Distributed Sensing for Cooperative Robotics

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Abstract

This document presents an ongoing research in distributed sensing for cooperative robotics. The main goal of the research is to develop a sensor architecture that allows each member of a group of cooperating robots to use the sensor data of its teammates in order to improve the execution of its own part of the task. The first situation to be tackled is the localization problem of a group of robots carrying an object. Preliminary investigations show that distributed sensing can improve the robots and the object localization.

1 Introduction

Sensing is one of the fundamental issues of robotic systems. It is responsible for providing information that allows robots to self localize and to interact with the environment. A robotic sensing system may be as simple as a single sensor or composed by multiple sensors, of different sensing modalities, with different characteristics, whose data are processed and combined to provide information that is more accurate and more robust when compared to a single sensor alone. This technique, known as sensor fusion, has been used in robotics research mainly due to the nature of typical localization and manipulation tasks, and to combine the information of different sensors present in most of the commercial robots.

Distributed and cooperative robotics has been the focus of attention of many groups in recent years. The idea of using a team of robots (in general mobile robots) instead of a single one to execute a task, came from the necessity of accomplishing a task that is too difficult or too complex for a single robot. In other situations to use a group of simple robots can be more efficient, easier, less expensive, more flexible and more fault-tolerant than having a single powerful, highly specialized robot for each task.

Following this trend of flexibility and versatility by distribution, a new research field called "Distributed Sensing" has arisen. It is based on two key ideas: 1) sensor fusion can improve the robot knowledge about the world and 2) multiple mobile robots endows more flexibility in the execution of tasks. In general, with Distributed Sensing or "Distributed Sensor Fusion" information is extracted from data of several sensors of several sensing modalities, that are scattered in the working area. This definition can be further expanded to include active sensors that can move and interact, and, thus, modify their environment. Next, we discuss previous work related to sensor fusion and cooperative robots.

2 Related Work

A considerable number of recent papers have considered different aspects of data integration of multiple sensors. This multi-sensor data fusion refers to any stage of the integration process where a combination of different sources of sensor information is given. In [Abidi and Gonzales, 1992], the authors provide a general exposition of sensor fusion methods. Specifically in the area of mobile robot sensor fusion, the work by [Kam et al., 1997] is an interesting survey of the techniques and tools used to tackle the problem. Those tools include Kalman Filtering [Kalman, 1960], rule based techniques and behavior based techniques. Other approaches came from the information theory, such as Dempster-Shafer, fuzzy logic and neural networks. These techniques are applied in several other works such as [Kobayashi et al., 1998] that proposes a method to localize a mobile robot based on fusing data from global and local sensors using Kalman Filtering tuned by a fuzzy system. The Kalman Filter is also used in [Roumeliotis and Bekey, 2000], one of the first articles to consider distributed and mobile sensor fusion in order to improve the localization of a group of mobile robots.

In cooperative robotics there is a large variety of recent articles. Among them, the work of [Cao et al., 1997] and later of [Parker, 2000] are important surveys that describe the main research directions of the area. The research in cooperative robots can vary much depending on the task to be executed by the group of robots. Several works were published with different approaches such as [Sugar and Kumar, 1999] that examines the process of multiple robots handling objects, [Goldberg and Mataric, 1999] where a multi-robot team is used in collection tasks and [Hirata and Kosuge, 2000] where a group of robots is used to help humans carrying objects. A very interesting project in cooperative robotics is shown in [Budenske et al., 2000]. In this paper, a large robot deploys multiple small robots that act as distributed mobile sensors, that send data to and receive instructions from the "mother robot". Those robots are used in reconnaissance and surveillance missions.

