Distributed Robotic Target Acquisition using Bluetooth Communication

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ABSTRACT

This paper presents a distributed multi-robot system designed to solve a team-based search and destroy task. The project was divided into two phases. The initial phase was used to demonstrate the application of Bluetooth communication for coordinated robotic search. The second (current) phase of the project attempts to integrate these early developments. This integration allows two seeker robots to locate and coordinate an attack on a target (enemy).

The goal of the first phase was to develop a robot communication strategy using Bluetooth for the Honeybee task. The goal of the second phase was to take the communication strategy and use it in the team-based search and destroy task. A secondary goal in the current phase was to convert a model tank into a robust autonomous vehicle. We present the details of the phases, the progress made towards achieving the goals, and the directions we plan to take after the current phase is complete.

Categories and Subject Descriptors

I.2.9 [**Robotics**]: Autonomous Vehicles. C.2.4 [**Distributed Systems**]: Bluetooth Communication.

General Terms

Algorithms, Design, Experimentation.

Keywords

Robotics, Autonomous Vehicles, Bluetooth Communication.

1. INTRODUCTION

This paper presents a multi-robot system designed to use short range Bluetooth communication to solve a team-based search and destroy task. This project represents an extension to an earlier project described in [1] that used Bluetooth communication to solve a simple multi-robot search and communication task. The primary goals of this extended project include the development of a cheap and easily produced platform with Bluetooth capabilities, development of a more robust Bluetooth communication scheme, and the development of behavioral models that allow efficient team-based search and destroy tactics in a military-like scenario.

2. RELATED WORK

Previous work in the area of multi-robot communication has focused primarily on the 802.11*x* wireless standard. Gerkey et al. [3] developed Player, a network server that provided "transparent network access to all sensing and control" of multiple robots (p. 1226). Nguyen et al. [5] developed a system for increasing the range of a wirelessly controlled robot by using small slave robots that followed the main robot and relayed the signal onward.

In order for a multi-robot system to solve any task which requires coordinated movements through communication, the information being communicated must be accurate. Location data are the primary information to be communicated. If both localization systems are inaccurate, even slightly, the error will compound and the accuracy and efficiency of the system will suffer tremendously. Barnhard et al. [1] described a simplified version of landmark-based navigation similar to the one presented by Uther et al. [6], which outlined the use of vision processing to find a robot's location and orientation by noting the location of various markers surrounding the task area. In a similar fashion, the present system uses landmark cues to determine location as well. This method will be described in detail in the following section.

3. PRELIMINARY WORK

Because of the inherent complexity of the system, it was decided that development should be divided into two phases. The first phase consisted of two robots, Odin and Hodur[1], which were

[1] The names Odin and Hodur come from Nordic mythology. Odin is named after the most prominent Norse deity and Hodur after the Norse god of winter. We chose Nordic names because the Bluetooth Protocol is named after Harold "Bluetooth" I, the king of Denmark and Norway in the middle 900's.

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designed to coordinate their movements to solve the "Honeybee" task. The primary goal of the first phase was to create a robust communication system for the transmission of location information to enable coordinated movement between two robots.

The "Honeybee" task is based on the behavior of the common honeybee, in that each worker bee, upon the discovery of a food resource, is able to use communication to direct other workers in the hive to the resource for collection [4]. In the task, there are two robots, a "guide" robot and a "blind" robot. The goal of the task is for the guide robot to locate a simple target (a small light bulb for example) within the environment and lead the blind robot to it solely through the communication of its location.

The robots used in the first phase consisted of two modified Brainstem Palm Pilot Robot Kits (PPRK) from Acroname Robotics. A Brainstem is a micro-controller with a 40 MHz RISC processor, 1 MBit Inter Integrated Circuit Bus (IIC) port, 5 digital input/outputs, and 4 high resolution servo outputs. It is useful for controlling basic robotic functions. The PPRK is a robot kit developed by Carnegie-Mellon University that is characterized by a holonomic drive system and a chassis that is easy to modify. These were interfaced with Compaq iPAQ 3970s running Pocket PC 2002 and Windows CE 3.0, which were used for primary control of both robots. One particular reason for the choice of the iPAQ as the controller was the ability to use Bluetooth wireless technology to establish a robust communication link between the two robots. The Bluetooth protocol allows for the creation of a short-range radio link between electronic devices and is primarily used for wireless desktop applications. It is characterized by a 30 foot range and a data transmission speed of 1 Mbps. Despite the possible use of the Brainstem as the primary controller, both phases only used it to relay messages between the iPAQ and the robot's sensors and actuators.

