Fast and Robust Trilateration for Multi-Robot Tasks

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***Abstract*— The ability of robots to quickly and accurately localize their neighbors is extremely important for robotic teams. Prior approaches typically rely either on global information provided by GPS, beacons, and landmarks, or on complex local information provided by vision systems. In this paper we describe our trilateration approach to multi-robot localization, which is fully distributed, inexpensive, scalable, and robust. Our prior research [5] focused on maintaining multi-robot formations indoors using trilateration. This paper pushes the limits of our trilateration technology by testing formations of robots in an uncontrolled outdoor setting with relatively large inter-robot distances and high speeds. Rigorous experimental results demonstrate surprising robustness.**

I. TRILATERATION APPROACH

This paper provides an overview of our novel trilateration technology for multi-robot systems. Our goal is to create a plug-in hardware module to accurately localize neighboring robots, without global information and/or the use of vision systems. Our trilateration approach is not restricted to any particular class of control algorithms [1], [2], [3], and does not preclude the use of other technologies, such as beacons, landmarks, pheromones, vision systems, and GPS.

In 2D trilateration, the locations of three base points are known as well as the distances from each of these three base points to the object to be localized. Looked at visually, 2D trilateration involves finding the location where three circles intersect [4]. To accomplish this, each of our robots has one radio frequency (RF) transceiver and three ultrasonic acoustic transceivers. The ultrasonic transceivers are the "base points." Suppose robot 2 simultaneously emits an RF pulse and an ultrasonic acoustic pulse. When robot 1 receives the RF pulse (almost instantaneously), a clock on robot 1 starts. When the acoustic pulse is received by each of the three ultrasonic transceivers on robot 1, the elapsed times are computed. These three times are converted to distances, according to the speed of sound. Because the locations of the acoustic transceivers are known, robot 1 is now able to use trilateration to compute the location of robot 2 [5], [6].

In order to function, acoustic energy needs to be focused in the 2D plane. Ultrasonic acoustic transducers ("transceivers") produce a cone of energy along a line perpendicular to the surface of the transducer. The width of this main lobe is roughly 30°. To produce acoustic energy in the 2D plane we added parabolic cones. A parabolic cone is positioned under the transducer, with its tip pointing toward the transducer (Fig. 1). The parabolic cone acts like a lens, distributing emitted acoustic energy into the 2D plane while also collecting acoustic energy at the receiving acoustic transceivers.

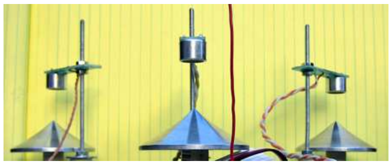

Fig. 1. Acoustic transducers and parabolic cones.

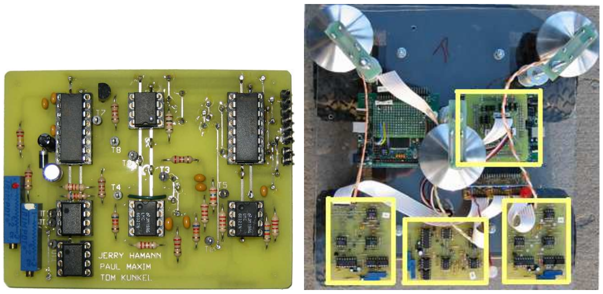

Fig. 2. The XSRF acoustic sensor printed circuit board (left), and the completed trilateration module (top-down view, right).

II. TRILATERATION ELECTRONIC HARDWARE

Fig. 2 (left) shows our in-house acoustic sensor boards (denoted as "XSRF" boards, for *Experimental Sonic Range Finder*). There is one XSRF for each acoustic transducer. The XSRF calculates the time difference between receiving the RF signal and the acoustic pulse. A MAX362 chip controls whether the board is in transmit or receive mode. When transmitting, a PIC microprocessor generates a 40 kHz signal, interfaced with the acoustic transducer. This generates the 40 kHz acoustic signal.

In receive mode, a trigger indicates that an RF signal has been heard and that an acoustic signal is arriving. When the RF is received, the PIC starts counting. To enhance the sensitivity of the XSRF, three stages of amplification occur, providing a gain of roughly 15 at each stage. Between the second and third stage is a 40 kHz bandpass filter to eliminate out-of-bound noise that can lead to saturation. The signal is passed to two comparators, set at thresholds of ± 2 VDC. When the acoustic energy exceeds either threshold, the PIC finishes counting, indicating the arrival of the acoustic signal.

