Information Fusion 12 (2011) 58–69

Contents lists available at ScienceDirect

Information Fusion

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

Grid-based localization and local mapping with moving object detection and tracking

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ARTICLE INFO

Article history:
Received 31 July 2007
Received in revised form 24 July 2009
Accepted 7 January 2010
Available online 2 February 2010

Keywords:
Occupancy grid
Simultaneous localization and mapping
Moving object detection
Multiple object tracking
Interacting Multiple Model
Laser radar data fusion

ABSTRACT

We present a real-time algorithm for simultaneous localization and local mapping (local SLAM) with detection and tracking of moving objects (DATMO) in dynamic outdoor environments from a moving vehicle equipped with a laser scanner, short-range radars and odometry. To correct the vehicle odometry we introduce a new fast implementation of incremental scan matching method that can work reliably in dynamic outdoor environments. After obtaining a good vehicle localization, the map surrounding of the vehicle is updated incrementally and moving objects are detected without a priori knowledge of the targets. Detected moving objects are finally tracked by a Multiple Hypothesis Tracker (MHT) coupled with an adaptive Interacting Multiple Model (IMM) filter. The experimental results on datasets collected from different scenarios such as: urban streets, country roads and highways demonstrate the efficiency of the proposed algorithm.

1. Introduction

Perceiving or understanding the environment surrounding of a vehicle is a very important step in driving assistant systems or autonomous vehicles. The task involves both simultaneous localization and mapping (SLAM) and detection and tracking of moving objects (DATMO). While SLAM provides the vehicle with a map of static parts of the environment as well as its location in the map, DATMO allows the vehicle being aware of dynamic entities around, tracking them and predicting their future behaviors. It is believed that if we are able to accomplish both SLAM and DATMO reliably in real time, we can detect critical situations to warn the driver in advance and this will certainly improve driving safety and prevent traffic accidents.

In the literature, SLAM and DATMO have been attracted considerable research works [1–3] and they also are essential parts of the perception modules in driverless cars [4,5] winning the recent series of DARPA Grand Challenge competitions.[1] However, for highly dynamic outdoor scenarios like in crowded urban streets, there still remains many open questions. These include, how to represent the vehicle environment, how to obtain a precise location of the vehicle in presence of dynamic entities, and how to differentiate moving objects and stationary objects as well as how to track moving objects reliably over time.

In this context, we designed and developed a generic perception architecture addressing these problems focusing on outdoor dynamic environments [6]. The architecture (Fig. 1) is comprised of two main parts: the first part where the map of vehicle environment is constructed and dynamic objects are identified; the second part where detected moving objects are verified and tracked.

In the first part of the architecture, to model the environment surrounding the vehicle, we employ the occupancy grid framework proposed by Elfes [7]. In order to perform mapping or modeling the environment from a moving vehicle, generally a precise vehicle localization is necessary. To correct vehicle locations from odometry, we introduce a new fast laser-based incremental localization method that can work reliably in dynamic environments. When good vehicle locations are estimated, by integrating laser measurements we are able to build a consistent grid map surrounding of the vehicle. And when new laser measurements are coming, dynamic objects can be then detected based on their discrepancies with the constructed grid map. Related results have been presented in our previous publication [8] and in this paper we employ the radar data combined with object detection results from laser data in order to obtain a more robust performance.

In the second part, previously detected moving objects in the vehicle environment are passed to the tracking process. Since some objects may be occluded or not detected, some are false alarms, tracking helps to identify occluded objects, recognize false alarms and reduce missed detections. In general, the multiple object

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[1] www.darpa.mil/grandchallenge/index.asp.

