GROUP BEHAVIOR IN MOBILE AUTONOMOUS AGENTS

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Introduction: In the natural world, some types of insects live in social communities that seem to be very complex, yet are composed of simple insects. These communities of insects can accomplish great feats that are far beyond the abilities of individual insects. For example, ants working together can construct huge mounds in the ground that contain miles of connected passages. Bees construct hives that allows the swarm to store food and raise the young bees in a safe environment. All of these insects take advantage of the group behaviors that they exhibit. Using these biological models as a starting point, this project uses similar group behaviors in a group of ten mobile robots to explore the competitive advantage of cooperation within the group.

MAIN BODY

Integrated system: The purpose of this project is to research cooperative strategies for mobile autonomous agents in multi-robot communities. The main scope of this project involves the potential of software to drive the hardware so the hardware was ancillary to the project. Ten Talrik Junior platforms were used to provide mobility to the robots to enable complex group behaviors that involve multiple autonomous agents each acting independently, yet communicating among themselves to increase efficiency in completing objectives. The ant colony and bee hive were studied to provide a biological perspective on cooperative behavior among mobile agents. However, the intent of this project is not merely to imitate what insects do in groups, but to use the analogous behavior of insect social structures as a starting point in the design of individual roles within social groups and achieving group objectives collectively.

Mobile platform: The main focus of this project is the software so the mobile platform was chosen on the basis of it's utility, rather than its innovation in hardware. The Talrik Junior platform was chosen for its proven ability as a mobile platform. The TJ platform allows the autonomous agent to take advantage of a high level of mobility while still providing a base for mounting additional electronics such as printed circuit boards and sensors. The TJ platform uses readily available parts and is considered by many experienced "roboteers" to be a simple, reliable platform that is easy to troubleshoot. Due to the high number of robots involved in this project, it was determined that the reliability of the TJ was advantageous. Additionally, TJ platforms can be produced in high quantities, lending themselves to the nature of this project.

The TJ platforms were sanded, primed, and painted with several coats of silver spray paint. The silver paint was not durable and it showed finger prints wherever it had been touched so the platforms were coated with polyurethane sealer that provided a very durable and attractive finish. Many people question if the platforms are actually made of metal because they no longer resemble wood.

Actuation: The robots use two Hitec HS-422 servos for mobility. A servo is operated by telling it the position to rotate to, indicated in degrees. I hacked these servos to make them work as motors by physically breaking off the connection between the final gear and the position potentiometer. Each servo includes a controller that tells the current position and the desired one. The farther the degree difference the faster it will rotate. The microprocessor will control these servos by telling them what speed to rotate. The function call to drive the motors is: *motorp(a, b);* where a is the number for the left or right servo (0 or 1) and b is the relative speed of the motor. Therefore, the variable b is used to tell the servo how fast to go. These servos are lightweight and very efficient- developing 43.4 oz-in (3.1kg-cm) at 4.8V and weighing only 1.60oz (45.5g). Note that these servos develop 51.8oz-in (3.7kg-cm) as used in this application (5.0 Volts). This configuration was very simple and reliable yet when driven by the appropriate software, the TJ platforms are very maneuverable and robust. The entire platform must be pivoted to allow the robot to look to the side or rear.

Sensors: The TJ platforms are designed for three forward facing and one rear facing bump switch. This was determined to be sufficient for this application because when combined with infrared collision avoidance, the bump switched were rarely used. The platforms all have three forward looking infrared and one rear looking infrared sensor to use for collision avoidance and advanced group behaviors. The infrared sensors are comprised of an emitter/detector pair. The emitter is a high output LED with a wavelength of 940nm. The detector is a Sharp digital IR detector hacked to read analog IR at 40KHz (see Figure five below). These sensors produce analog channel readings that are connected to the microprocessor's A/D converter.

The forward looking infrared sensor group is used for communication between robots in close proximity. The protocol for establishing this type of communication is:

- Bump contact establishes intent to communicate
- Robots pivot to face each other
- Forward facing infrared sensors are aligned
- Each robot uses right sensor to transmit data
- Each robot uses left sensor to receive data
- Each robot uses center sensor as a "data clock" to signify valid data

In this manner any two robots may communicate at any time during autonomous behavior.

