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 improving robustness of the system, increasing relevancy of the measurements and cutting costs since requiring smaller and less precise sensors. Spatially distributed sensors fuse their measurements into the same coordinates requiring relative positions of the sensors. In this paper, we present a distributed multi-robot sensing system in which relative poses (positions and orientations) among robots are estimated using an infrared location system. The relative positions are estimated using intensity and bearing measurements of the received infrared signals. The relative orientations are obtained by fusing position estimates among robots. The location system enables a group of robots to perform distributed and cooperative environment sensing by maintaining a given formation while the group measures distributions of light and magnetic field, for example. In the experiments, a group of three robots moves and collects spatial information (i.e. illuminance and compass heading) from the given environment. The information is stored into grid maps and illustrated in the figures presenting illuminance and compass heading. The experiments proved the feasibility of the distributed multi-robot sensing system for sensing applications where the environment requires moving platforms.**

I. INTRODUCTION

Distributed sensing [1], [3] refers to measuring systems where instead of one sensor multiple sensors are spatially distributed improving robustness of the system, increasing relevancy of the measurements and cutting costs since requiring smaller and less precise sensors. In robotic domain, distributed sensing enables multi-robot systems (MRS) to perform mapping and exploration [15], to allocate tasks among robots [11], and to plan paths and to navigate in unknown or partially unknown environment [2], for example.

Distributed sensing systems collect spatial information requiring the system to be aware of positions of distributed sensors. Position estimation can be realized either using an absolut positioning system, like GPS, in which positions of sensors are estimated in relation to environment or estimating relative positions between sensors. Absolut positioning systems require mounting the positioning system into a given environment which increases costs and takes time except for GPS in which, however, accuracy is sufficient only in outdoor applications. Relative postions between sensors enable distributed sensing using sensors' coordinate system. However, since relative positioning systems are missing global positions of sensors, in moving platforms, like robots, error of the positions increases boundlessly.

In this paper, we present a distributed multi-robot sensing system using the infrared location system [7]. The location system estimates relative poses (positions and orientations) among robots. Related systems have been presented exploiting several techniques including laser range finders [12], [9], [6],[10], ultrasonic TOF measurement [13], [4] and vision [8], [14] for location and recognition of other robots. Comparison between the infrared location system and the related systems was discussed in [7].

To validate the distributed sensing system for applications where an environment requires moving platforms we built experiments where a group of three robots measured spatial information in a given environment maintaining a triangle formation. In the experiments one robot was acting as a leader and two other robots maintained the relative positions in the leader's coordinates. Formation control was realized using in each robot two P controllers one performing rotational and the other translational speed controls. Spatial measurements were placed into grid maps according to the leader's odometry and the relative positions of the followers.

In the experiments we measured distributions of light and chances in a magnetic field in a given environment building grid maps of illuminance and compass heading. The spatial distribution of light gives a good value about the structure of the environment and about the condition of the pendants. The chances in the magnetic field can be used to recognize cablings and the structures in the environment. In addition, since both the illuminance and the compass heading are spatially distributed they can be used in position estimation and mapping applications. The following sections describe the priciples of the infrared location system in brief and the experiments including the formation control method and the spatial measurements.

II. THE INFRARED LOCATION SYSTEM

The infrared location system, originally presented in [7], is a vital part of the multi-robot system [5] enabling 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 robots. However, radio transmission is used to share the estimates among the group in order to enable robots to estimate relative orientations.

The main principle of the location system is to use intensity and bearing measurements of the received signals to estimate the radial and angular coordinates, respectively, of the other robots in polar coordinates. Sharing these estimates among the group of robots makes it possible to estimate the relative orientations and improved positions. In addition, each robot is identified through different freqeuncies in the received signal.

The main components of the location system presented in Fig. 1 are upward pointing emitter, rotating receiver and two microcontrollers to perform position estimation and rotation speed control of the receiver. A conical mirror is used to reflect the signal from emitter sideways into unified zone. Rotating receiving mechanism called beam collector is used to collect the signals from other robots. Signals are received through a small aperture in the beam collector and reflected to the receiver using a mirror. Scanning the surroundings at a constant rotation speed is realized using a DC motor, Hall-effect-sensors and discrete PID controller.

