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On the behaviour of low cost laser scanners in HW/SW particle filter SLAM applications

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HIGHLIGHTS

- A particle filter SLAM methodology in hardware is proposed to overcome the particle filter low speed problems.
- The proposed system is validated on a low cost and standard laser scanner sensors.
- Possible use of low cost laser scanner for different robotics applications is confirmed.

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ABSTRACT

Particle filters (PFs) are computationally intensive sequential Monte Carlo estimation methods with applications in the field of mobile robotics for performing tasks such as tracking, simultaneous localization and mapping (SLAM) and navigation, by dealing with the uncertainties and/or noise generated by the sensors as well as with the intrinsic uncertainties of the environment. However, the application of PFs with an important number of particles has traditionally been difficult to implement in real-time applications due to the huge number of operations they require. This work presents a hardware implementation on FPGA (field programmable gate arrays) of a PF applied to SLAM which aims to accelerate the execution time of the PF algorithm with moderate resource. The presented system is evaluated for different sensors including a low cost Neato XV-11 laser scanner sensor. First the system is validated by post processing data provided by a realistic simulation of a differential robot, equipped with a hacked Neato XV-11 laser scanner, that navigates in the Robot@Factory competition maze. The robot was simulated using SimTwo, which is a realistic simulation software that can support several types of robots. The simulator provides the robot ground truth, odometry and the laser scanner data. Then the proposed solution is further validated on standard laser scanner sensors in complex environments. The results achieved from this study confirmed the possible use of low cost laser scanner for different robotics applications which benefits in several aspects due to its cost and the increased speed provided by the SLAM algorithm running on FPGA.

1. Introduction

The ability of simultaneously localizing and building the spatial model of an environment is a key issue to achieve intelligent navigation for mobile robots and has several applications in the field of mobile robotics [1,2]. Such ability is known as simultaneous localization and mapping (SLAM) [3–5]. SLAM is the concept of localizing the robot while simultaneously generating a map of the environment, and then using the map in subsequent localization steps. For building a spatial model of a robot's environment, modern mobile robots rely on sensors such as laser range finders (LRF), cameras, and infrared technology.

LRF are one of the most popular used sensors for performing SLAM [6]. However, the high price tag in the most commonly used laser scanners, SICK LMS 200 and Hokuyo URG-04LX [7], has been

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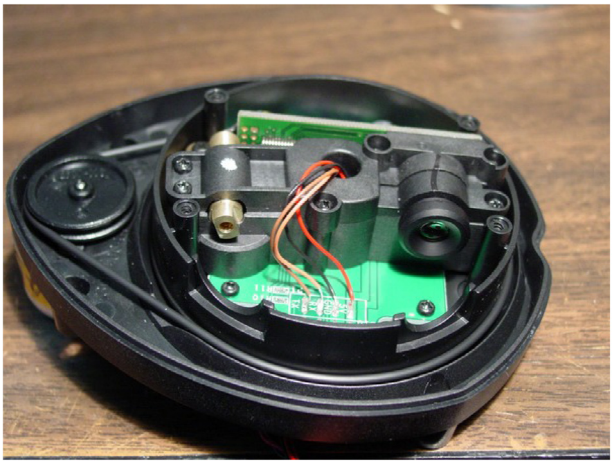

Fig. 1. Neato XV-11.

a major drawback for many hobbyist and educational robotics practitioners which results in the need for alternative low cost laser scanners. A domestic vacuum cleaner robot, the Neato XV-11 [8] includes an alternative low cost 360 degree laser scanner (Fig. 1) with a one degree resolution [9]. The laser scanner (Fig. 1) allows robotics practitioners to use it in their projects.

