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Map Aided Localization and vehicle guidance using an active landmark search

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ABSTRACT

In this paper, we address the problem of robust data association in active search for simultaneous vehicle localization and path tracking. We show that the classical landmarks active search approach, which consists in focusing processing resources on windows-of-interest where landmarks are supposed to be, is weak when faced with wrong data association. In some cases, the system will break down and will not be able to estimate the vehicle's pose. This is a consequence of the focusing principle of this method. We propose a probabilistic framework to manage all matching hypotheses that incorporate a confidence level regarding the estimation of the vehicle's pose that will evolve as a function of the probability that a right data association has been made. The system can also undo a previously made matching hypothesis when the confidence level on the vehicle's pose estimation is too low. We illustrate the practicality of this approach by guiding an experimental vehicle in a real outdoor environment.

1. Introduction

Recent years have witnessed growing interest in autonomous robots: several industrial and scientific research projects are aimed at obtaining increased autonomy of mobile robots, in order to reduce the intervention of human operators. For instance, such systems are used for tourist itineraries, cleaning vehicles, farm vehicles guidance, etc. A number of guidance devices have already been developed (for example in agricultural context, CLAAS [1], John Deere [2], see also [3]). However, these systems have been designed to perform specific tasks (harvesting [1], achieving perfectly straight runs [2], and so on). In this paper, we are interested in vehicle localization dedicated to automatic guidance. The development of this autonomous robot relies on a Map Aided Localization (MAL) approach. The map is supplied to the system beforehand. It is obvious that environment perception is a key to an efficient localization system. Several researchers have addressed this problem using a range-finder (see, e.g., [4–7]), others using a camera (see, e.g., [8–10]) or both (see, e.g., [11]). However, one sensor can only perceive a small part of the environment and in most cases, it measures a single physical component (e.g. luminance for a camera). A multi-sensor approach is a way to improve environment perception: a wider and more complete area can be perceived from a given position. Consequently, it will be possible to observe a large diversity of landmarks along the trajectory to be followed. This permits use of the localization system in wider environments and with better precision or accuracy.

As the goal of the system is to guide the vehicle accurately, accurate localization is necessary, but most of all a reliable position estimation is required. Effectively, the system is based on a MAL approach. In those systems, the major challenge concerns the problem of data association (see, e.g., [12,13]): this means performing a matching between a landmark (an item of information on the map) and a feature extracted from sensor data (an observation). Two kinds of matching can lead to wrong data associations: a matching with another landmark and a matching with a spurious measurement. Several years ago, an original solution appeared to reduce this problem. This method, also called active search, was introduced by Fox [14]. Used then by Davison [10], this approach consists in searching for the landmark in a small part of the sensor data. This region of interest (ROI) is defined in such a way that the landmark is inevitably inside this region when the vehicle's state estimation is right. It is composed using the estimated vehicle position, its uncertainty area and the landmark position in the map (Fig. 1). Thus, as the feature detection algorithm searches for the landmark in a ROI, the signal to noise ratio is increased and the system has a greater probability of recognizing the landmark sought. In addition, it permits the suppression of all the outliers responsible for numerous difficulties in MAL approaches. In the end, the detection returned by the feature detection algorithm is associated with the landmark sought and the vehicle's state is updated. This data association in the active search approach is a $1 \times n$ problem. It thus consists in making the association between the landmark

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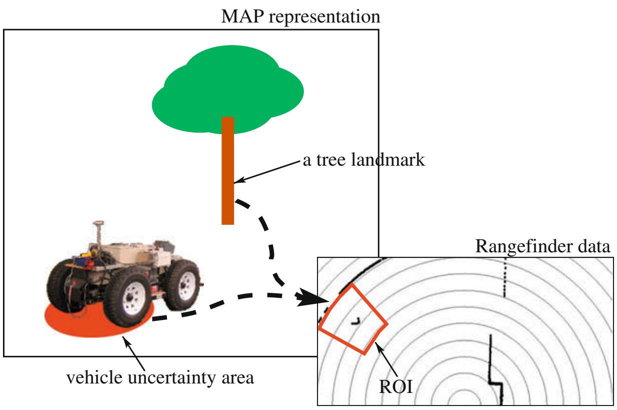

Fig. 1. Illustration of the active search method representing the ROI of a tree landmark in the range-finder data.