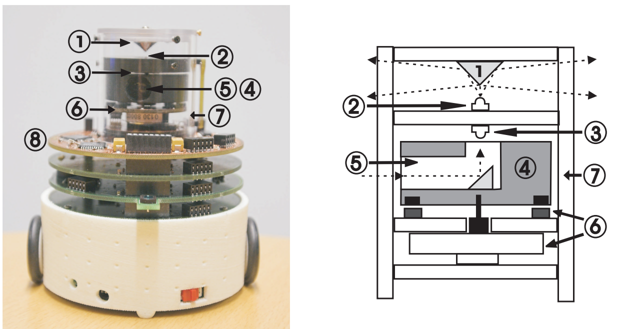

Fig. 1. The actual system and the illustration of mechanics: 1) mirror, 2) emitter, 3) receiver, 4) beam collector, 5) aperture, 6) DC motor and Hall-effect-sensors, 7) see-through body, 8) control electronics.

Fig. 2 presents a block diagram of the infrared location system. One microcontroller estimates the position of detected and identified robot using an intensity of the received signal and a bearing of the beam collector. The other controls the speed of the beam collector using a discrete PID controller. The microcontrollers exchange information containing a bearing of the beam collector to be used in position estimation and a modulation frequency setup which defines the identification frequency of the robot.

The measurement range of the location system is up to five metres. Standard deviation for radial coordinate is relative to the distance between a position estimating and a target robot giving the best estimates when the target is near. Standard deviation for angular coordinate is close to one degrees. Position error results mainly from noices in the infrared location system and irregular ground giving at highest over 20 cm error.

III. EXPERIMENTS

These experiments were built to validate the distributed multi-robot sensing system for applications where an environment requires moving platforms. For example, cooperative mapping in unknown environment requires moving platforms which are capable of measure the spatial information and estimate the relative positions among robots.

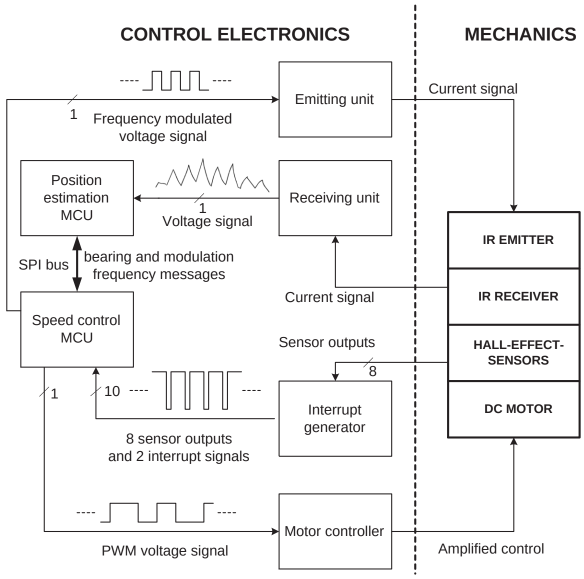

Fig. 2. Block diagram of the infrared location system.

In our experiments we implemented a distributed sensing system in which a group of three robots measured spatial information in a given environment. The group was moving accross the environment maintaining a given formation and stored illuminance and compass heading measurements to grid maps.

A. Formation control

Pose estimates given by the infrared location system were exploited in realizing formation control in a group of three robots. One of the robots was acting as a leader and the other two were following the leader in a given formation. In our experiments we used P controller to control the movements of the following robots. Each robot was controlled with two P controllers, one for translational speed control and the other for rotational speed control. The infrared location system updated the relative pose measurements for P controllers approximately every three seconds. Between these updates new poses were calculated using previous measurements from the location system and odometry information of robots. Fig. 3 presents the priciple of formation control where one of the following robots is controlled using simultaneously both translational and rotational speed controls in order to reach a given objective position relative to the leader robot.

Fig. 4 presents initial arbitrary poses of robots estimated by the infrared location system and Fig. 5 picture of actual poses. Fig. 6 presents estimated poses and Fig. 7 actual poses after the movement is completed. In the figures, robots are distinguished with different colors: blue represents the leader, green the first follower and yellow the second follower. Triangle formation in the final configuration was built before the group started moving and measuring spatial information. The P controllers maintained the given triangle formation through the measurements.

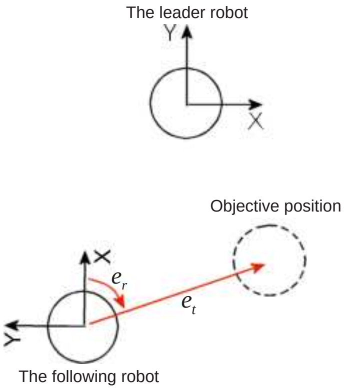

Fig. 3. The pose of the following robot relative to the leader is estimated and used to control the robot to the objective position. P controllers use rotation e_r and translation e_t errors to control rotational and translational speeds of the robot.