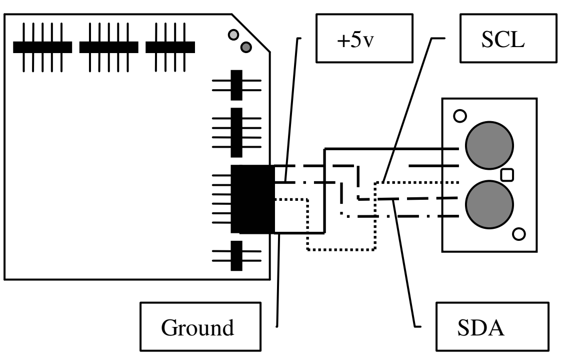

Figure 1: The Brainstem/SRF08 Interface

Each PPRK robot was modified from its original state by removing the infrared sensors from the chassis and adding a Devantech SRF08 Ultrasonic Sensor and a Devantech CMPS03 Magnetic Compass Sensor. The SRF08 utilizes sonar to detect objects in the environment up to approximately 20 feet away. The CMPS03 is an electronic compass that uses the Earth's magnetic field to detect orientation to an accuracy of 1˚. Figures 1 and 2 illustrate the interface between a Brainstem and each of the respective sensors. Both the SRF08 and the CMPS03 are capable of being connected directly to the IIC Bus on the Brainstem and referenced as addressable devices. In both Figures 1 and 2, the SCL and SDA connections represent the communication lines for the IIC Bus. Both robots were identical in that they both possessed the same modifications.

The behaviors developed in the first phase consisted of both search and localization behaviors. Since the SRF08 sensor also has the ability to take light intensity readings, we chose a light bulb as the target. Thus, the search strategy in both phases consists of a greedy algorithm designed to maximize the light intensity reading.

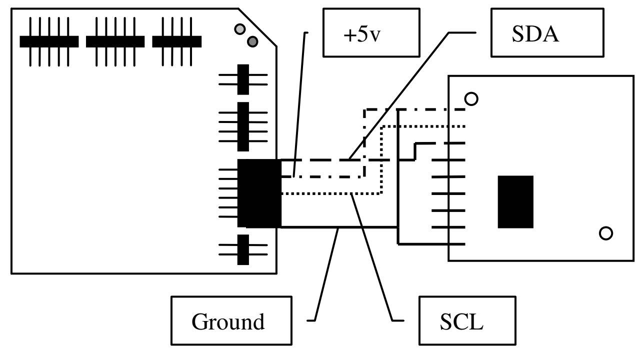

Figure 2: The Brainstem/CMPS03 Interface

In order to simplify the task, a simple landmark-based localization scheme was used (see Figure 3). The environment in which the task took place was surrounded by a rectangular wall, with each wall aligned with the polar coordinates. Each of these walls was visible to the robots via the SRF08 ultrasonic sensor. In order to find its location, the robot simply needed to turn to two cardinal directions separated by a 90˚ angle (e.g. South and East), and take distance readings for each of the walls. In this way, unique coordinates were obtained that were subsequently transmitted via a Bluetooth radio link.

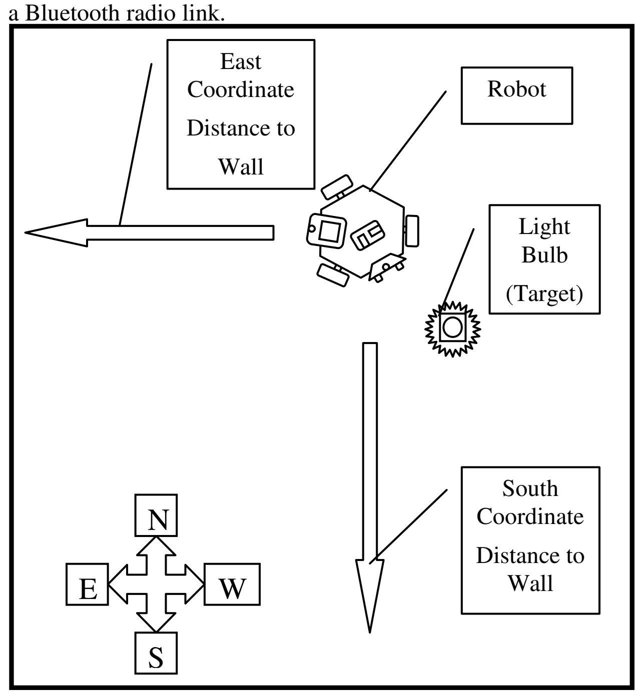

Figure 3: The Localization Process

4. CURRENT WORK

4.1 Task Description

The task for the current phase uses the same environment as the first phase; a playing field surrounded by four walls placed at cardinal directions with a light bulb placed somewhere within the environment to serve as the target. The current task differs from the first, however, along a number of factors. First, all the robots participate as a team in the search, allowing for a quicker search time. This also reduces the possibility of a system failure through the failure of one robot. Second, the main goal in the first task of leading the blind robot to the target has become a sub-goal in the present task, with the main goal now being to find the target and destroy it in a coordinated fashion. Finally, because this is a military-like scenario, the robots must exercise greater caution throughout the execution of the task.

