Blue Swarm 2.5

A Step Toward an Autonomous Swarm of Search and Rescue Robots

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Abstract

Urban search and rescue is a difficult domain for autonomous mobile robots to operate in. The environment can be expected to be highly unstructured, with many obstacles and hazards for a robot to deal with. In addition, if human rescue teams are going to accept robotic assistance, they need to be assured that the robots are going to be helpful, not a hindrance. With these factors in mind, we have been working toward the development of an autonomous swarm of small, inexpensive search and rescue robots. The robots should be autonomous in order to provide useful information to human rescuers without requiring specialized knowledge in operating robots. A swarm is useful because it allows for losses of individual robots and for redundant communications pathways, without losing overall effectiveness of the swarm. The robots should be small so they will not pose a danger to rescuers or the victims being searched for. And they should be inexpensive because worrying about the loss of robots should not be a consideration for human rescuers. Blue Swarm 2.5 is the latest incarnation in our quest for an autonomous rescue robot swarm.

This paper describes our efforts to develop an effective rescue robot swarm. The paper starts by describing the past incarnations of the swarm, including the research objectives being pursued and the results obtained. Then the most recent version of the swarm, Blue Swarm 2.5, is described. Finally, the plans for Blue Swarm 3, the first fully functional rescue swarm, will be described.

Introduction

Urban search and rescue is a challenging, but very important domain for robots to operate in. Recent disasters, both natural and man-made, have demonstrated the need to be able to locate victims quickly to improve their chances of survival and the difficulty of operating in an urban disaster environment. Locating victims within the first 48-72 hours of a disaster is critical to their survival as the odds of surviving diminish rapidly with the passage of time, dropping almost to zero after 72 hours (Murphy 2002). The urban search and rescue environment is a difficult environment to operate in because it is highly unstructured and hazardous. Even if the floor plan for a collapsed or partially collapsed building is known beforehand, it will have little relevance to the floor plan after the collapse. Even an intact building could have little resemblance to its pre-disaster appearance if the floors are covered with rubble, like upset furniture and office waste. Many disaster sites also contain hidden hazards, like leaking gasses, flooding, and fires. Another consideration in the design of a robotic search and rescue system is its acceptability to human rescue teams. Rescue teams want robots to assist them without requiring specialized knowledge to operate them and without increasing the personnel requirements at the disaster site (Murphy, et al. 2000). Rescuers need to be doing their jobs rescuing survivors, not operating robots. Most importantly, rescuers need to have some degree of confidence that the robots are not going to pose a hazard to rescuers or survivors or present an obstacle to rescuers trying to do their jobs (Murphy 2002).

Taking these challenges and constraints into consideration, we decided that a swarm of small, inexpensive autonomous robots would be the best approach to the urban search and rescue problem. A swarm of robots can quickly cover a disaster area, even if it is highly unstructured. Swarms of robots are also more robust, since they can handle the loss of individual robots and they can provide multiple communications paths when communications are hindered by rubble, smoke, and dust. If the robots are autonomous, they can act as a force multiplier for the human rescuers at a disaster site, without requiring specialized knowledge to operate them. And by being small and inexpensive, they don't pose a hazard to rescuers or survivors and rescuers don't need to be concerned about the potential loss of some or all of the robot rescue swarm.

The Blue Swarms

Utah State University has been involved in the American Association for Artificial Intelligence (AAAI) Urban

Search and Rescue (USR) robotic competition since 2000. Each year, we have fielded a robot swarm or a robot that addressed an element of the overall development of a robotic swarm that could tackle the challenge of robotic rescue. The Blue Swarm 2.5 at this year's competition continued that trend. The Blue Swarm name is derived from the Utah State mascot, Big Blue, and the fact that the first swarm consisted of little blue robots.

