Search and Rescue: An Educational Test-bed for Robotics Systems Integration

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Abstract

We present a search and rescue problem as a final project for an undergraduate-level Introduction to Robotics course. To successfully complete the project, a participating robot has to solve four sub-problems that are currently among the most actively researched areas in robotics: computer vision, manipulative robotics, localization, and multi-robot cooperation. By immersing the students in the details of these sub-problems, we aim to have them develop a deeper appreciation of the difficulties. In many cases, this experience also motivates the students to pursue research in those areas. We describe several example systems that use easily obtained hardware components such as LEGO pieces, the Handyboard, sonar, compass, CMUCam, and servomotors. However, each of the sub-problems is easily extendable to increase the complexity/creativity of the solution as well as accommodate for new and more powerful devices.

1 INTRODUCTION

The objective of our upper-level undergraduate Introduction to Robotics course CS445 is to explain how to build a robot and to describe the current state of the field of robotics. In our curriculum design, the class has both a lecture and a laboratory section, each taught in separate time-slots and classrooms. The lectures make sure that all the general knowledge is formally covered, while the laboratory sections enable the students to get hands-on experience in implementing a robot. An ideal setup would be to have the lecture contents and the laboratory activities reinforce each other.

One of the difficulties in realizing this relationship is that the students have little or no prior knowledge of robotics. Even though the robotics course CS445 is classified as an upper-level elective class, the pre-requisite is only a freshman programming course. However, software is only one part of the requirements. The students also have to construct the hardware (robot body), and integrate both parts.

Fortunately, the robotics platform “the Handyboard” [13] has a manageable learning curve; students can build a functional robot within a three-hour session. We can then quickly start conducting experiments with different sensors and motors, going into basic linear control theory (PID) and filtering techniques, for example. In parallel, these topics are also covered in the lectures. Afterward, however, we would like to progress to issues that are current in robotics research. The problem is: how to go about providing complementary laboratory exercises?

We present a search and rescue problem, which incorporates four current actively researched sub-fields: computer vision, manipulator robotics, mobile robot localization and navigation, and cooperative robotics. Although we still use lectures to describe cutting edge approaches, we find that when the students are challenged to solve these problem themselves, they have a better grasp of the issues involved. Even though the lab version of the problems are simplified, the tangible nature of their real world implications are still evident.

2 RELATED WORK

Search and rescue, an active application-oriented sub-field of robotics, has several international competitions (AAAI USAR, the Rescue Robot Contest, and RoboCup-Rescue) being contested [1] in challenging environments [2] and requires many resources.

One of the contributions of our course (which is similar to several others [6, 8]) is taking the essence of the search and rescue problem and packaging it such that it can be administered within an undergraduate class curriculum in the form of a competition, an effective motivational tool [3]. Our robot competition activities are well documented online [7] with examples from previous years.

In addition, by explicitly incorporating the different sub-problems (vision, manipulation, localization, and cooperation) we better connect the concepts that we introduce in the classroom with the problems the students face in their robot implementation. We believe this is an important point in our effort to make our classroom material more closely in tune with the contemporary research efforts [4, 5], and also to encourage students to pursue research in robotics.

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3 Project Design

The basic story of search and rescue is that a disaster has occurred in a remote location. A group of robots are then given the task of finding eight victims and bringing them to a makeshift hospital. In addition, the robots have to retrieve a supply box that has been previously dropped off by a helicopter near the hospital. There are points associated with these actions. The team that accumulates the most points and finishes in the shortest amount of time wins. The points and time limit for the contest is described at the end of this section.

Figure 1 illustrates the disaster area, with the pertinent actors and objects of interest: robots (blue disks), victims (green blobs), supply box (orange rectangle), makeshift hospital (yellow rectangular area) and storage space (pink square space). The field is a 12'x12' flat surface enclosed by a half-foot tall wall on all four sides. A flat environment allows for a wheeled-robot design, while the walls are critical for robot localization. The figure roughly depicts the relative sizes, with respect to the field, of the robots (most designs are about 1 foot diameter), victims (about 8x3 inches), and supply box (36"x 9"x 4").