Each robot will also have a sonar emitter facing forward and a sonar receiver that faces 360 degrees. These sonar sensors are used for group behaviors that require longer range communication, such as a cry for assistance or a summon from the "Queen" robot. The intent is for each robot to be enabled to listen from all directions and be able to transmit in any direction by pivoting to face a target.

Behaviors: This project used modular code because it was reusable, which allows for more complicated behaviors in the robots. The robots have a hierarchy of behavior states that can be affected by factors external to the robot and internal to the robot. For example, a robots highest priority is basic collision avoidance. Once this is established, it can seek to participate in the group behaviors with other robots. The group behaviors are executed while at the same time, basic collision avoidance is continued. Below is a list of possible individual behaviors:

- Collision avoidance
- Physical contact avoidance

- Finding the “queen” robot
- Navigation to /from a sector
- Communicating with another robot
- Self diagnostic
- Self calibration
- Check battery level
- Adapt to group behavior communicated from other robot.

In addition to these individual behaviors, the group may be able to:

- Swarm together
- Follow the leader
- Disperse apart
- Search the area
- Avoid a certain sector

A system of communication has been established so that robots may talk to each other and exchange information regarding:

- Identify individual robots
- Identify robots who are not part of the group
- Recruiting help from fellow robots for task completion
- Share group behavior strategies
- Share learned information about the environment

I believe that robots that can work together have a definite advantage over single robots or swarms of robots who do not communicate. It would therefore be very beneficial for robots to have a system of informing each other of their experiences and learned knowledge so that they will be more robust and efficient overall as a group.

Experimental layout and results: Several different experiments will be set up to test the efficiency of the group behaviors to determine if this group of ten robots, acting together and communicating, can complete simple group tasks more quickly than a group of ten identical robots who do not cooperate or communicate, but merely wander around oblivious to the presence of the other nine robots. Consider the cooperative robots to be group A and the uncooperative robots as group B. The group tasks will be tested as follows:

- Swarm together: First, group A will use sonar to signal the group to come together quickly. Then group B will wander randomly looking for the other robots and try to find them using collision avoidance routines. The times will be compared.
- Follow the leader: Group A will follow a leader robot who will navigate a predetermined course using dead reckoning. Obviously, group B will be unable to do this behavior so group A will be measured on its ability to stay together in the presence of obstacles and other robots.
- Disperse apart: Group A will use sonar and each robot will try to go as far away from the sonar as it can go. Group B will wander random using collision avoidance to

disperse. Completion is defined as when the robots are all at least twelve inches away from all other robots. The times will be compared.

- Search the area: Group A will use navigation techniques, such as dividing the search region into smaller sectors and different robots searching each sector. Group B will wander randomly until the target is found. The times will be compared.

Obviously the group with the shortest time to complete the mission will be the most efficient at completing the task

Sensor Systems

The robots in this project are equipped with infrared sensors, sonar sensors, and contact sensors. The basic purpose of the sensor suite in these robots is to allow each robot to avoid obstacles, avoid bumping into other robots, and to find other robots for group behaviors. The secondary purpose of the sensor suite is to allow the individual robots to communicate with each other.

Infrared System

The robots use infrared for collision avoidance. The standard infrared system was determined to be adequate for the swarm of robots to avoid each other, as well as avoiding obstacles. The IR system consists of an infrared LED and an infrared detecting circuit. The IR LED can be turned on to emit a 40kHz IR signal and the IR detecting circuit can be used to read the strength of the reflected signal. The IR LED is collimated with a black tube made from heat shrink tubing that is 2 cm long and has an inside diameter of 5 mm. Figure 1 shows the construction of the collimated LED emitter.