Blue Swarm

The focus for 2000 was on exploring the bottom-end of the cost and complexity spectrum for robots making up the swarm. The objective was to build a swarm of six robots with simple collision detection sensors to determine if sufficient area coverage could be achieved using a relatively unsophisticated control algorithm. To this end, the Blue Swarm was built from modified *Red Fox* toy cars, a remote-controlled car with two separate driving motors readily available (at the time) at K-B toy stores nationwide for under $10. This toy car, currently marketed by Echo, was the same toy car used by Jonathan Connell as the basis for his Photovore, described in (Connell 1988). The *Red Fox* cars were modified by connecting their motors to the Tutebot circuit from (Jones and Flynn 1993). The Tutebot circuit is a reactive circuit consisting entirely of analog electronic components. The heart of the circuit is four 5 volt relays. The circuit reacts to collisions sensed by one of the two bumper switches mounted on the front of the robot, which causes the robot to back up, turn, and then go forward in a new direction. It was our belief, based on simulation results, that this simple approach to exploring the environment would provide nearly full coverage of the yellow area in the USR arena, which was the area best suited to small wheeled robots.

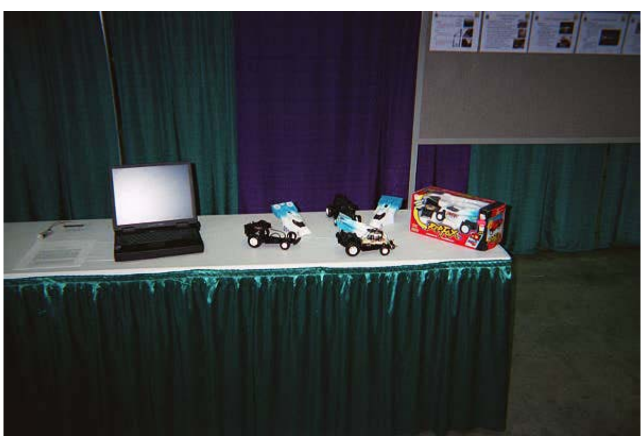

Figure 1. The Blue Swarm on display at the AAAI 2000 Mobile Robot Exhibition.

Unfortunately, in practice there were a number of problems with the Tutebot circuit. Control over the motor speed was insufficient, either being too slow or too fast, which would either prevent the robot from moving over small obstacles or would cause it to collide with obstacles at too high a speed to react properly. Even more critical was the frequent failures of the relays, which wouldn't allow the robot to operate for more than a short period of time between failures. The cause of the frequent failures was never determined. Because of these problems, the Blue Swarm never competed in the USR competition in 2000. Instead, a display illustrating the conversion of a *Red Fox* car to a simple robot was presented in the Mobile Robot Exhibition, as shown in figure 1.

Blue Swarm 2

In 2001, the lessons learned from the Blue Swarm were applied to the Blue Swarm 2, as discussed in (Boldt and Stormont 2001). The Blue Swarm 2 still used the *Red Fox* toy cars used in the Blue Swarm as a base, but a slightly more sophisticated control circuit was used. The Blue Swarm 2 robots used a Parallax Basic Stamp 2 programmed in pBasic to implement the wander algorithm intended for the Blue Swarm. The robots still used only bumpers to detect obstacles and the objective was still to determine if the simulation results that showed that a small swarm of robots could cover the yellow area sufficiently were correct. In addition to turning in a random direction when an obstacle was encountered, the Blue Swarm 2 robots would also periodically turn in a random direction just to ensure a truly random wandering behavior.

The results from the Blue Swarm 2 were very encouraging. Five robots were fielded in the USR competition in 2001 and they consistently managed to explore all of the accessible portions of the yellow area in a reasonable period of time. Our simulation results had been validated in practice. However, while our research objective had been satisfied in 2001, we didn't score any points in the competition because the robots couldn't detect a simulated victim or communicate with the outside world. Some of the Blue Swarm 2 robots are pictured in figure 2.

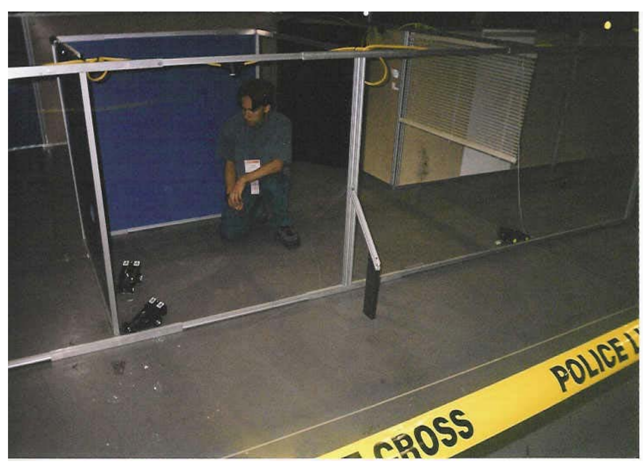

Figure 2. Team member Brandon Boldt observes the behavior of three Blue Swarm 2 robots in the yellow area.

