RoboToy

A Robotic Toy for K-12 Robotics and Programming Exposure

ELECOMP Capstone Design Project 2024-2025

Sponsoring Company:

Intelligent Control & Robotics Lab. (ICRL)
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Kingston, RI 02881
http://web.uri.edu/icrl

Entity Overview:

For more than 50 years, robots have been confined to manufacturing facilities and other specialized application fields. But robotics technology is getting ready for widespread adoption and integration in the human society. New applications of mobile robots, both for professional use and for the general public, are being invented at an increasing pace. At the same time, new challenges arise when robots break free from the known controlled environment of factories to move into the real wide world.

The Intelligent Control and Robotics (ICRobots) laboratory at the University of Rhode Island is a world class research lab specializing in mobile and aerial robotics and multi-robot systems. Our vision is to bring cutting-edge robotic technology to application and consumers, to contribute to a better future.

The ICRobots lab includes three directing faculty members, from 2 different departments, 10+ graduate students and several undergraduate students, with $2M+ in research funding from many state and federal agencies.

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Project Motivation:

Exposure to computer science by teaching young people how to program is a way to promote greater social equity in terms of representation and access to technological professions. On the one hand, computer science skills can provide access to well-paying jobs, which could help provide greater financial stability for marginalized groups who have not had the opportunity to accumulate wealth in recent generations. On the other hand, the increased participation of people from under-represented groups in computing can also promote diversity in the field, and ultimately result in an increase in the total number of workers. The ICRobots lab is partnering with the URI COE to bring STEM programs focused on robotics in the most diverse schools in Rhode Island, across the entire spectrum of the K-12 programs.

However, tools for teaching programming and robotics in early education (K-5) are still underdeveloped. Inherently, programming requires basic skills like reading and math that are still being acquired in early stages of education, which add to the burden of learning new skills. Graphical programming tools have been developed to introduce programming foundational concepts in an easier setup, but they still require the ability to use computers and Human Interface Devices (HID) as mouse and keyboards. Moreover, they lack the contact and manipulation experience provided by physical toys, which is fundamental in early childhood.

https://spielgaben.com/why-are-physical-educational-toys-better-for-young-children/

Developing new robotic tools for early programming experience will allow to bring the best STEM education in Rhode Island since early childhood, specifically in those community that needs it the most.

Concept Design and Current Status:

This project is being presented to capstone students for the second year. In the first year, the students designed and implemented the prototype of a wheeled mobile robot (the RoboToy) with a program compartment in which it is possible to insert program blocks. Each block represents a simple programming instruction and once it is started, the robot follows program indicated by the user by inserting the blocks. Key accomplishments from the previous year include

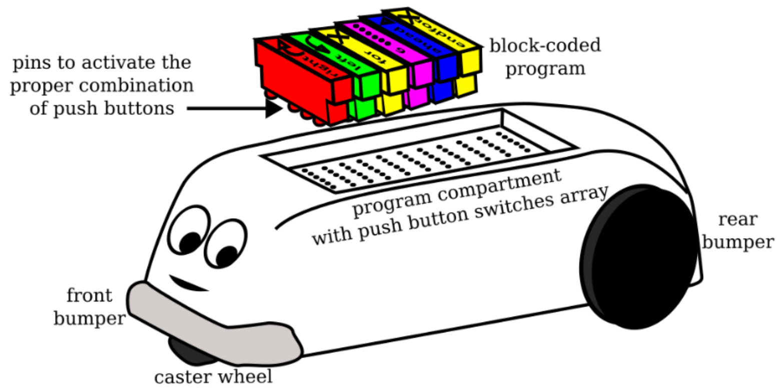

Figure 1: concept design of the RoboToy

- the design of the mechanical components of the RoboToy
- the design and implementation of the electrical components and program compartment
- the development of the prototype firmware
- the initial testing of the RoboToy

Links to the Summit Video and all Summit posters (see page 11) from last year are provided below

Video: https://www.youtube.com/watch?v=lGj8-YDGDAA&list=PLOw1iKK9kRQz7BWOMx6gfVj-6FX19qbSr&index=11

Poster: https://web.uri.edu/elecomp-capstone/wp-content/uploads/sites/481/POSTERS_SUMMIT_2024.pdf

However, the RoboToy requires more development before it can be employed in actual robotic demonstrations and potentially distributed to schools in RI. In particular, the electrical and software/firmware components must undergo a full cycle of development and testing.

Anticipated Best Outcome (ABO):

The Anticipated Best Outcome (ABO) of this project is a fully functional prototype of a single robotic kit with a ground robot and coding blocks that can be replicated and delivered to K-5 classrooms around Rhode Island. The robot must be able to read a sequence of blocks that is inserted in a slot on its back. The robot should be powered through regular AA batteries and integrate 2-4 bumper or IR sensors and one speaker, which are already integrated in the current design.

The robot should be able to read a maximum sequence of 16-32 blocks, where each block represents a line of code. The set of available commands should include typical commands for a ground robot as go forward, go backwards, go right, go left, stop, make a twist, and make a sound. In the current design, a small robotic arm with gripper is also integrated on the mobile robot and special commands must be developed for its actuation. Moreover, special blocks should exist to implement for loops and if statements. It is anticipated that the overall sets of commands could reach 16 different commands, but the overall command set will be defined during development with the TDs. The blocks representing the code lines should be visually different in a way that can be easily recognized by illiterate users.