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doi:10.1016/j.inffus.2010.01.004

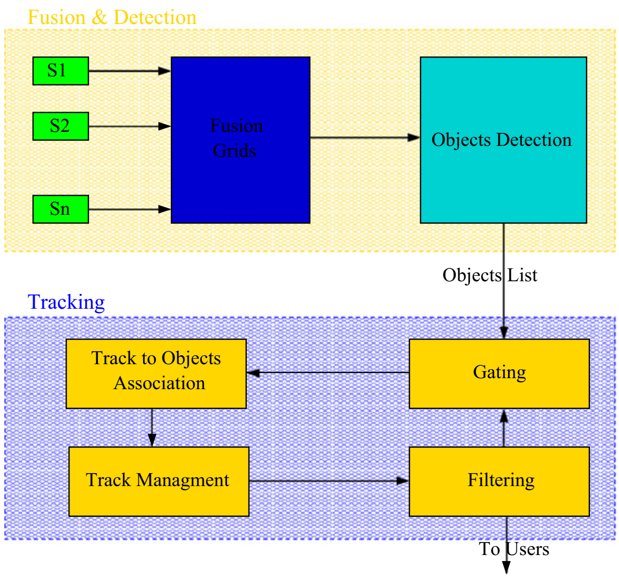

Fig. 1. Architecture of the perception system.

tracking problem is complex: it involves the definition of filtering methods as well as the data association methods and maintenance of the list of objects currently present in the environment [9]. Regarding the filtering techniques, Kalman filters [10] and particle filters [11] are mostly used. These filters require the definition of a specific dynamic model of tracked objects. However, defining a suitable motion model is not trivial and Interacting Multiple Models (IMM) [12] have been successfully applied in practice. In our previous works [13], we have developed a fast method to adapt on-line IMM according to trajectories of detected objects and so that we obtain a suitable and robust tracker. To deal with the data association and track maintenance problem, we extend our approach to multiple objects tracking using the Multiple Hypothesis Tracking (MHT) approach [14,15].

1.1. Experimental platform

The proposed algorithm for solving SLAM and DATMO is tested on data collected from the Daimler demonstrator car equipped with a camera, two short-range radars and a laser scanner (Fig. 2). The laser scanner can detect obstacles at a range of 70 m under a field of view of 160°. It provides raw data as a list of impacts with an angular resolution of 1°. The radars detect targets up to 30 m within a field of view of 80° and return pre-filtered data as a list of "dot" objects with their estimated positions and Doppler velocities (Fig. 2 right). In addition, vehicle odometry information such as velocity and yaw rate are provided. The measurement cycle time of the sensor system is 40 ms.

In our implementation, laser data is used to perform mapping as well as detection and tracking of moving objects. Radar data is then fused with laser data to confirm the results obtained by laser data in order to give a more reliable results on detection and tracking objects in the radar field of view. Images from camera are only for visualization purpose.

2. Related work

Before discussing in detail our approach to problems of SLAM and DATMO, it is interesting to recall some notable works in the domain.

One of the first works on SLAM with DATMO was that of Prassler's group [1]. They described a first system on automated wheelchairs for static and dynamic object detection, moving object tracking and obstacle avoidance. The environment is represented by a time stamp grid map that provide a interesting way to detect and track moving objects. However, this method rely completely on odometry information with suppose that the odometry is ideal and it cannot detect objects moving slowly. Although the proposed solution is not really complete, it identified the need of both SLAM and DATMO for automated mobile systems.

Hähnel et al. in [2] used a feature-based approach to identify pedestrians from laser range scans and use Joint Probabilistic Data Association particles filters [16] to track moving pedestrians indoor. The corresponding measurements are then filtered out and classical scan registration and mapping techniques in static environment are used. However, this approach is not able to work in outdoor environment where various dynamic objects cannot be described by simple features.

Wang [3] developed the first outdoor real-time system solving both SLAM and DATMO simultaneously for urban environments from a ground vehicle. To correct the vehicle odometry he used an ICP-based matching scan method and moving objects are detected based on a simple geometric analysis. He also presented a mathematical framework integrating both SLAM and DATMO and showed that they can be mutually beneficial from each other. The idea is that the results of SLAM will be more accurate if moving objects can be filtered out and thanks to a more accurate pose estimation and a better map from SLAM, DATMO can detect and track moving objects more reliably.

Recently, in the DARPA Urban Challenge competition, we have been witnessed significant advances in efforts of building autonomous vehicles. It is shown that driverless cars, for instance: Boss [5] and Junior [4], are capable of operating autonomously and safely through urban-alike environments. However, testing scenarios for the competition contains only vehicles as moving objects which limits their approaches to be only able to detect and track

Fig. 2. Left: the Daimler demonstrator car. Right: an example of sensor data, laser measurements are displayed in small red dots and radar measurements displayed as bigger dots. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)