Blue Swarm Sentinel

Recognizing that it would be necessary to identify victims and report results to human rescuers at a base station, the Blue Swarm Sentinel was developed for the 2002 USR competition. The Blue Swarm Sentinel was a modified Radio Shack *Sentinel* radio-controlled tank. The modifications are described in detail in (Bhatt, et al. 2002). The objective for 2002 was to integrate a sensor into the robot that could detect the heat signature from a simulated victim and then report that victim's location to a rescuer GUI using an RF modem. The Blue Swarm Sentinel would also be able to report the locations of obstacles encountered, thus building up a map of the area explored on the rescuer GUI. The Blue Swarm Sentinel used an internal network of three Parallax Basic Stamp 2e microcontrollers. The Basic Stamps communicated with each other using serial communications and with the rescuer GUI via separate transmit and receive channels. Each stamp had a specific function, either motor control, sensor monitoring, or communications. The Blue Swarm Sentinel also carried an X10 wireless color video camera on its turret to provide a video feed to the human operator. The human operator could manually drive the tank to a desired location using steering commands on the GUI and then switch over to autonomous mode by clicking a button on the GUI. The ultimate goal was to have the Blue Swarm Sentinel act as a coordinator and communications node for the Blue Swarm 2 robots. It would be able to discover items of interest on its own and also observe when one of the Blue Swarm 2 robots had made a discovery. The Blue Swarm Sentinel is shown in figure 3 with its base station RF module.

Figure 3. The Blue Swarm Sentinel and its base station RF module.

Unfortunately, the Blue Swarm Sentinel never competed in 2002. Just prior to the competition, several RF components failed. Also, the team was never able to satisfactorily resolve synchronization problems with the serial communications between the Basic Stamps. The team had to find an alternative to compete in the 2002 USR competition, so the Breadboard Special was built. The Breadboard Special was built using a second *Sentinel* chassis. The motors were connected via an H-bridge to a Parallax Board of Education. A second Board of Education monitored a scratch-built ultrasonic sonar sensor and a Parallax compass application module. The robot was supposed to communicate with the base station using a Parallax RF transceiver module, but the module never had sufficient range due to a large percentage of structural steel in the convention center that affected all of the competition participants. The Breadboard Special did manage to explore the arena somewhat, although its limited sensors meant it would frequently get stuck on obstacles. And the usefulness of the rescuer GUI was never demonstrated due to the communications problems. The Breadboard Special is pictured in figure 4 as it prepares to enter the USR arena.

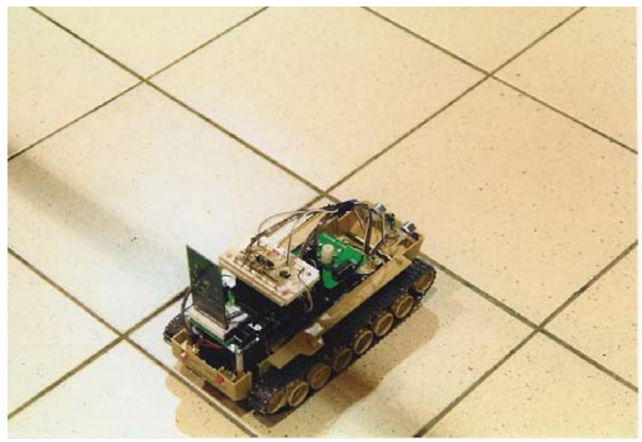

Figure 4. The Breadboard Special prepares to enter the USR arena.