Although there are many papers related to cooperative robotics, our focus is mainly on those where distributed or mobile sensors are used. An important work by [Rus and Kotay, 1998] points the main advantages of a mobile sensor in a cooperative task. In that work, the authors use a mobile sensor platform to provide flexibility in information gathering to improve the task of furniture placement by two mobile robots. In [Chaimowicz et al., 2001], an architecture to allow robot cooperation is described and implemented. In that architecture, a mobile sensor is considered as a member of the group, and as such may become the group leader. Similarly, in [Rus and Kotay, 1998] the authors use an extra mobile robot that has the special role of acting as a mobile and remote sensor.

We propose the use of information from sensors of any robot in the group by any other robot in the team. At the surface, this approach may look very similar to previous ones described before, but it is substantially distinct in the underlying architecture. In the first case, as described in [Chaimowicz et al., 2001] and [Alur et al., 2000], the robots in the group do not have access to sensor data of other teammates, but only receive processed information or commands based on sensor readings. In [Chaimowicz et al., 2001], for example, the mobile sensor becomes the leader when it decides that its data information becomes important to the group. As the other robots only have to follow the leader, the sensor information is not used directly in their control. The approach proposed here is closer related to the one presented in [Roumeliotis and Bekey, 2000] and [Stroupe et al., 2001]. In those cases each robot have access to their teammates sensor data (or some related information), and then it combines that information with the one coming from its own sensors. In those papers the robots use distributed sensing to improve self localization or target localization. In the next section the describe our approach in more detail.

3 Methodology

We propose that any robot in the team may use raw or unprocessed data from sensors mounted on any other robot of the team, in order to enable or improve the execution of cooperative tasks. At first, this cooperative task can vary from a simple convoying or localization mission to a more complicated object transportation and handling process. The main objective is to get away from any hierarchy, at least at the sensory level. To do this, each robot must broadcast its sensor data (or some combination thereof) to their teammates, and the robot, based on some predefined criteria, decide if the information received is relevant to the task at hand and thus should be considered.

Suppose, for instance, that a group of robots have to execute a task and, in order to do this they should localize themselves in an unknown environment. If each robot has an individual sensor fusion system and a vision-based pose estimation system, the localization of the group could be improved as follows: consider that robot "A" has an estimation of its localization by its own fusion system and it also knows its relative position to robot "B" by its vision system. By using the same set of information (localization and relative position) broadcasted by robot "B", robot "A" may improve its own localization. Since both robots have an estimation of their localization, the key idea is to combine the information based on their statistical measurement of "quality" also transmitted by the robots. This idea was shown to be very efficient in [Roumeliotis and Bekey, 2000] on a simulated situation with 3 mobile robots.

In our work, we propose to develop a sensing system architecture based on this idea, that can be generalized for a great variety of tasks and robots. Central to the tasks to be investigated, are those that demand tight cooperation. In those situations the task can not be accomplished by a single robot and require strong robot coordination in order to be completed. The cooperation model may include different types of robots on the ground, in the air and underwater, but equipped with a large variety of sensors.

4 Preliminary Investigation

Our first approach to study the proposed methodology consists in use a distributed sensor fusion to improve the localization of a group of robots in a tightly coupled task. The problem can be written as: "Given the fact that a group of two or more mobile robots are able to cooperate and to move carrying a rigid object around a unstructured environment, the problem consists in estimating precisely and in real time the object and robots global positioning based on the robots sensors and the kinematics of the movement". Since this problem is too generic the first situation to be studied can be stated as:

- The group is composed by two identical non-holonomic robots;
- The transported object is a rigid retangular box;
- The robots are equipped with sensors allowing the estimation of the relative box orientation;
- The individual robot localization is made only by encoders;
- The communication between the robots is fast and reliable;
- Both robots have the same processing capabilities.

A schematic of this situation can be seen in Figure 1.