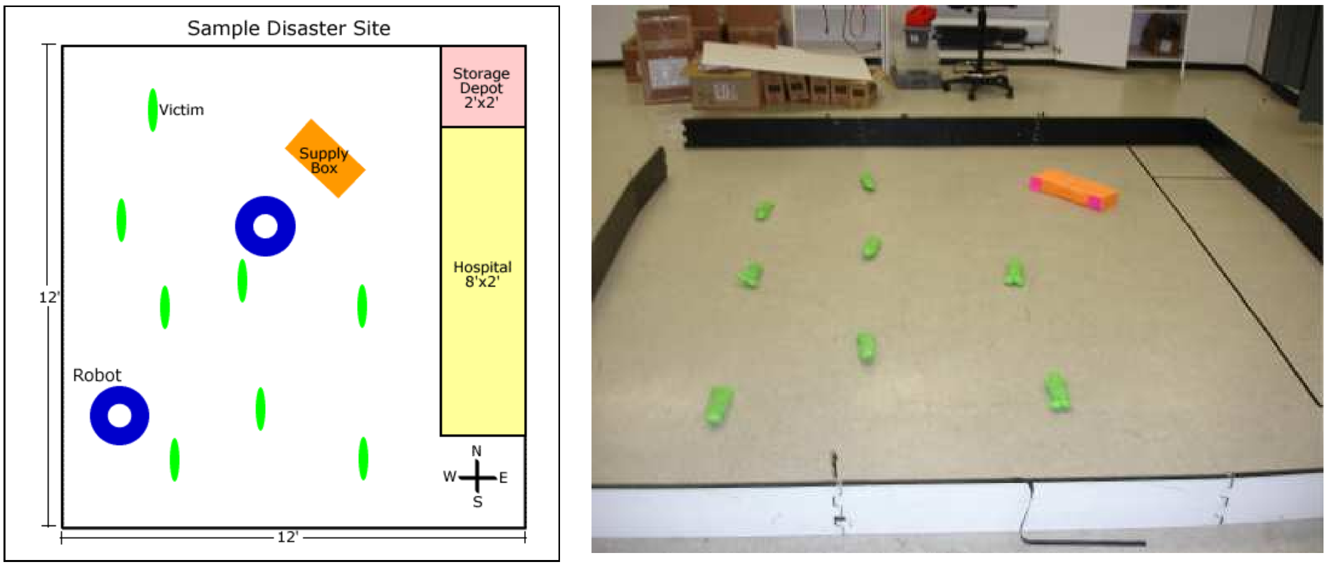


Figure 1: Diagram and Photograph of the Search And Rescue Field

To simplify the vision system, we control the colors of the field and all entities in it. The floor is a uniform gray shade, while the wall is black. On the other hand, the victims are neon green, the box is orange, and the robot can be colored in any way.

The robots enter the field from an upper-left corner opening. In addition, although exact locations of the box and the victims are unknown, we specify that the victims are roughly placed in the lower diagonal of the field while the box is somewhere in the upper-right quadrant. This information provides additional programming complexity for the search algorithms. Also, we make sure that the victims are scattered far enough apart so that the robots have maneuvering space in between them.

One rule that has to be enforced is the robots' treatment of the victims. The robots cannot run over a victim. Otherwise, the victim dies and cannot be saved for points. Also, when picking up victims, the robot needs to lift them off the ground and not drag them to the hospital.

For the supply box, an explicit collaboration is enforced: the box has to be pushed by two robots. This is because we construct the shape and weight of the box such that it cannot not be moved (or it would take a long time) by just a single robot.

Note that we do not put any implementation constraints such as what sensors the students can use.

In summary, the rules of the game are as follows:

1. The participating teams are given 10 minutes to perform all tasks (victim rescue and supply box retrieval).
2. Victims have to be off the ground when moved.
3. Each victim that is placed fully within the hospital area is worth 10 points.
4. Each time a victim is placed in the hospital area, it can be removed from the field so that the robot would not confuse itself.
5. If the supply box is moved to a location such that a majority (50%) of its base area is within the storage space, the team receives 50 points.
6. Touching a victim in an attempt to avoid it costs 2 points, on each occurrence.
7. If a robot runs over a victim, the victim is taken off the field.

4 Project Administration

In this section we discuss the particulars of the project management as well as how to go about dividing the work so that students are not overwhelmed. The class has an enrollment between 20 to 50 (typically 30) students. Given this variability, the course is assigned either 1 or 2 Teaching Assistants (TA) for laboratory sessions. Even though the TA to student ratio is not low (30:1), in practice the TA is not overburdened since we have a half hour lab lecture session where all the experiment or project requirements are discussed. In addition, we foster an environment where the students help each other. The search and rescue field, for one, is shared for the whole class, and the students need to take turns to test their system. One thing that does increase demands for the TA is the extra lab sessions in the weekends that intensify toward the end of the semester.