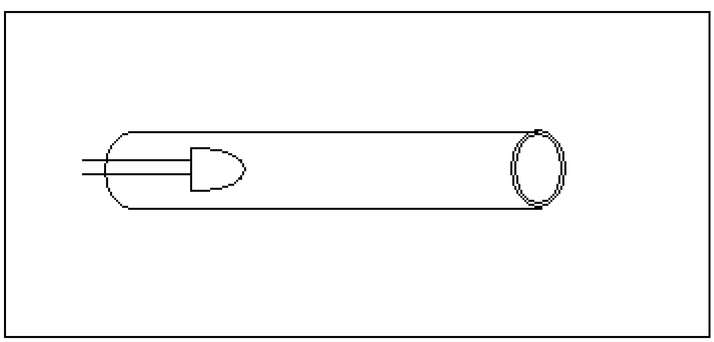
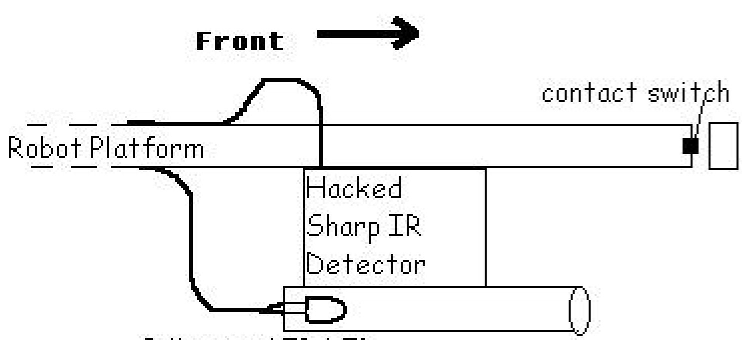


Figure 1: Collimated Infrared LED

The IR detector is made from a Sharp GPIU58X 40kHz infrared receiver that has been



hacked to produce an analog value of the signal strength. The Sharp IR receiver is wired to the input port of the A/D converter on the microprocessor. Each robot has three forward facing IR sensors and one rear facing IR sensor. Figure 2 shows the mounting hardware for the emitter and detector. Figure 3 shows the arrangement of the IR sensors.

Figure 2: Sensor Hardware

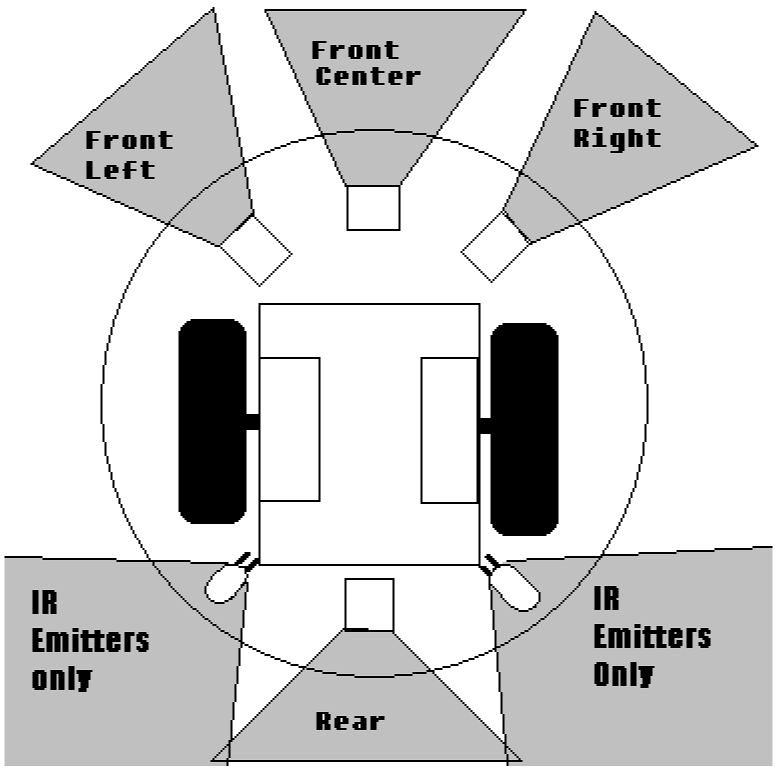


Figure 3: Top View of IR Placement

Notice in Figure Three that the IR emitters in the rear corners are not coupled with IR detectors. These IR emitters are used in the "following" behavior in which the robots follow the rear IR emitters of the lead robot. When the leading robot turns it would lose the follower because the center IR emitter would not be visible form the rear oblique angle. This problem was fixed by adding peripheral IR LEDs to aid the follower robot.