sought and n possible results of the feature detection algorithm. In this paper, the feature detection algorithms return a single result: the one that best matches the landmark sought. However, the active search method has an important drawback. Since the ROI is based on the estimated vehicle position, a single wrong data association can lead to a divergence and to a failure state for the system. Unfortunately, little or no attention has been given to this problem for Map Aided Localization systems using an active search method. However, the data association problem is widely investigated in mapping approaches [15–17] where several alternatives have been proposed. In Simultaneous Localization and Map building (SLAM), an efficient and effective data-association scheme must establish the difference amongst spurious measurements, new measurements, and missed detections in addition to the basic function of associating currently available features with measurements. The most widely employed data-association method in SLAM is the nearest neighbor (NN) data-association algorithm [18]. It associates a feature with the nearest observation in a chosen validation region based on a particular distance measure, which is usually the Mahalanobis distance. Although it is quite easy to implement, its performance is poor. Further, data-association decisions are hard, meaning that decisions once made cannot be reversed. In the Graph-SLAM approach [19] (an offline SLAM method), the data association is handled by means of a data association tree where an iterative greedy search algorithm is performed over all data association variables. Thus, this approach suggests propagating all possible hypotheses and using the most probable one. Because of the greedy search, this approach is unsuitable for embedded systems.

The multiple hypotheses tracking (MHT) method is the most structured and optimal approach employed for multi-target tracking and for data-association decisions. In this algorithm, decisions are delayed until a number of additional measurements are received so that incorrect associations made in the past can be corrected if necessary. For example, Multiple hypotheses tracking (MHT) defers the association decisions in conflicting situations and forms a tree of all probable association hypotheses, which are then propagated through subsequent iterations in the belief that new information will most likely resolve conflicts, if any. Therefore, MHT is capable of dealing with missed detections, spurious measurements, and track initiation. Nieto [12] proposes an implementation of this algorithm called FastSLAM for SLAM approaches using a particle filter. However, the major drawback of MHT is that the hypothesis tree grows exponentially in time, requiring exponential memory and computational resources, making it impracticable and unsuitable for real-time implementation in an automatic guidance system.

Other approaches suggest efficient data-association algorithms for clutter or spurious measurements. They are based on the use of a larger amount of information to resolve ambiguities and make consistent matchings. The first, proposed by Wijesoma [20], consists in using several measurement frames. The second, proposed by Neira [13], uses several feature-observation associations and shows that all associations should be considered together.

Due to the fact that the system is dedicated to controlling the vehicle, it must use a localization approach based on an efficient, real-time data-association algorithm. For this reason, a mono-modal probability density function for the vehicle's pose estimation was chosen to propagate only one vehicle position hypothesis insuring the stability of the control law and the optimization of computing time. The hypothesis to be propagated will be evaluated on line allowing the possibility of revising data associations made previously. This process, essential for robustness in the presence of spurious measurements, represents an alternative to a MHT approach.

In this paper, we study the problem of data association with an active search method. This approach uses a cognitive process to detect landmarks and to construct a matching hypothesis. This cognitive process is based on a perceptive triplet notion represented by a landmark, a sensor and a detection algorithm able to extract the landmark in the sensor data. Thus, in order to reduce the risk of wrong data associations, our system will have to select the triplet to run that displays the greatest probability of leading to a right data association.

2. Vehicle localization principle

2.1. General principle

The proposed autonomous vehicle guidance system estimates the vehicle's pose periodically. After this task, it steers the front wheels and fine-tunes the vehicle's speed in order to track the trajectory previously recorded or defined (Fig. 2).

To locate the vehicle, several sensors were fixed on the vehicle. First of all, a low-cost GPS enables global location of the vehicle with 3m accuracy. Then, some exteroceptive sensors were incorporated (two sensors for our application: a camera and a range-finder) and some proprioceptive sensors (odometer and gyrometer) were used to provide a relative localization.

This localization system belongs to the Map Aided Localization family and uses a Geographical Information System (GIS) to identify all landmarks of the environment. Each landmark (e.g., a tree, a wall, a lane side, etc.) is located on the map and characterized by certain parameters: name, type, etc. From the vehicle's pose, the localization system chooses a landmark to observe and defines a ROI in the sensor data where the landmark is supposed to belong. It then makes the detection using the exteroceptive sensor and performs a data association between the selected landmark and the detection (Fig. 3).

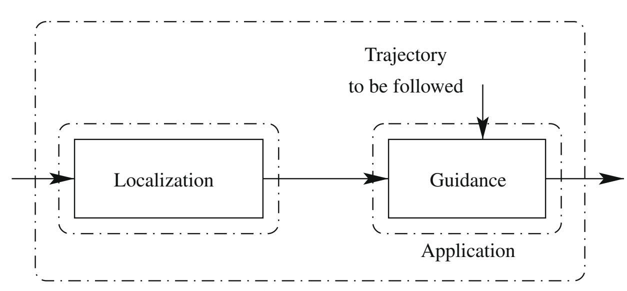

Fig. 2. Illustration of our system: we only discuss the localization part in this paper.