Each group is provided with all the equipments needed: LEGO pieces, Handyboard, and various sensors. The students do not need to purchase any of them, but they are charged with $175 lab fee. Because the course has been offered for more than 10 years, we have plenty of spare parts accumulated from purchases for replenishment.

Our CS445 class carries 4 credit hours, the highest number at our computer science department. To properly control the course load demands, we team up groups of 4 - 6 students, each team building two autonomous robots. From 4 years of using the project, we have found the main reason certain teams fail is not because of the members' lack of ability, but mostly because of time mismanagement: spending too much time on things that are not critical. To maximize the number of successful teams, we divide the requirements into three milestones.

As previously mentioned, we have 4 lab sessions (once per week) prior to the final project. The project then takes up the remaining 9 weeks, three weeks per milestone. It is important to note that the requirements of a milestone implicitly carry over to subsequent deadlines. The teams that are behind at one stage will have to work extra hard to catch up.

The first milestone requires each robot to identify a victim in front of it (no search is required), pick it up, move with the victim in its possession, and avoid a second victim placed in front of the first one. By performing the task, the team will have successfully implemented a locomotion system, a vision system, and a manipulator system.

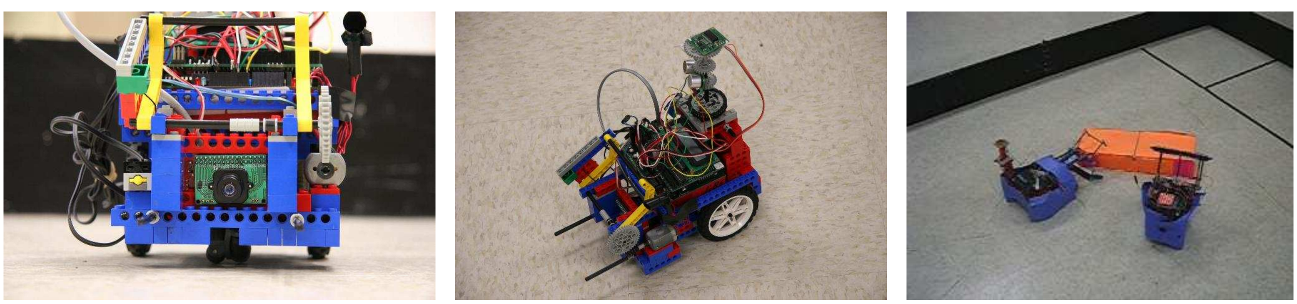
These might sound excessive for the first milestone, but we find that this forces the students to start building fully working robots early on. Because of the use of LEGO [11], no design is ever final. In fact, most teams redesign their robots multiple times over the course of the semester. Also, being able to lift a victim once is not hard, making this action repeatable and robust is far harder. In this milestone we are only looking for the former, while the latter will be achieved in the second milestone.

In the second milestone, a robot team has to rescue 8 victims in 10 minutes, all the allotted competition time. In the next milestone, this time is cut down by at least 3 minutes for retrieving the supply box. In addition to consistently be able to pick up victims, the robots also have to localize and find their way to the hospital to drop the victims.

In the third and final milestone, all tasks are due. The new addition is moving the supply box to the storage area and this requires cooperation between two robots.

5 Implementation Issues

To better prepare the lab instructor, we discuss some of the different design decisions that are involved in building a search and rescue system. We use examples from over the years, which ones are effective and which ones are overly complicated. Here, instead of dividing the implementation into milestones, we divide it into sub-systems.



(a) vision to identify a victim (b) localization to go to the hospital (c) cooperation to push a supply box

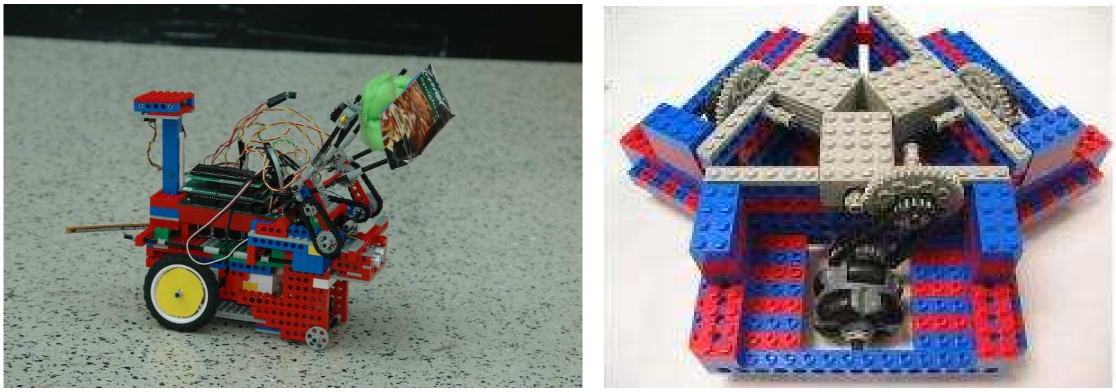
Figure 2: Different sub-systems implemented in the robot.