When the target is found, the robot that found it must communicate the target's location to all the other robots involved while at the same time keeping a safe distance from the target (depending on the current attack strategy). While the other robots are en route to the target, a decision must be made regarding the attack formation that is to be used. The final requirement of the task is that the system must be able to adapt quickly to the loss of any team member, in order to carry on the mission.

4.2 Robot Architecture

One of the primary goals of the current phase was to develop a more robust robot platform. The PPRK robots used in the first phase, while being quite well suited to the Honeybee task, had a number of design limitations that made them unfit for the current task. First, a PPRK cannot react quickly enough to succeed in a fast paced environment; and second, it is difficult to modify the chassis of the PPRK to accommodate additional sensors as well as a projectile launcher.

Figure 4: The Motorworks Missile Launcher

It was decided that the new platforms would consist of model tanks (see Figure 4), modified to be autonomous robotic vehicles with Bluetooth radio communication capabilities. Each tank runs on a standard 9.6 volt battery, has two individually driven treads, and also has a rotating turret with a built in projectile launcher. The firing mechanism is capable of individually firing 12 foam missiles, allowing for multiple attack sequences without reloading. In addition, it is operated by a small DC motor, allowing for simple programmatic operation. This chassis is also able to move very quickly, allowing for the quick reaction times required in the task. The tank is able to climb up to a 30˚ incline, as well as cross small ditches and other obstacles.

The control architecture for the new chassis is similar to the architecture used in the PPRK in that it still consists of the iPAQ/Brainstem interface. However, to allow for more sensory apparatus and control, the current architecture consists of two Brainstems (per tank) networked together across the IIC Bus. Figure 5 presents the wiring diagram for networking two Brainstems across the IIC Bus. Adding a second Brainstem presents a distinct advantage, because it allows each Brainstem to work on a task in parallel. The current system uses two Brainstems because we needed more input/output ports than were available on one Brainstem. For greater ease in design, we allocated one of the Brainstems completely for motor control, and the other for sensor control. The iPAQ remains the master controller of the system; all instructions from the iPAQ are routed through a single Brainstem, which then proceeds to route instructions by address across the IIC Bus to the correct receiver. In this way, it is simple to add more sensors or motors to the system by merely adding more Brainstems to the on-board controller network.

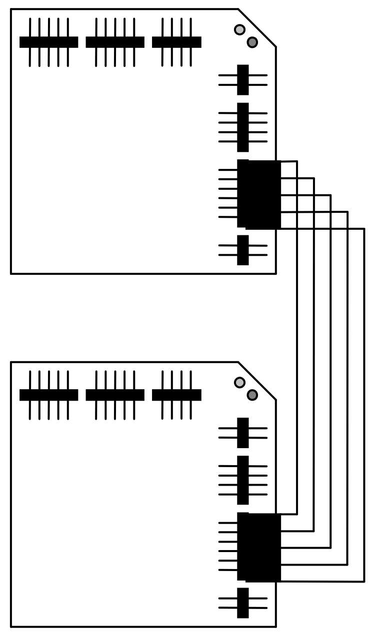

Figure 5: Networking Two Brainstems via the IIC Bus

The new chassis still has a CMPS03 compass sensor to obtain orientation information, but now also possesses two SRF08 ultrasonic sensors mounted on each side of the front of the vehicle for better targeting and tracking. The motors of the tank are controlled by two Texas Instruments SN754410 Quadruple H-Bridge Drivers which are interfaced with the Brainstem's digital outputs. An H-Bridge is a circuit which allows for the reversal of current through a DC motor, controlled by logic signals, to allow for the motor to be run in two different directions. To simplify operation, it was decided that the turret of the tank should be locked in place so that all targeting and tracking would be done by rotating the entire body of the robot. We plan to remove this constraint in the next version. Each robot was capable of communicating with others via a Bluetooth radio connection, which is a feature of the Compaq iPAQs.

Figure 6: The Modified Tank Chassis

Overall, the final product (see Figure 6) is an extremely robust chassis that is fairly easy to construct. In addition, the capabilities of each robot easily exceed the qualifications required for the task at hand.