Blue Swarm 2.5

This year's entry in the USR competition focused on issues of sensor characterization, sensor fusion, and attempts to resolve the communications problem from 2002. It was called Blue Swarm 2.5 because, even though it was using a different set of robots than Blue Swarm 2, it was really just a refinement on the swarms that had gone before and wasn't attempting to develop any capabilities that hadn't been present in either the Blue Swarm 2 or the Blue Swarm Sentinel. Blue Swarm 2.5 consisted of two Parallax BoeBots with a Basic Stamp 2e taking the place of the standard Basic Stamp 2. (The Basic Stamp 2e is an extended memory version of the Basic Stamp 2.) The BoeBots also had a crawler kit replacing the wheels that are normally found on the BoeBot. For sensors it had a Devantech SRF04 ultrasonic rangefinder for medium- to long-range obstacle detection, a Sharp GP2D02 infrared rangefinder for short- to medium-range obstacle detection, a pair of infrared emitters and detectors for collision avoidance, a Melexis MLX90601 infrared temperature sensor to detect the heat signature from simulated victims, a Parallax Compass AppMod for heading determination, and a CMUCam for color blob detection. The BoeBots also had either a Parallax 416 or 433 MHz RF transceiver for communicating to the base station. Instead of a rescuer GUI, this year the sensor data was being gathered in a data file to allow later analysis of the data to provide characterization of the sensor data to determine sensor confidence levels at various ranges and in different conditions that could be incorporated into the next iteration of the Blue Swarm. See figure 5 for a picture of the Blue Swarm 2.5.

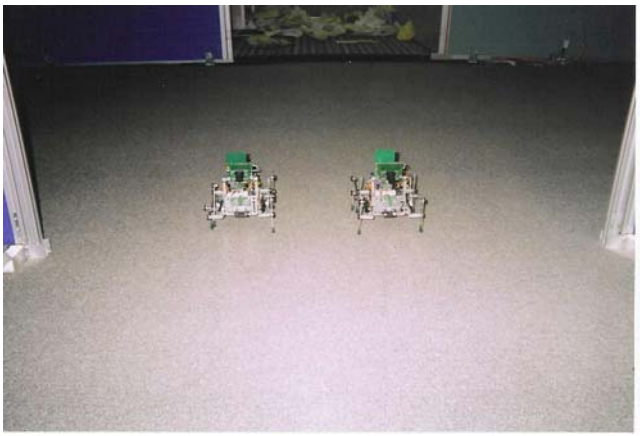

Figure 5. The two robots making up the Blue Swarm 2.5 prepare to enter the yellow area of the USR arena.

In the actual competition, the most serious problem encountered was a problem communicating to the base station. This wasn't the same problem encountered in 2002. This time there was a synchronization problem between the BoeBots and the base station. Because the serial communication routine was contained in the same program loop that also contained the sensor checking and movement routines, the communication system couldn't communicate until its portion of the program had been reached. If the communications routine was running all the time, there was no problem communicating to the base station, even with both BoeBots communicating simultaneously. But when the communications routine could only communicate part of the time, it was unable to synchronize communications with the base station, even when flow control tokens were used. The problem was that the RF transceivers would send out a signal whenever power was applied, which the transceiver at the base station accepted as data. If an attempt was made to use a start token, the base station would never accept any data. Even though this problem was worked throughout the competition, a resolution for the problem was never found. Thus, we were unable to collect the sensor data which was one of the primary objectives for Blue Swarm 2.5.

On the positive side, even though the Blue Swarm 2.5 consisted of only two robots, they did manage to consistently explore all of the accessible parts of the yellow area and did make some test runs in the orange and red areas, to varying levels of success. The crawler kits did allow the robots to handle some obstacles a wheeled BoeBot would not have been able to handle. But there were some problems with the crawler kits. Because the legs were made of relatively thin metal stock, they could get bent by traversing some of the more difficult obstacles. They would also bind at the joints if they weren't regularly lubricated. More serious was a problem with getting stuck on long, thin obstacles like window blind mounting rails or pipes. Figure 6 shows the unused nylon roller ball mount on the back of a BoeBot stuck on the end of a pipe, which prevented the BoeBot from moving any further. This wasn't as great a problem as the front and middle legs clamping down on obstacles. The front legs would go over the obstacle and then clamp down on the obstacle as the front legs moved backward and the middle legs moved forward. At this point, the servo motors would stall and reset the Basic Stamp, effectively shutting down the robot. (At least the robot wouldn't keep trying to move the servos until it caused damage to them.)