5.1 Building a Robot: the Locomotion System

Pertaining to the physical aspect of the robot, the two main foci are torque and maneuverability. The latter is critical for approaching and avoiding victims properly. Speed is not as important because there is plenty of time to perform the tasks considering the size of the field and that all teams use the same LEGO motors.

The main concern for torque is for the robot to be able to carry its own weight. We always advise students to minimize the robot weight as much as possible. The victims themselves are not heavy as they are dolls filled with cotton balls. The weight of the supply box to be moved is not a concern either because we allow the teams to adjust the box weight to their liking. For this task, we are more concerned with the cooperation aspect not the strength of the robots.

Figure 3 shows some of the examples of the robot locomotion implementation:a two wheel (differential) drive and an omni-directional drive, where the robot can move a move to any direction on a plane. A word of waarning, however, the omni control is difficult.



(a) Two Wheel Drive (b) Omnidirectional Drive

Figure 3: Different Robot Locomotion Designs.

5.2 Vision: Identifying the Victims and Supply Box

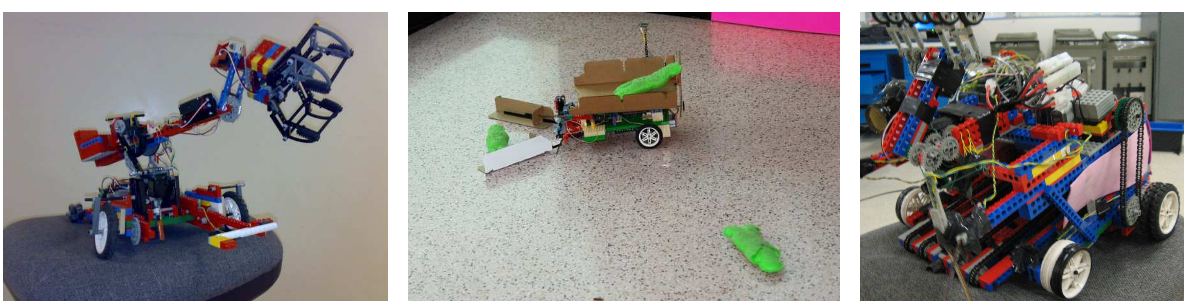
To identify the objects of interest (victims and supply box), the robot has to perform color blob detection using a CMUCam [12]. Because of the limited capabilities of this vision system, we control the environment so that shape recognition is not needed, just color thresholding.

The camera location (on the robot) is also critical in spotting a victim. If the camera is too high and pointing to a location far away from the robot, it will have a large blind spot near it. This forces the system to guess the location of the victim once its approach is reasonably close. On the other hand, if the camera is pointed down, its field of view will be limited to only a few feet in front. We find that putting the camera slightly above the ground level (figure 2(a)) provides the best view, long range with no blind spot.

5.3 Manipulation: Picking Up the Victims

The important objective in designing a manipulator is maximizing its area of effectiveness. Ideally, we would like the manipulator to be able to perform its task when the robot is reasonably close to the victim, regardless of actual alignment. This is because the vision system cannot guarantee that the robot is in front of a victim at an exact angle.

There are several ways to pick up a victim. Figure 4 show several different designs. One is using a claw; the claw grabs the victim and lifts it above the camera. Another is a scooping mechanism, where the robot digs the victim from underneath. A conveyor belt design (figure 4(c)), on the other hand, allows the robot to pick up more than one victim before returning to the hospital. The robot has an opening in the middle to store the victims, while the gate is used to is



(a) Claw (b) Scooping (c) Conveyor Belt

Figure 4: Different Manipulator Designs.

