A DISTRIBUTED MULTI-ROBOT SENSING SYSTEM USING AN INFRARED LOCATION SYSTEM

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Abstract: Distributed sensing refers to measuring systems where, instead of one sensor, multiple sensors are spatially distributed to improve the robustness of the system, increase the relevancy of the measurements and cut costs, since smaller and less precise sensors are used. Spatially distributed sensors fuse their measurements into the same co-ordinates, which requires the relative positions of the sensors. In this paper we present a distributed multi-robot sensing system in which the relative poses (positions and orientations) of the robots are estimated using an infrared location system. The relative positions are estimated using intensity and bearing measurements of received infrared signals. The relative orientations are obtained by fusing the position estimates of the robots. The location system enables a group of robots to perform distributed and co-operative environment sensing by maintaining a given formation while the group measures distributions of light and a magnetic field, for example. In the experiments, a group of three robots moved and collected spatial information (i.e. illuminance and compass headings) from the given environment. The information was stored on grid maps that present illuminance and compass headings. The experiments demonstrated the feasibility of using the distributed multi-robot sensing system in mobile sensing applications.

1 INTRODUCTION

Distributed sensing (Brooks and Iyengar, 1998), (Catterall et al., 2003) refers to measuring systems where, instead of one sensor, multiple sensors are spatially distributed to improve the robustness of the system, increase the relevancy of the measurements and cut costs, since smaller and less precise sensors are used. In the robotic domain, distributed sensing enables multi-robot systems (MRS) to perform mapping and exploration (Sujan et al., 2004), allocate tasks among robots (Pagello et al., 2006), and plan paths and navigate in an unknown or partially unknown environment (Cai et al., 1996), for example.

Distributed sensing in an unknown enviroment benefits from knowing the relative locations of sensors. The relative locations enable the sensors to place their measurements into the same sensor-centric map. Autonomous sensing systems are able to use one sensor as an origin of the co-ordinates, while the other sensors measure the surrounding area. Such systems do not require an external infrastructure for positioning (GPS, WLAN, etc.). However, the measurement range of the relative location system must be sufficient to encompass the sensing area.

In this paper we present a distributed multi-robot sensing that uses an infrared location system (Kemppainen et al., 2006). The location system estimates the relative poses (positions and orientations) of the robots. Related systems have been presented that exploit several techniques, including laser range finders (Schneider and Wildermuth, 2004), (Montesano et al., 2004), (Howard et al., 2003),(Moors et al., 2003), ultrasonic TOF measurement (Shoval and Borenstein, 2001), (Grabowski et al., 2000) and vision (Montesano et al., 2005), (Spletzer et al., 2001), to locate and recognise other robots. A comparison of the infrared location system and related systems was discussed in (Kemppainen et al., 2006). We selected infrared sensors since they are small and capable of relative angle measurements between an emitter and receiver. In addition, infrared radiation

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does not reflect from walls and object surfaces as much as ultrasound. In relative angle measurements, the effects of multipath reflection would be crucial because of ambiguous angle estimates.

To demonstrate the distributed sensing system in mobile sensing applications, we conducted experiments where a group of three robots measured the distributions of illuminance and a magnetic field while maintaining a triangle formation.

2 INFRARED LOCATION SYSTEM

The infrared location system, originally presented in (Kemppainen et al., 2006), is a vital part of the multi-robot system (Haverinen et al., 2005) that enables the robots to maintain a given formation while sensing the environment. The key idea of the location system is to estimate the relative positions without data transmission between the robots. However, radio transmission is used to share estimates among the group in order to enable the robots to estimate their relative orientations.

The location system uses intensity and bearing measurements of received signals to estimate the locations of other robots in polar co-ordinates. By sharing these estimates among the group of robots, it is possible to also estimate their relative orientations. In addition, each robot is identified through different frequencies in the received signal.