4.3 Bluetooth Communication Interface

In a team-based task such as this, one of the most important aspects is the communication system, which facilitates coordinated team activity. This is because failure of the communication system can lead to disastrous results. In fact, a failure in communication can be more damaging than the loss of any single member of the team because it has an effect on the actions of all the robots involved in the task. In contrast to this, if the communication system is robust and adaptable, then the loss of one of the team members will only have a minor effect on the outcome of the task. In a situation such as this, the remaining robots could adapt their behavior based on the realization that one robot has been lost, and continue on to complete the task with only a minor reduction of effectiveness. This is particularly advantageous in our military-like scenario, where it is almost guaranteed that several of the robots will be lost before the task is complete. As autonomous vehicles, they have the ability to decide whether to continue or withdraw, depending on the attack strategy.

The communication system that was developed in the first phase is extremely susceptible to the loss of either of the robots involved in the Honeybee task. For example, if the guide robot is lost while searching for the light bulb, then the whole process is unsuccessful because the blind robot will continue to wait for the coordinates without realizing that the task is no longer achievable. In the same way, if the blind robot fails, the seeker will send the first coordinate and wait forever for an acknowledgement that the coordinate had been received. Thus a major goal of the second phase was to expand the current communication system so that it is no longer dependent on any single robot, in order to minimize the impact of team member losses on the team's overall performance.

To come up with a model for maintaining the status of all the robots involved in the task, we turned to the idea of Routing Information Protocol in the field of computer networking. The *Routing Information Protocol* (RIP), helps the members of a network maintain a list of all the active routers in the system. In RIP, each member sends its entire table of active routers to its nearest neighbor every 30 seconds. Upon receiving the table, the member updates its own table to reflect the new information [2].

The communication model for the current phase works similarly to RIP. In the system, each robot sends out a "heartbeat" signal at regular intervals to all the other robots within its range. Each robot maintains a Status table that contains a Boolean status variable for each robot, as well as the time allotted since the last heartbeat received from each robot. If the robot does not receive a heartbeat signal from a particular robot for an extended period of time, then the robot switches the status variable to "0" or inactive ("1" means active), signifying that the other robot is either not functioning or has passed out of range.

Table for Robot 1			Table for Robot 2		
Robot #	Status	Time	Time	Status	Robot #
Robot 1	1	NA	1	1	Robot 1
Robot 2	1	1	NA	1	Robot 2
Robot 3	1	2	12	0	Robot 3
Robot 4	0	13	5	1	Robot 4

New Table		
Robot #	Status	Time
Robot 1	1	1
Robot 2	1	1
Robot 3	1	2
Robot 4	1	5

Figure 7: Combining Status Tables

In addition to the heartbeat signal, each robot also sends a copy of its status table to all the other robots that it still considers active. Upon receiving a status table, each robot updates its own table to reflect the new information. This is done by always reverting to the most recent heartbeat time. Thus, in Figure 7, robots 1 and 2 are combining their status tables. In this example, an elapsed time of ten minutes results in a classification of inactive, as shown by Robot 4's time of 13, which means no heartbeat has been received for 13 minutes. Thus Robot 1 has labeled Robot 4 as inactive. But Robot 2 lists Robot 4 as still active, since the last heartbeat it received was only 5 minutes ago. So, the new table for both robots (1 and 2) reflects that Robot 4 is still active and the new time is reverted to 5 minutes. A similar process is done for Robot 3 also.

One of the limitations of the iPAQ 3970s that we used was that the Bluetooth version does not allow for the creation of a robust local area network (e.g. many clients conversing simultaneously). Instead, facilities are provided to establish a direct virtual serial connection between two devices. Had we used a newer model iPAQ running the Windows CE .NET framework, this problem would not have been present. As a result of this restriction, we were forced to implement a staggered message passing scheme. Thus, when one robot wants to communicate with another, a serial connection is opened; the communication proceeds; and then the connection is closed again to allow for other communication to take place. If a connection is initiated with a robot that is already engaged with another, the initiating robot receives a "busy signal" and knows to attempt reconnecting later.

It is important to note that our prototype communication system is not intended to replace current military communication protocols. Bluetooth is not an adequate solution for such applications mainly because of its limited range. Instead the focus of this project was the development of communication strategies for coordinated robotics rather than a communication system itself. Thus, the strategies we are developing could easily be implemented with a more applicable communication protocol.

4.4 Behavior

The behaviors in the current phase are similar to those in the previous phase in that they are divided into two parts. The first part consists of locating the target through a distributed search. This is characterized by each of the robots searching for the target independently, using a greedy method similar to the one used in the Honeybee task. The search differs from the previous phase, however, in that when the target is found, the robot does not approach it. Instead, it stays at a safe distance and waits for the rest of the team to arrive (again, this depends on the attack strategy in use). With a large number of robots engaged in the search, it can proceed very quickly.