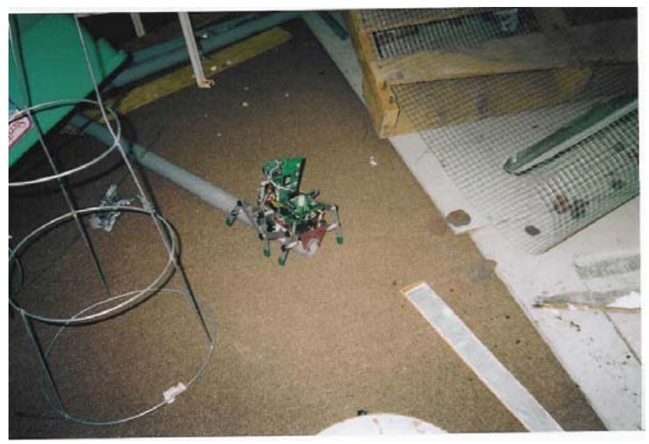

Figure 6. The nylon roller mount on one of the BoeBots (the nylon roller is not installed in the crawler configuration) gets stuck on the end of a pipe in the red area of the USR arena.

Figure 7. One of the Blue Swarm 2.5 BoeBots has flipped over while trying to climb up the ramp in the orange area.

Figure 7 illustrates another interesting problem resulting from the configuration of the BoeBots in Blue Swarm 2.5: because the robots were top-heavy, even a minor incline, like the ramp in the orange area, would cause the robots to flip over and do a dead bug imitation. The robot would continue to swing its legs in the air until it was manually shut down. The lesson learned from all of this was that a legged configuration is probably the best for the USR competition, but the legs need to have greater step clearance and be individually controllable so they can be freed when they become trapped or adjust for inclines. The other lesson was that the next swarm needs redundant communications channels in case the RF system doesn't work – something we actually realized in 2002, but were unable to do anything about for this year's entry.

Plans for the future: Blue Swarm 3

For next year, we plan to use the lessons learned since 2000 and build the first fully functional robotic rescue swarm. We expect the swarm to consist of at least twelve robots. The robots will be legged and have most of the same sensors that were on the BoeBots in Blue Swarm 2.5. The CMUCam may be replaced with a camera that is capable of sending still frames to the base station. The robots will also have redundant communications channels – both RF and infrared. They will be programmed with a swarm behavior that causes individual robots to be repulsed by other robots and by obstacles that don't show signs of being a victim, until they only have line-of-sight communications with two neighboring robots. At that point they will stop moving and become part of a dynamic communications network created by the robots in the swarm. The network will be used for creating a map of the area that will be relayed back to the base station receiver. Some initial simulations have been done for this behavior and have shown great promise in all areas of the USR arena. Figure 8 shows a screen shot of one of these simulations that was done in StarLogo and was described in (Stormont 2003).

Another objective for the 2004 USR competition is to get more students involved. In past years, the team has varied from one to four students. For next year, we would like to get at least eight students from electrical and computer engineering, mechanical engineering, and computer science involved. The AAAI mobile robot competitions always provide a rewarding experience for students involved in them and the USR competition provides many opportunities for student participation from a wide range of backgrounds. We are looking forward to a productive and interesting challenge in San Jose.

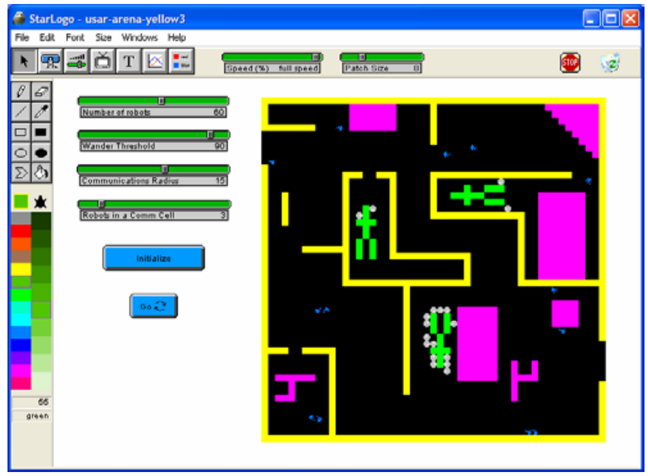

Figure 8. A StarLogo simulation of a robot swarm acting as a communications network in the yellow area.

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