Figure 1 presents the main components of the location system. A conical mirror reflects an emitted signal sideways into a unified zone, whereas beam collector collects signals from other robots. A servo system with a DC motor, Hall-effect sensors and discrete PID controller is used to rotate the beam collector at a constant angular velocity. The measurement range of the system is approximately five metres, giving the most accurate estimates for radial co-ordinates when the distance between two robots is in the range of [0.5; 2.5 m].

3 EXPERIMENTS

Experiments were conducted to demonstrate the feasibility of using the distributed multi-robot sensing system in mobile sensing applications. For example, co-operative mapping in an unknown environment requires moving platforms that are capable of measuring spatial information and estimating the relative positions of the robots. For our experiments, we

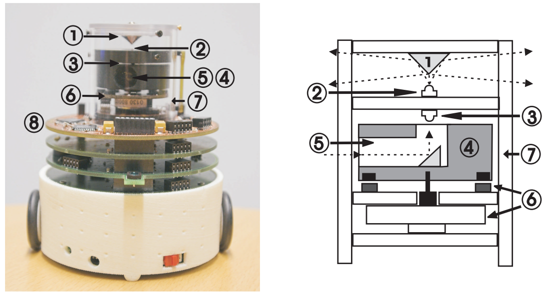

Figure 1: The actual system and the illustration of mechanics: 1) mirror, 2) emitter, 3) receiver, 4) beam collector, 5) aperture, 6) DC motor and Hall-effect-sensors, 7) see-through body, 8) control electronics.

implemented a distributed sensing system in which a group of three robots measured spatial information in a given environment.

3.1 Formation Control

Formation control enables a multi-robot system to measure spatial distributions while moving across the measurement area. The measurement range of the infrared location system is restricted to five metres, and to be able to fuse spatial measurements onto the same map, the multi-robot system is required to maintain limited relative distances. Formation control is required not only to limit the distance between the robots, but also to enable co-ordinated sensing in order to reduce mapping time.

In our experiments one of the robots acted as a leader and the other two followed the leader. Together they constituted a right-angle triangular formation where the distance between the leader and the followers was 1.5 metres. For each following robot, formation control consisted of two P controllers; one for translational and the other for rotational speed control. The infrared location system updated the relative pose measurements approximately every three seconds, giving the relative poses of the following robots in the leader's co-ordinates. Fig. 2 presents how errors in the relative orientation and position were used in the rotational and translational speed controllers (respectively).

The control cycle length in each controller was 200 ms, while the location system updated poses only once every three seconds. In order to update pose errors in each control cycle, each robot estimated their relative movements using odometer readings. In the experiments, the odometer readings enabled the formation to be driven at a 10 cm/s translational velocity.

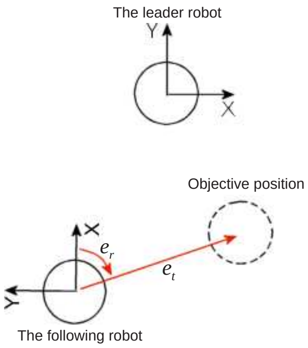

Figure 2: The pose of the following robot relative to the leader is estimated and used to control the robot to the objective position. P controllers use rotation e_r and translation e_t errors to control rotational and translational speeds of the robot.

3.2 Spatial Measurements

In the experiments, three robots measured distributions of light and a magnetic field over a given environment, producing maps of illuminance and compass headings. Fig. 3 presents the trajectories of the robots while moving and measuring the environment. The leader was driven from position (50 cm, -250 cm) to position (20 cm, 450 cm), while the group maintained a triangular formation. Spatial measurements were stored on grid maps presented in the leader's co-ordinates.