Infrared Communication System

The robots also use the IR system for communication with other robots. The communication between robots follows the following protocol:

1. Two robots locate each other and align front to front using IR docking behaviors.

2. Each robot listens and if the other is not transmitting, it starts tot transmit.
3. The sender communicates by turning on the front left IR and front right IR at the same time. When these two IR LED's are on, the data bit corresponds to state of the center LED. For example, table 1 shows a typical asynchronous transmission. Notice that the front left and front right are used as a "data strobe" to indicate that valid data is on the center LED.

Front Left	Front Center	Front Right	Data Transmitted
On	On	On	1
Off	Don't Care	Off	None
On	On	On	1
Off	Don't Care		None
On	Off	On	0
Off	Don't Care	Off	None
On	On	On	1

Table 1: Asynchronous Transmission Sequence

This method of communication allows four bit words to be sent continuously. The sender transmits four bits, then waits a short time and sends the same four bits. The receiver will send an error message if the two words are different. If the sender received the same two words, it will send the received word back to the initial sender. This procedure continues until all data is exchanged.

This system is used to transmit group "moods" in our project. The four bits allow a single word to represent fifteen different messages. These fifteen messages correspond to the current "mood" of the swarm. For example, a single robot can discover something that makes it happy, so it will communicate this feeling to the others who will communicate it to whoever they communicate with. In this fashion, the "mood" of the group is dynamic and very contagious.

The communication system has an accuracy of 90% at ranges of one inch. The system is designed for this distance so the behaviors align the robots at this distance when they want to initiate a conversation. In the alignment behavior it is critical that the robots align straight with each other. As with all infrared systems, this system is less dependable in the presence of fluorescent lighting.

<u>Sonar System</u>

The robots use sonar for long range communication. Each robot has a sonar receiver but only one robot has a sonar emitter circuit. The robot with the emitter can initiate group behaviors such as swarm, disperse or go to sleep. The reason that all robots do not have a sonar emitter is that only a few robots need to have the capability to talk to the entire group at once.

To determine the maximum range of the sonar system we tested the receivers at various distances from the sonar transmitter. The sonar system is very directional and the signal can be detected at ranges of 15 feet or more. Also, it is important to have the sonar emitter and receiver at the same height with the transducers horizontal for maximum range. In this application, a maximum range was not reached, as long as the receiver is facing the transmitter.

Contact Detection System

Each robot has a collision avoidance system that is based on IR sensors. However, these cannot detect certain types of obstacles, such as narrow chair legs, so contact switches monitor the perimeter of each robot. These switches are connected to a resistor network that is connected to an analog input port so that all four switches use the same input. See the analog values in Table 2.

Analog Value	Front Center	Front Left	Front Right	Rear Center
0	X			
43		X		
79			X	
21				X
126	X		X	
59	X	X		
101		X	X	
110	X		X	X
139	X			X
150		X		X
132			X	X
162	X	X	X	X

Table 2: Contact Switch Analog Values

IR Sensor Range Tests

Turning on each IR LED and recording the value from the corresponding analog input tested the range of the IR sensors. Table 3 displays the results as a sheet of paper was placed at various ranges in front of each sensor. Notice that he results are nonlinear. The entire range of the analog values was between 127 and 86. This range was used in the calibration routine to verify that the sensors were all connected. For instance, a value of zero on the IR analog port would indicate that no sensor was connected.

Distance (inches)	Front Center	Front Left	Front Right	Rear Center
0	127	127	127	127
2	117	126	126	126
4	95	109	119	102
6	91	101	108	100

8	89	93	101	98
10	87	89	93	91
12	87	88	91	90
14	87	87	88	87
16	87	87	87	87
18	87	86	86	86
20	86	86	86	86

Table 3: IR Sensor Readings

Software Strategies

The strategy in programming this group of robots was to use the same code for each robot, so each robot was downloaded with the same program. This main program was able to determine which type of robot it was running in and test to ensure that all the sensors were attached. The software calibrates all the sensors for their maximum and minimum readings continuously during run-time.