Once the target has been discovered, the robot that has discovered it (primary attacker) sends a quick notification to all the other robots that are still active, whereupon they begin to prepare for the localization procedure by turning to a cardinal coordinate. Note that an inactive robot (with respect to the primary attacker) will also be notified indirectly.

After determining its location, the primary attacker begins the process of deciding an attack formation. The formation chosen for this task is determined based on the attack strategy and current situation. The example formation in Figure 8 allows each of the robots to localize easily, as well as maintain a clear line of site to the target to prevent "friendly fire" problems.

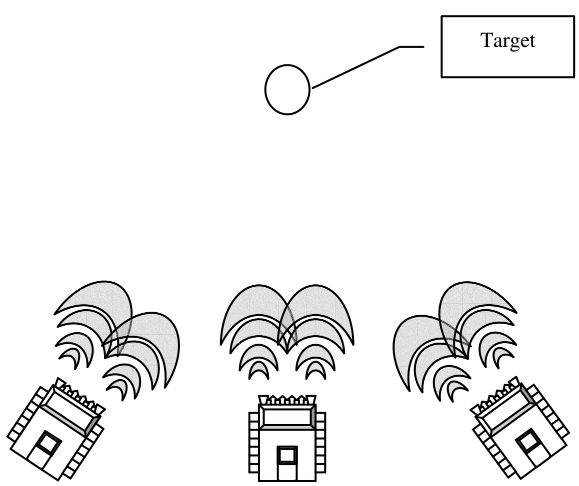

Figure 8: An Attack Formation

At this point, a quick determination is made to figure out how many other robots there are in the task force, this number is then passed via Bluetooth to all of the other robots in their status tables. Depending on the number of surviving robots, different attacks can be agreed upon and executed. For example, once all of the robots have maneuvered themselves into the correct position, each robot, in order will send the message that it is in position and ready to fire. Once every robot has locked in on the target, the fire command will initiate, and the target will be destroyed.

5. CONCLUSIONS AND FUTURE DIRECTIONS

We have presented a two-phase project with the goal of using Bluetooth communication to control distributed team-based multi-robot systems. The first phase used the Honeybee task to develop and test a robust Bluetooth communication scheme. The second phase applied what was learned to a more difficult military-like search and destroy task. Preliminary performance of the cooperating tanks indicates that Bluetooth communication is a viable option for applied multi-robotic systems.

There are several areas of the current system that warrant improvement. First, the present system is unable to account for moving targets. Future work will focus on developing the system's ability to dynamically track moving objects. In addition, work will continue on developing improved strategic planning in the overall system. Furthermore, Bluetooth communication should be improved to allow for robots that have gone out of range to reconnect seamlessly and easily to the rest of the group. Finally, a major limitation of the current system is that all activity must occur in a constrained environment, in order for the localization procedure to work. Future work will also focus on developing the system's ability to work in more complex environments.

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7. REFERENCES

[1] D.H. Barnhard, J.T. McClain, B.J. Wimpey, W.D. Potter. Odin and Hodur: Using Bluetooth Communication for Coordinated Robotic Search. *Proceedings of the 2004 International Conference on Artificial Intelligence (IC-AI '04)*. Las Vegas, Nevada, Submitted.

[2] B. A. Forouzan. *TCP/IP Protocol Suite*. McGraw Hill, Boston, 2003.

[3] B.P. Gerkey, R.T. Vaughan, K. Stoy, A. Howard, G.S. Sukhatme, and M.J. Mataric. Most Valuable Player: A Robot Device Server for Distributed Control. *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems*, 1226-1231, Wailea, Hawaii, October 29th – November 3rd, 2001.

[4] R.E. Koning. Honeybee Biology. *Plant Physiology Website*. http://plantphys.info/plants_human/bees/bees.html (visited 10/20/03), 1994.

[5] H.G. Nguyen, M.R. Pezeshkian, M. Raymond, A. Gupta, and J.M. Spector. Autonomous Communication Relays for Tactical Robots. *11th Int. Conf. on Advanced Robotics*. Coimbra, Portugal, June 30th – July 3rd, 2003.

[6] W. Uther, S. Lenser, J. Bruce, M. Hock, and M. Veloso. CM-Pack'01: Fast Legged Robot Walking, Robust Localization, and Team Behaviors. *RoboCup-2001: The Fifth RoboCup Competitions and Conferences*, 693-696, 2001.