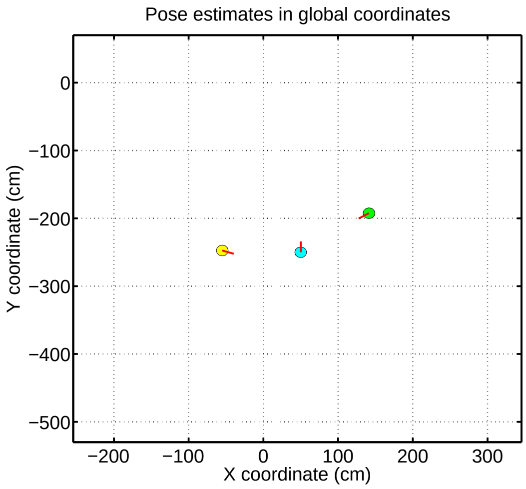

Fig. 4. Estimated initial poses. Blue color represents the leader, green color the first follower and yellow the second follower.

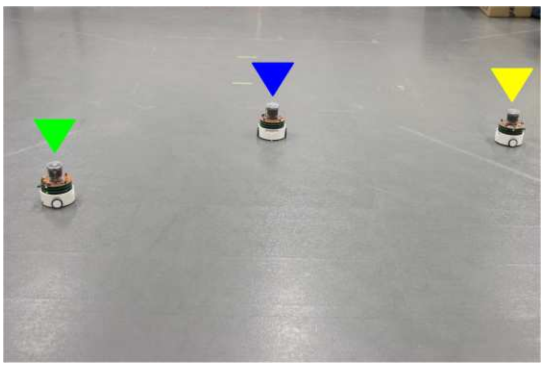

Fig. 5. Actual initial poses.

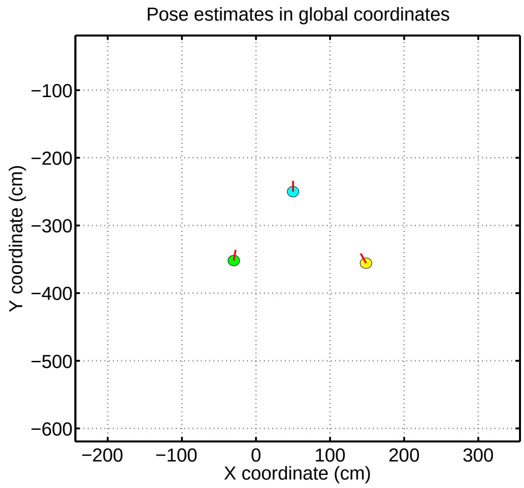

Fig. 6. Estimated final poses.

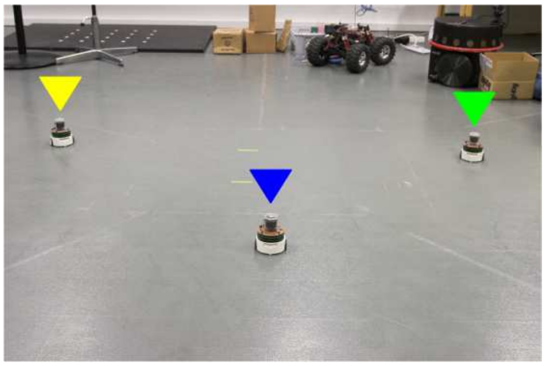

Fig. 7. Actual final poses.

B. Spatial measurements

In the experiments three robots measured distributions of light and magnetic field over a given environment producing maps of illuminance and compass heading. Fig. 8 presents trajectories of the robots while moving and measuring the environment. The leader was controlled to move from position (50 cm, -250 cm) to position (20 cm, 450 cm). The two following robots maintained the formation using the previously descibed P controllers. Each robot measured illuminance and compass heading and these measurements were stored into grid maps using estimated positions in global coordinates.

Fig. 9 presents a grid map of illumincance in global coordinates. The illuminance is presented in gray-scale where the highest intensity is described with white color and the lowest intensity for the cells not visited with black color. The size of one cell in the grid map is 100 cm. This gives spatial information of the distribution of light in the given environment. The cells with the highest intensities are close to pendants and the cells with the smallest intensities excluding not visited black areas are shadowed areas close to chairs, plants and walls.

