CS476C – Senior Capstone Design in Computer Science

Project Description

Project Title: Thirty Gallon Robot, Navigation Module	
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Project Overview:

Autonomous and semi-autonomous mobile platforms have been slowly making their way from the lab into the consumer market in recent years. Whether it's small programmable toys like the Lego MindStorms kits or consumer items like the Roomba, developing mobile platforms with "brains" – which are often referred to generically as "autonomous mobile robots" – that are able to do various clever things is becoming an important new area of computer science.

Of course, learning to program and develop solutions for mobile robots requires that you have access to an actual robot to test your solutions on; there is limited fun/utility in programming some novel navigational technique for a robot that only runs in a virtual simulator! Until quite recently, classroom use of real robots was prohibitively expensive, with only the most well-funded research labs able to afford the robots themselves. In recent years, however, technology manufacturers packed more and more computing power into ever smaller and cheaper packages; other components like accurate motors, batteries and sophisticated sensors have become cheaper and available on the consumer market as well. As a result, it has now become feasible to construct simple, relatively cheap robots with a surprising amount of sophistication.

The project sponsor has been following this trend with interest, with particular focus on developing a flexible, cost-effective robotics platform to use within college level programs for educational purposes. This means first developing a low-cost, easy-to-assemble robot that has an open-ended set of capabilities, attachments, and other devices with the goal of having something that can be programmed to do a maximum number of things, i.e., would offer a large number of interesting robot programming challenges. Once you have the robot, the challenge becomes developing some proof of concept "programs" for it, that demonstrate some of the cool things the robot could do around an educational setting.

The Challenge: Building a capable, programmable robot on the cheap.

The high-level goal of this project is to develop a simple, cheap, easy-to-build and yet very capable robotic platform that could serve as the implementation target for a robotics course. Although the robot should be capable of being programmed in a large variety of ways, we have set "giving building tours of a campus building" as a concrete proof-of-concept test piece that demonstrates all of the core capabilities of the platform. Based on an overall itinerary of places to visit and some sort of internal representation of the building layout, the robot would plan a route and then take off and lead the tour…of course avoiding people and other obstacles along the way. Presumably it would also be provisioned with information displays or short explanatory videos that it can play for the tour group at stops along the way. Note that, as this is a multi-story building, the robot must be able to navigate not just hallways but the elevator, as well as doors (perhaps invoking human assistance if closed); it will not be required to manage stairs. This task and all of its implications represents the core specific functional goal of the project.

As a broader goal, the aim is to refine the mobile robotics platform to the point where it can be disseminated to any school wanting to train students in robotics on a tight budget. This will require refining both hardware and software to be as clean and easy to source/build/deploy as possible; any high school tech club should be able to join in. We envision a website that contains complete parts lists, sources, and assembly instructions, as well as a growing archive of programs developed by various community members.

Project Details: Focus on the navigational module

To help break this ambitious project down, it was split into the following three significant milestones:

I. The Basics. Build the basic mobile robot platform. Provide basic sensors, actuators and mobility and support basic programmability.

II. Add basic mobile navigation: building map, self-localization, planning/navigating, object avoidance.

III. Proof of concept. Program the robot to give tours of the NAU Engineering Building

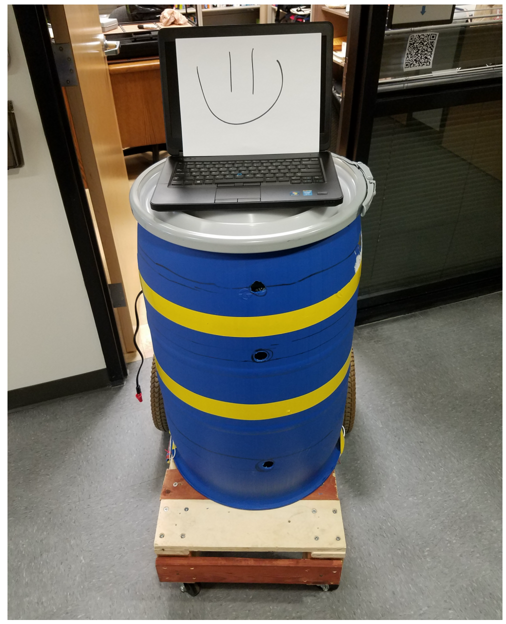

Figure 1: Currently implemented robot

Part I has been completed: the robot (Figure 1) is built, and is mobile and programmable, i.e., the physical platform is considered complete. The robot's "brain" is an onboard Raspberry Pi, and it also has microprocessors that control the two drive motors and one that controls the actuating arm. The arm will not be necessary until the robot needs to change floors in the future (i.e., to push an elevator button) but it is ready to be put into play when the robot can be navigated to the elevator