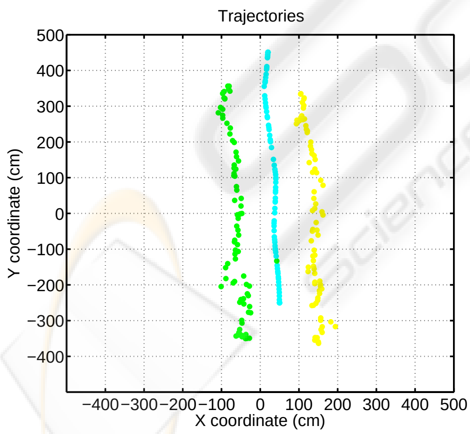

Figure 3: Trajectories in global coordinates.

Fig. 4 presents a grid map of illuminance, where the highest intensity is depicted with white colour and the lowest intensity, for the cells not visited, with black colour. This gives spatial information about the distribution of light in the given environment. The cells with the highest intensities are close to lights and the cells with the smallest intensities are shadowed areas close to chairs, plants and walls.

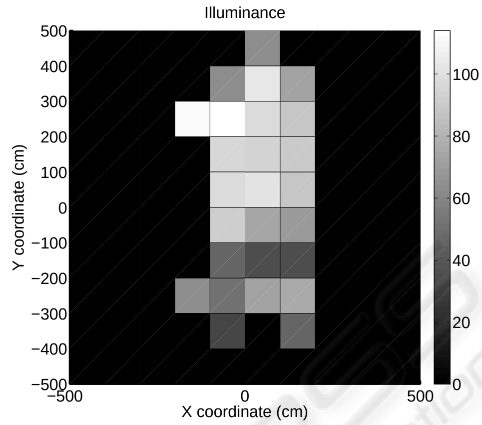

Figure 4: Illumincance in global coordinates.

Fig. 5 presents a grid map of compass headings with a bidirectional arrow, where red points to the north and white to the south. Since compass headings are disturbed indoors by electric cables and metal structures, the values of the compass headings give us spatial information about the magnetic field in the environment. However, in the experiments, the magnetic field of the measured environment was parallel, which gave us small spatial variations in compass heading.

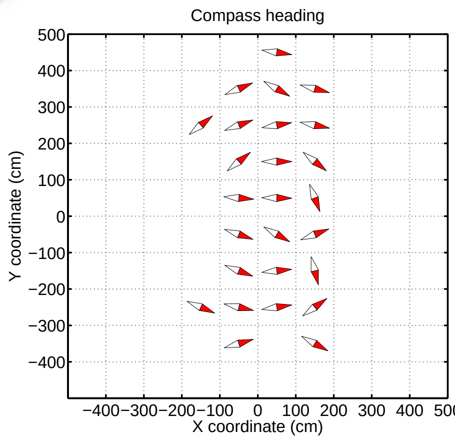

Figure 5: Compass heading in global coordinates.

The experiments demonstrated distributed sensing in a group of robots to produce distributions of illuminance and a magnetic field. All the measurements were tied to the co-ordinates of the leading robot. Since the ground truth positions were missing, positioning errors in the global co-ordinates of the sensing robots were affected by the odometer error of the leading robot and the errors of the infrared location system. In addition, the grid size in the experiments was 1x1 metres, which gave only a coarse picture of the true distributions. However, these preliminary experiments demonstrated the feasibility of using the infrared location system in distributed autonomous sensing systems.

4 CONCLUSION AND FUTURE WORKS

In this paper we presented a distributed multi-robot sensing system that uses an infrared location system. The infrared location system estimates poses in a multi-robot system, enabling the robots to maintain a given formation while sensing the environment. In addition, knowing their poses enables the robots to place their measurements on the same map.

We conducted an experiment where a group of three robots moved and measured spatial information in a right-angle triangular formation. Leader-follower formation control used pose estimates and P controllers to control the rotational and translational speeds of the following robots. In the experiments we measured spatial distributions of illuminance and a magnetic field, which gave us information about shadowing objects, metal structures and electric cables. In addition, since the information is spatially distributed, it can be used in mapping and localization applications.

The main contribution of the research was the construction and validation of a distributed multi-robot sensing system for mobile sensing applications. Future research will focus on developing methods for multi-robot exploration utilising spatial information.

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