Fig. 10 presents a grid map of compass heading in global coordinates. The compass heading is presented with a

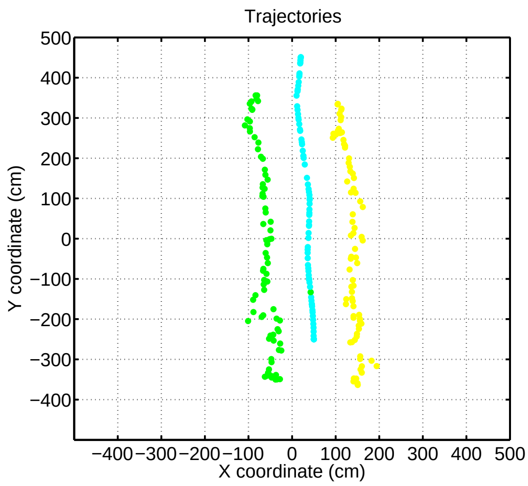

Fig. 8. Trajectories in global coordinates.

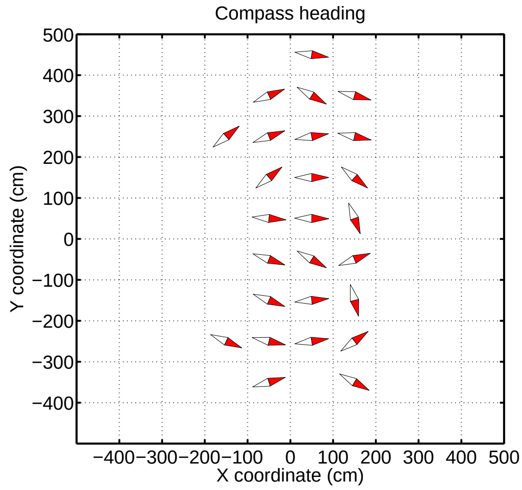

Fig. 10. Compass heading in global coordinates.

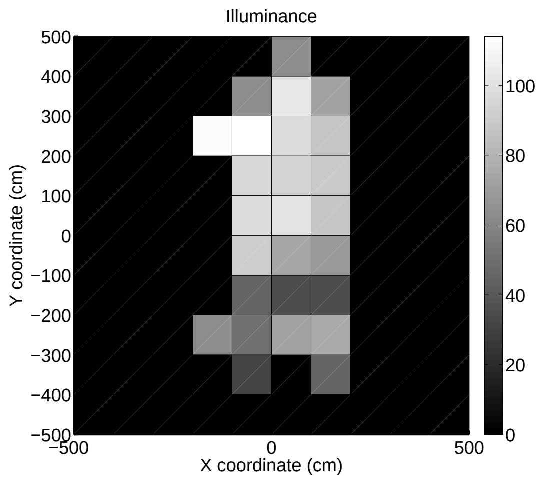

Fig. 9. Illumincance in global coordinates.

bidirectional arrow where red points to the north and white to the south. The size of one cell is the same 100 cm as with the illuminance map. Since in indoors compass heading suffers from cablings and metal structures values of the compass heading give us spatial information of 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.

The previous experiments proved that the spatial distribution of light gives a good value about the structure of the environment and about the condition of the pendants. The chances in the magnetic field can be used to recognize the cablings and the metal structures in the environment. In addition, since both the illuminance and the compass heading are spatially distributed they can be used in position estimation and mapping applications.

The previous experiments proved the feasibility of the infrared location system in building distributed sensing systems where the environment requires moving platforms. Factors that affect to the accuracy of the spatial measurements in global coordinates are the accuracy of the infrared location system and the accuracy of the leader's odometry. The accuracy of the infrared location system affects to the spatial measurements of the following robots. This factor remains the same through the measurements unlike the accuracy of the odometry which affects to the all measurements and increases boundlessly. Integrating the absolute positioning system, like GPS, to the leader would restrict the error of the odometry and would enable distributed sensing in larger environments.

IV. CONCLUSIONS AND FUTURE WORKS

In this paper, we presented a distributed multi-robot sensing system using an infrared location system. The infrared location system estimates poses in a multi-robot system enabling robots to move to and to maintain a given formation while sensing the environment. In addition, poses enables the robots to place their measurements into the same map presenting spatial information in robots' coordinates.

We build an experiment where a group of three robots moved and measured spatial information in a given triangle formation. Leader-follower formation control used pose estimates and P controllers to control rotational and translational speeds of the following robots maintaining the triangle formation during the experiment. In the experiment we measured spatial distributions of light and chances in a magnetic field producing grid maps of illuminance and compass heading. The experiments illustrated that the illuminance can give us information about shadowing objects in the environment, and conditions and positions of pendants, for example. At the same time, compass heading can be used to recognize metal structures and cablings. In addition, since these information are spatially distributed they can be used in mapping and location applications.

The main contribution of the research was to build and validate a distributed multi-robot sensing system for sensing applications where the environment requires moving platforms. In the future the research will focus on developing methods for multi-robot sensor fusion exploiting sensing capabilities of the presented sensing system.

V. ACKNOWLEDGMENTS

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