The behaviors were divided in to two categories: individual behaviors and group behaviors. A single robot can perform an individual behavior, but a group behavior requires multiple agents. The following list describes each individual behavior:

- Self-identification: each robot determines which behaviors can be used according to which type of robot it is.
- Calibrate IR: determines the minimum and maximum values for the IR sensors.
- Self-diagnostic: determines if any sensors are not connected properly to the microprocessor.
- Bumpers: uses bumpers for collision avoidance.
- IR: uses infrared for collision avoidance.
- Sonar: emits sonar.
- Battery: checks battery status.
- Detect IR: looks for infrared from other robots.
- Display functions: display various numbers on the LED display.
- Behavior selector: determines which behavior to assume.
- Curve left/right: used to turn instead of pivot.
- Rotate: spins the robot around its center 360 degrees.
- Follow: follows IR source- typically the rear of another robot.
- Moods: determines which mood to assume.
- Happy/Angry/Sleepy/Frightened mood: act according to the current mood.
- Do nothing: robot waits certain amount of time with sensors off.
- Roll left/right: pivots robot 90 degrees.
- Count up/down: displays sequence on LED display.
- Get Happy/Angry/Frightened/Sleepy: assume the appropriate mood state.
- Test: functions that explicitly test certain hardware/ software components.

The following list describes some of the group behaviors:

- Find queen: locate queen's sonar source.
- Go to queen: seek origin of queen's IR source.
- Listen to queen: receive data via sonar from queen.
- Swarm: robots come together and stop.

Each robot has determines its mood based on its battery condition, environmental factors, and communications it has received. The happy mood is acquired when the robot has a high charge on its batteries. This mood causes the robot to become very active, driving its motors at full speed, spinning frequently, etc. The angry mood occurs when the robot is bumped too many times or other factors, such as when it gets trapped in a corner. Then the robot becomes belligerent and rams into obstacles and turns very sharp corners. The frightened mood causes the robot to avoid physical contact with all obstacles and other robots. The frightened robot drives backwards when it sees an obstacle in front. When the battery state is very low, the robot gets sleepy. In the sleepy mood, the robot drives slowly and stops often to conserve power.

The robots can communicate their mood state through the IR communication system. When a robot receives a mood from another robot it can choose whether to assume that mood or not. For example, a happy robot can tell a sleepy robot that he is happy. The sleepy robot will try to assume the happy mood but if he is unable to (his batteries may be too low) then he will continue being sleepy. In this sense, the robots do not issue orders to one another, but merely communicate their mood to each other.

Conclusion

The hardware for the robots was built in the first three weeks. The remainder of the time was directed into software. It was worth the effort because we have incorporated many behaviors into the robot platform. The robots were built using a modular approach in order to save time and facilitate easy repairs and maintenance of the robot fleet. If a part on any of the robots breaks, it can be easily removed and replaced within ten minutes. This is very uncommon in the design of many contemporaneous robotic platforms, which require tedious repairs for the most basic problems. This strategy enabled many robots to be maintained and operated by a few engineers. The modular strategy was used in the software also. Each program is identical, although it may be running on different hardware. The software incorporated functions that simplify programming by combining frequently used algorithms into functions that can be executed by a simple one-line function call. These strategies were necessary to deliver ten robots ready to operate in a multi-agent community.

Documentation

The following is a list of sources for information, specifications, and design. Notice that the complete documentation for the assembly of a TJPro is available from the Mekatronix home page.

Fred Martin, The 6.270 Robot Builder's Guide, MIT Media Lab, Cambridge, MA, 1992

Intelligent Machines Design Laboratory Web Page:
http://www.mil.ufl.edu/
http://www.mil.ufl.edu/imdl

Mekatronix home page:
http://www.mekatronix.com/