Also for the success of SLAM applications that uses low cost laser scanners, the use of robust and accurate estimation methods is crucial for optimizing the high uncertainties and/or noise generated by the sensors. As such, existing SLAM algorithms involve complex and intensive computations for accommodating the errors from sensors and the robot's motion as well. One of the most common and successful filters for SLAM are the particle filters. Particle filters, are sequential Monte Carlo and recursive Bayesian estimation methods which provide accurate estimations and addresses systems that are non-linear and non-Gaussian sensor models [10,11]. However, the disadvantages of the complex algorithm architecture, enormous computations and the low speed solutions and physical cost of implementing the algorithm place a limitation for the SLAM application in most real time robotics applications. To overcome such limitation, an efficient implementation of the particle filter based SLAM algorithm can be achieved using flexible hardware/software platforms, such as field programmable gate arrays (FPGA).

In our previous work [12] presented at the *ROBOT'2015—Second Iberian Robotics Conference*, preliminary results were achieved for addressing some of the challenges in the implementation of the particle filter SLAM on an FPGA based on the Neato XV-11 laser scanner. By using a SimTwo [13] realistic simulations software that supports several types of robots, the behavior of the laser scanner is first mimicked based on its model in a virtual simulation environment. Then a simulation is performed by navigating a robot equipped with a hacked Neato XV-11 laser scanner in a Robot@Factory competition maze [14]. Based on the actuator [15] and laser scanner models [16] used in the simulator, the simulation finally provides the robot odometry and laser scanner data information for performing SLAM on the FPGA.

Working on that, this paper presents further improvements and results for comparing and validating the proposed system under complex environments based on real datasets obtained from other types of laser scanners as well. The main contributions of this work are:

- The verification on the possible use of a low cost laser scanner for robotic applications based on an FPGA implementation.
- A simple and compact map representation without introducing additional complexity to the particle filter SLAM is proposed. It enables to maintain more particles with less memory, and avoids the heavy time cost at the resampling step when the entire map has to be copied over from an old particle set to a new one.
- An observation model is proposed which takes into account the error in the measurement and matching between laser scans and map data.

The rest of the paper is organized as follows. Section 2 presents a literature review on the acceleration of particle filter algorithms for different applications focusing in particular to SLAM. In Section 3 a general background information on particle filtering algorithm and a description to the application of particle filter to the SLAM problem is presented. Section 4 is a discussion about the probabilistic sensor measurement model and the occupancy grid map representation of the robots environment used in the implementation of the algorithm that simultaneously builds the map. In Section 5 the explanation on the FPGA implementation is provided. Section 6 presents the performance evaluation of the particle filter applied to the SLAM problem based on the different laser scanners. Finally Section 7 provides the conclusions of this work.

2. Related work

Particle filters are one of the effective means for solving the SLAM problem and are the preferred choice in the robotics community. However, the intensive computations required by particle filter algorithms result in a high computational complexity in real-time SLAM applications. As a result, for real-time SLAM application acceleration of the underlying particle filters computations is important. In this sense, there exist several studies aimed at accelerating the computations in particle filter algorithms and make them amenable to real time problems. These studies, in general, can be classified under two major topics:

- Algorithmic modifications and adaptive particle filtering.
- Hardware implementations to accelerate the intensive computations based on an FPGA and/or other hardware platforms.

2.1. Algorithmic modifications and adaptive particle filtering approaches

Due to the complexity of the particle filters dependency on the number of particles used for the estimation, several attempts with the adaptive particle filter approach have been considered in the literature. The adaptive particle filter approach aims to increase the efficiency of the particle filter by adapting the size of the particle sets during the estimation process rather than using a fixed particle size.

The work presented in [17], for example, uses a Kullback–Leibler distance (KLD) sampling method that helps to choose a small number of particles if the density is focused on a small part of the state space, and a large number of particles if the state uncertainty is large. The investigations on the efficiency of this approach to the particle filter was conducted for a mobile robot localization problem. An improvement to the KLD sampling is conducted in [18], by adjusting the variance and gradient data to generate particles near the high likelihood region. A similar study in [19] uses the adaptive particle filter approach in mobile robot localization application for reducing the run-time computational complexity in particle filter. With a similar reasoning, the study in [20] suggested to vary adaptively the number of particles based on the estimation quality for reducing the complexity in particle filter.

Besides the adaptive particle size approach for handling the real time computational challenges with particle filters, there have been also studies aimed at modifying the basic particle filter algorithm to achieve the same objective. For example, the work