markov models.

The above analysis on the state-of-the-art highlights that PFs combined with laser scanners are widely used in the localization of MRs and pedestrians in dynamical environments. This combination has proved to be successful in the current research trend focused on the development of efficient algorithms. These algorithms are embedded in many control strategies. The current control strategies include optimal control [21–25], sliding mode control [26–28], stable nonlinear control [29], fuzzy logic and control [30–33], neural networks [34,35], adaptive control [36,37], repetitive and iterative learning control [38,39].

This paper offers a new pose estimation algorithm, which computes the difference between the MR desired pose and the MR current pose using the difference between the MR sensor reading (i.e., the reading of the real-world sensor), and the reading of a virtual (i.e., simulated or experimental) sensor that describes the actual desired pose. In this context, a sensor denotes any type of scene measurement and environmental data acquisition system. The simulated sensors are used to acquire virtual data from the reconstructed environment map, stored in the MR memory. The information perceived by the virtual sensors is further compared with the actual real-world measurement obtained from the real sensor. The notion of virtual is used in this paper as a synonym of simulated, i.e., computed offline in an abstract environment. A pose estimation algorithm is proposed in the framework of this approach. Therefore, our approach is a reconciliation between two sources of information, namely the desired trajectory is expressed as a collection of sensor particles readings.

The odometry can be applied to obtain the posture by generally measuring the rotating angles of the MR's driving wheels. The odometry-based algorithms are considered to be fast, but they use the results of measurements that can be affected by slippages due to the possible low quality of the sensors. Our approach is based on the virtual sensor that uses the result of a simulation. In other words, the desired posture is imposed and the measurements corresponding to these postures are simulated.

Our approach is important because it offers the following advantages in comparison with other current approaches reported in the literature [16–20]:

- It offers the reduction of the computation time required for localization within the reconstructed environment map.
- The pose estimation algorithm is organized as a control algorithm in a conventional control loop. In this regard it can benefit from the specific features related to robotic navigation problems viewed as control problems from the performance specifications point of view.

The combination of these two advantages leads to a low-cost navigation strategy with enhanced performance given by the new pose estimation algorithm. This strategy can be inserted in robot control structures and algorithms.

The rest of the paper has the following structure: the pose estimation problem is stated mathematically in Section 2. Our pose estimation algorithm is described in Section 3. Simulation and experimental results are given in Section 4. The conclusions are discussed in Section 5.

2. Problem statement

A set of assumptions is defined before going into the mathematical description of the problem set forth. Firstly, the navigation domain, or map, has to be known, or reconstructed, while the virtual population of sensor particles is simulated. The MR pose is derived from the comparison between the simulated sensors and the actual observations. Secondly, the sensors do not measure directly the MR pose, but a particular interaction with the environment. For example, if a laser scanner is used for measurements, the observations depict the length of each reflected light beam associated with a firing angle. Thirdly, the desired trajectory of the MR is defined as a successive set of poses. The two characteristics of PF approaches, which are actually correlated, the need of simulation of a virtual population of sensors and the difference between the information structure of the desired trajectory and the sensor measurements, require a high computation time.

The estimator proposed in this paper computes the MR pose in terms of the comparison of two data sets. The first data set is the MR sensor reading and the second data set is the reading of the virtual (simulated) sensor. The problem to be solved is the calculation of the MR pose using the two data sets, that is, data from the real measurements and data from the virtual sensor. The difference between the two poses is expressed in pose coordinates.

The firing angle α_i is the angle between the laser beam and the central axis of the sensor, and this central axis is in our case the same as the central axis of the MR as shown in Fig. 1. The distance between the sensor and a target point is ρ_i, and the target point is the intersection of the laser beam with an object in the environment, as shown in the sensor measurement setup presented in Fig. 1.

Using the notations $\alpha_{\min}$ for the minimum measured firing angle, $\alpha_{\max}$ for the maximum measured firing angle and Δ_α for the sensor angular resolution, with these three parameters fixed and given by the sensor manufacturer, and the notation n for the number of measured positions, we define the following $2 \times n$ sensor reading matrix M:

$$M = \begin{bmatrix} \rho_1 & \cdots & \rho_i & \cdots & \rho_n \\ \alpha_1 & \cdots & \alpha_i & \cdots & \alpha_n \end{bmatrix}. \quad (1)$$

The first row in M denotes the distance between the current sensor and the target point $\rho_i,\ i = 1 \ldots n$, and the second row gives the