Part II is partially complete: there is a navigation module capable of gross navigation, but testing and refinement was significantly inhibited by COVID. A central challenge for all mobile robots is keeping track of exactly where the robot is. The design of the current prototype of the navigation module uses the network WIFI access points within the building to locate the robot based on signal strength from each access point. However, it takes about 8 to 11 seconds for the robot's location to be fully processed and location accuracy is not adequate for reliable navigation. Thus, this prototype will need to be refined (or simply re-designed completely) to support smooth movement in near-real time.

Minimum viable product:

The overall goal of this phase of the project is therefore centered around re-designing or improving the navigational capabilities of the robot. A clear specific goal for this team can be stated as follows: "The robot is turned on. It consults its location module to determine accurately where it is. It is told to go to location B. It navigates to location B, avoiding people and other obstacles". Specific challenges and constraints relevant to this task include:

- The weaknesses in the current navigation module prototype must be resolved, i.e., the navigation module needs to be replaced and/or refined so the robot can navigate and move in real time.
    - The current Wifi system can be used as a gross location indicator. If this system could be refined to only evaluate a given number of the strongest WIFI responses in a given sweep that is likely to improve the localizing performance; it is unknown if the WIFI access software is open source
    - Additional support via sensors, including the previously installed camera that might identify a door frame, office number, or physical building characteristic, checking the map reference, and so on, may also be used to support faster and more accurate location access
    - If there is a way around the WIFI system, this could be applied but the most likely solution will be a hybrid combination of this and other strategies
    - This is a problem looking for a creative solution
- The graphical display (i.e., monitoring interface for some human developer/monitor of the robot) of the robot's location and movement is supported in the current software product and must be maintained

- As an easy starting point, the location the robot should navigate to can be given by clicking or otherwise indicating the location on the map in the monitoring interface.
- The robot reports progress along the way as well as arrival via the monitoring interface.
- The robot is given an accurate scale map of the building to use as a resource in planning routes and navigating

A nicely functional navigational module:

- Obstacle avoidance. Real places have real and unpredictable obstacles, e.g., people, chairs and furniture pieces that get moved around, and so on. A competent navigational module will have multiple "obstacle avoidance strategies" to make progress in such situations. For instance: going around the object, waiting for it to pass if it's moving, and even asking the person to move (works for people, not chairs!).
- Due to lack of physical testing and development access during the COVID year, the robot currently only possesses a single Kinect sensor. It will likely need to be outfitted with more and/or different sensors to satisfy the requirements specified here. Software must be developed so all sensors are controlled by the master Raspberry Pi processor.
- The robot's navigation process will be considered successful when it can arrive at its location within one meter for at least 95% of navigation tasks

Stretch Goals:

- A more capable communications interface: Rather than a click on the map in the monitoring tool, the robot accepts and parses simple typed sentences that specify the target location, e.g., a room number or other reference like "second floor lobby", "men's restroom") and so on.
- An even more sophisticated communication interface: A voice-to-text converter allows a user to speak a sentence like "robot, go to the second floor drinking fountain".
- Basic building tour foundation: can define a sequence of places to navigate to, and the robot goes from one to the other.

Knowledge, skills, and expertise required for this project:

- Research and analytical skills necessary to evaluate the current state of the robot and use this information to progress to the next current goals
- Extended design skills to develop and/or refine and then implement an overlying navigational strategy
- Ability to research navigational device(s), identify and select appropriate device(s), and then integrate these into the robot system
- Learning and understanding device and/or robot programming, possibly including implementing programs within the ROS environment

Equipment Requirements:

- Laptops or other development stations
- Robot, with currently integrated components; provided by sponsor.
- Note that equipment or parts that are not free or immediately available will be purchased and/or facilitated by the sponsor.

Software and other Deliverables:

- Demonstration of a fully functional navigational module, i.e., able to specify a location and the robot arrives there shortly afterwards.
- A strong as-built report detailing the design and implementation of the product in a complete, clear and professional manner. This document should provide an effective robot user manual, and strong basis for future development and/or extension of the product.
- Code base posted on Github or other version control system, as well as stored on a local USB drive and the given laptop

- Assembled and functioning hardware and software product capable of navigating the NAU Engineering Building as specified above