The key idea to solve this problem is to consider that once the box positioning is well know, the robots positioning are also know (it is true since the robots are in contact with the box and have sensors to measure its relative position and orientation). With

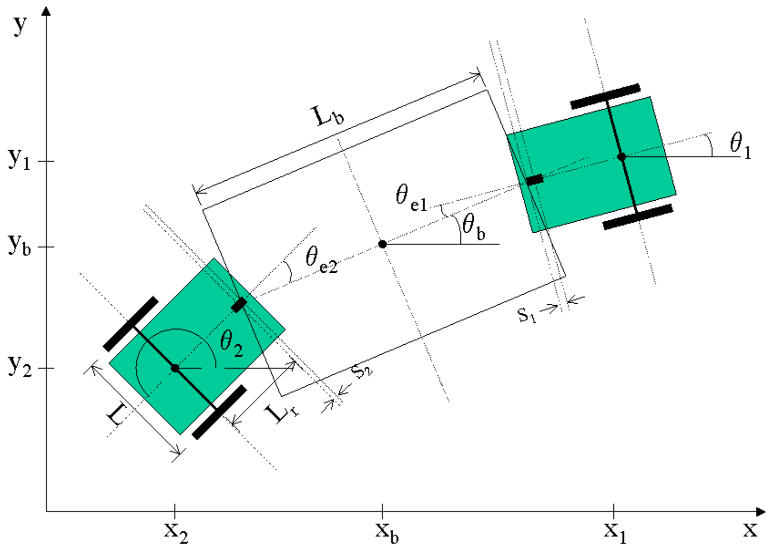

Figure 1: Two robots carrying a box.

this assumption, each robot uses its sensors in a local Kalman filter in order to estimate the box global positioning and exchange, in a predefined rate, the calculated information and the respective covariance. The information received is used as a common input in the local Kalman Filter. The whole system constituted by the two Kalman Filters (one for each robot) can be considered as a single one (related by the data covariance) whose characteristics must be investigated. The validation of this approach has been executed both in simulation and in real systems. The first real approach uses two Lego robots (Figure 2), with restricted processing and communication system, constructed specially to work in cooperative tasks. The construction of those robots is part of this work and its description was submitted to a national conference [Pereira et al., 2001]. The second stage of the validation step, to be carried out at the GRASP Laboratory from Pennsylvania University, will be executed using commercial robot platforms such as the one shown on the right in Figure 2.

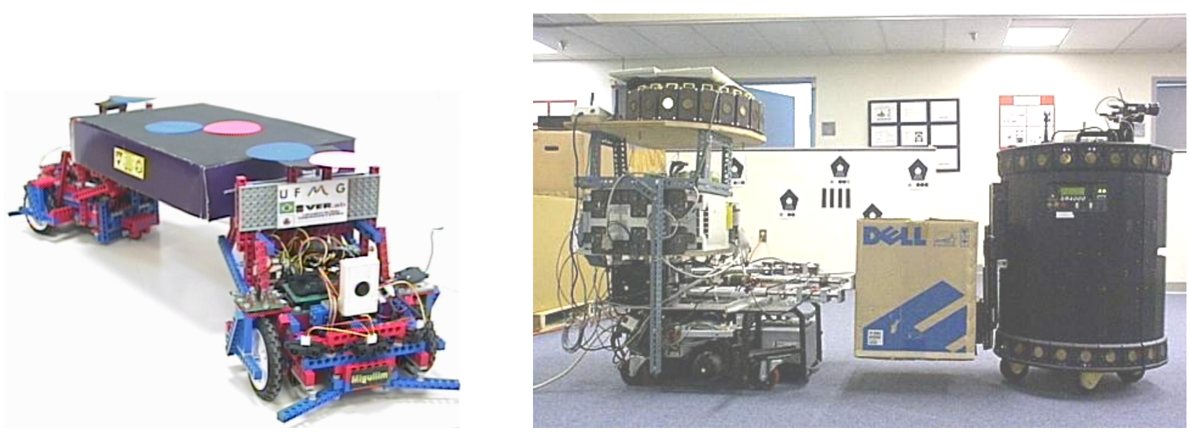

Figure 2: Robots carrying a box. On the left the Lego robots and on the right the commercial robots.

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