5.4 Localization: Bringing the Victims Home

The system tries to localize the robot within a Cartesian coordinate system of a square field (figure 1). The robot uses an SRF-04 sonar ([9])and a Devantech compass ([10]). The compass first point the robot perpendicular to a wall. It then uses the sonar to measure its distance to the wall. By doing this twice, one to the north or south wall, and another to the east or west direction, the robot will be able to pinpoint its exact location. Note that the north/south/east/west is a local label (within the field). They are not the global direction. We calibrate what degree the north wall is (for example) using the compass, and reference north with that value in the future.

This particular sonar has a maximum range of about 6 feet. This is why we restrict the field size to 12'x12', so that there is no dead zone in the middle if all four walls are further away than 6'.

The procedure for going to the hospital is to point the robot west, drive it to the west wall, then turn north or south and move forward/backward to make sure it is in the hospital region. In situations where a robot detects an obstacle (using vision), it must perform an avoidance procedure and re-localizes once it is out of harms way.

To minimize interference, the compass should be placed away from the battery or other electronic devices. Thus, we advice students to put the compass on a pole (figure 2(b)). Moreover, the sonar should be placed in front of the robot with no other parts occluding its transducer.

5.5 Cooperation: Retrieving the Supply Box

The procedure of retrieving a supply box (figure 2(c)) has a few steps. The robots have to identify the box (using vision) before cooperatively pushing it. However, in order to push the box to the correct direction, the robots need to be aligned properly. We decided to allow students to add smaller color markers (either yellow, cyan, or magenta) on the left and right sides of the box for each robot to target. This is helpful because, without it, the box is just one big orange blob with loose and unreliable shape.

There are many ways to synchronize the pushing procedure, either with or without explicit communication. It can be as simple as putting a flex sensor on the sides of the robots and have both start pushing a few moments after the flex sensors trigger. It can be as complex as implementing a radio frequency module and connecting it to the Handyboard.

In the Handyboard, there is an infrared communication module that can be used, although the range is shorter than radio frequency and requires line of sight. We simply extend the transmitter and receiver components using 1 - 2' cable to have it stick out of the robot body. Once the robots start to push the box, they can use the compass as direction feedback, since the path is just a straight line.

6 DISCUSSIONS & CONCLUSIONS

In order to gauge the effectiveness of the project, we evaluate the results both from the students' comprehension of the material as well as of their level of enthusiasm. In terms of comprehension, we have received mostly positive feedback on how the hands-on experience elucidates some of the issues that are not as clear to them. For example, in the lecture we go into multi-robot cooperation issues: what the basic problems are, what the hot research topics are, what other domains cooperation is applied to. One problem encountered in the lab is synchronization of action/information, a fundamental cooperation issue. This is also important in our box-pushing task, how to make both robots to push and maintain heading while pushing the box.

However, from the participation point of view, it is by and large a success. One of the most rewarding feelings as an educator is when the design of an activity fuels the students to be creative and go beyond the requirements. We witness this time and again in our lab. The students would come in for extra time, try different approaches, making the project more about learning and discovery and less about getting grades.

With that spirit, we do not put as much weight on the end competition, most of the points are already accumulated in the different milestone testings. This allows for a relaxing and enjoyable final contest. In addition, every semester, we organize a robotics exhibition at a local museum, the California Science Center [14]. The students are able to show their creations to the many elementary and middle school field trip students. On a few occasions, local network affiliates have filmed us for the evening news.

The level of interest also seems to continue once the students are finished with the course. Over the years, the project has motivated many students to further their interest in robotics research by working in one of the several labs on campus, or joining a robotics club that enters international competitions, or going on to a doctoral programs elsewhere. For schools that do have robotics research labs and graduate level courses in place, this is the kind of outcome we are looking for.

We believe the theme of search and rescue, because of its compelling nature, also helps the cause. We also think that other related themes such as securing a contaminated nuclear power plant (removing hazardous materials) would be just as credible. What matters is making sure that all the sub-problems (vision, localization, cooperation) exist within the project. We tried robot soccer in the past, for the time and equipment we have, the game is too simple because there is only one ball and most of the robots have a hard time finding it. With a theme where multiple actions can occur, from the observer's point of view, the game is much more exciting.

For future improvements of the project, we would like to scale up the complexity of the problem. In order to do that we have to improve the equipments such as to upgrade to a more powerful yet still portable processor. This would facilitate running advanced vision algorithms to solve a harder localization problems (e.g. SIFT landmark recognition).

Figure 5: Search And Rescue Exhibition at California Science Center

7 ACKNOWLEDGMENTS

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