This timing count provided by each PIC (one for each

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XSRF) is sent to a MiniDRAGON board[1] powered by a Freescale 68HCS12 microprocessor. The MiniDRAGON performs the trilateration calculations. Fig. 2 (right) shows the completed trilateration module from above. The MiniDRAGON is outlined near the center and the three XSRF acoustic sensors are outlined at the bottom.

III. SYNCHRONIZATION PROTOCOL

Trilateration involves at least two robots. One transmits the acoustic-RF pulse combination, while the others use these pulses to compute (trilaterate) the coordinates of the transmitting robot. Hence, trilateration is a one-to-many protocol, allowing multiple robots to simultaneously trilaterate and determine the position of the transmitting robot.

The purpose of trilateration is to allow all robots to determine the position of all of their neighbors. For this to be possible, the robots must take turns transmitting. For our current implementation we use a protocol that is similar to a token passing protocol, based on the unique ID assigned to each robot, ensuring that the robots take turns transmitting. Each robot maintains a data structure with the coordinate information, as well as any additional sensor information (also provided via the RF link), of every neighboring robot.

IV. OUTDOOR EXPERIMENT

This section presents an experiment that tests the trilateration system in an uncontrolled outdoor setting using a leader and three followers (Figure 3). We use our University of Wyoming “Maxelbots” (named after the two graduate students who designed and built them) with MMP5 platforms provided by The Machine Lab[2].

The Maxelbots were run outside in “Prexy’s Pasture”[3] at the center of the University. Prexy’s consists mostly of grass, of average height 5 cm (2″), interspersed with concrete sidewalks, trees, rocks, leaves, and other debris. The grass hits the bottom of the Maxelbot. Although generally flat, the ground slope can change rapidly (within 61 cm or 2′), by up to 20°, at boundaries. Results presented below are averaged over five independent runs, taken over a 20 minute interval.

The control algorithm used during these experiments simply maintains the proper distance by compensating with speed-ups, slow-downs, and turns. It is not designed to be particularly intelligent. The purpose of this experiment is to validate and test the hardware.

In this experiment, three Maxelbots are required to maintain a diamond formation. There is a leader and three followers. The leader goes on a curved path, and the followers have to maintain certain XY-coordinates with respect to the leader (see the “Ideal” column in Table I). The leader is running at 60% power, and the followers are at 80% power (up to 0.55 m (1.8′) per second). The wind speed near the ground ranged from 4 to 9 meters per second (10 to 21 mph).

Table I shows the XY-coordinates derived from the trilateration readings, for the three followers. From this table, it can be seen that the mean is very close to the ideal, and the standard deviations are small. Y is within 10% of the desired value (Y points to the front of the robot), while X is within 5%. In other words, a very good, robust diamond formation is maintained by the trilateration system despite ground disturbances, wind, dust, and relatively high speed.

Fig. 3. Maxelbots outdoors in UW’s Prexy’s Pasture.

TABLE I

ACCURACY OF THE THREE FOLLOWERS’ X AND Y POSITIONS IN A DIAMOND FORMATION.

	Ideal cm (inches)	Mean (inches)	Std. dev.
Maxelbot1-X	61 (24)	62.1 (24.5)	1.7 (0.7)
Maxelbot1-Y	61 (24)	54.8 (21.6)	2.7 (1.1)
Maxelbot2-X	-61 (-24)	-64.3 (-25.3)	4.2 (1.7)
Maxelbot2-Y	61 (24)	54.5 (21.5)	3.5 (1.4)
Maxelbot3-X	0 (0)	1.0 (0.4)	5.1 (2.0)
Maxelbot3-Y	122 (48)	111.8 (44.0)	4.6 (1.8)

V. SUMMARY

This paper describes a robust 2D trilateration framework for the fast, accurate localization of neighboring robots. The framework uses three acoustic transceivers and one RF transceiver. Our framework is designed to be modular, so that it can be used on different robotic platforms, and is not restricted to any particular class of control algorithms. In addition to being robust, our framework is fully distributed and scalable (http://www.cs.uwyo.edu/∼wspears/maxelbot).

To illustrate the general utility of our framework, we demonstrated the application of four Maxelbot robots maintain a diamond formation in an uncontrolled outdoor settings. The results from this experiment highlight the accuracy of our trilateration framework under challenging conditions.

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[1] Produced by Wytec (http://www.evbplus.com/)

[2] See http://www.themachinelab.com/MMP-5.html

[3] See http://www.laramie.willshireltd.com/PrexysPasture.html