In addition, the ABO includes the development of a graphical robot simulator that allows users to test different programs and interact with the RoboToy even if the hardware is not available. This will be a valuable development tool and a way to reach even more users. The simulator should be web-based and should have a server backend and a client frontend. The backend will handle the simulation logic, including the interpretation of block sequences, robot movements, and sensor interactions, while the frontend will provide an intuitive user interface for designing, running, and visualizing programs. The simulator will mimic the real-world behavior of the RoboToy, allowing users to gain experience with coding and robotics in a virtual environment. Additionally, the web-based nature of the simulator will enable easy access for students and educators, ensuring that the learning experience can be extended beyond the classroom and across various devices.

Activities that go beyond the ABO may include:

- Additional Sensors and Actuators: Develop expansion kits that allow users to add more sensors (like ultrasonic, temperature, or light sensors) and actuators (like grippers or additional motors). These kits would enable more complex projects, such as navigating mazes, following light sources, or interacting with other objects.
- Voice Control and Feedback: Integrate voice recognition and synthesis, allowing users to give voice commands or receive spoken feedback from the robot. This could add an additional layer of interactivity and accessibility.
- Different command modalities with larger and smaller blocks for different skill level of users

Project Details:

The current robotic kit includes a wheeled mobile robot and a set of coding blocks. The robot has unicycle kinematics with two independently actuated wheels in the back and one caster wheel in the front. The chassis of the robot is about 20 cm in length and 10 cm in width. All structural components have been modeled in CAD software and 3D printed for fast prototyping.

The onboard electronics is based on the Arduino framework to provide easy firmware coding and hardware access in the code. As depicted in Figure 1, each block has pins to activate the proper combination of push button switches. The switches will be placed in the block-coded program compartment in an array so that each block will activate only the pins on one line. The firmware will sequentially scan the array one line at a time to replicate how computers execute a computer program. Once the blocks are placed in the compartment in the order defined by the user, the robot will start moving following the sequence of commands dictated by the blocks. A series of LEDs highlights which line is being executed.

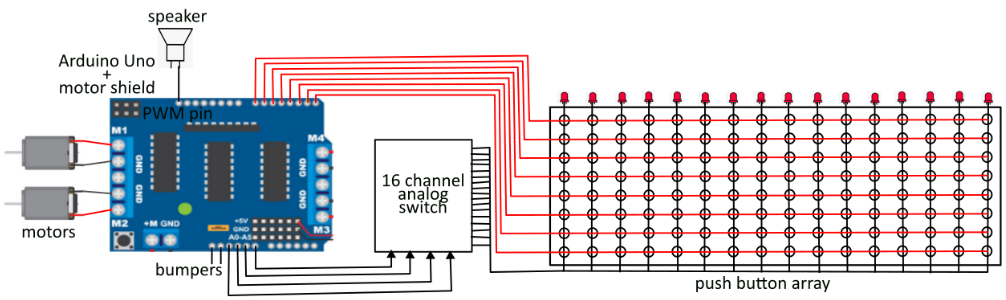

Figure 2: block scheme of the electronics.

The current implementation of the electronics of the robot follows the block scheme in Figure 2, in which the Arduino board is connected to the motors, speaker, and bumpers through the pins indicated above. The current design for the pushbutton array includes connection to the Arduino board pins through pin cables which makes it unreliable and complicated to assemble. On the hardware and electrical side, the pushbutton array should be modified to be implemented as an Arduino shield, to streamline the assembly process and improve reliability.

However, the main challenge of this project is expected to be the firmware and software development. On the one hand, the current firmware only implements simple commands and must be debugged and expanded. The implementation of if statements and for loops that accept conditions involving the sensor readings is particularly important for the final product usability and general user experience.

On the other hand, the development of the accompanying software simulation environment involves several key steps. First, the simulator must faithfully replicate the robot's behavior, including its movements, sensor interactions, and responses to different command sequences. The backend server will handle the simulation logic, interpreting the block sequences and running them as if on the physical robot. The frontend will provide a user-friendly interface where users can design and test their programs visually. This interface should allow users to place virtual coding blocks, observe the robot's simulated actions in real time, and receive feedback on the performance of their programs. The simulation environment will also include various virtual scenarios, such as obstacle courses or maze navigation, to challenge and engage users. Additionally, the simulator will feature options to save, share, and load programs, encouraging collaboration and iterative learning.

Hardware/Electrical Tasks:

- Modify the current button array design to be attached as a shield on the Arduino board

Firmware Tasks:

- Design the firmware architecture as a Finite State Machine.
- Implement elementary robot commands (actuate motors and speaker).
- Read robot sensors.
- Define a list of commands and encode them into bit strings.
- Implement the logic to activate, read, and execute the push button array.

Software Tasks:

- Create the simulation backend to replicate robot behavior based on input sequences.
- Design and implement a web-based frontend for users to create and test programs.\
- Integrate virtual sensors, motors, and environmental interactions in the simulator.

Joint Tasks:

- Integrate the electronics, firmware and hardware.
- Define sample block sequences of increasing difficulty (e.g., from a simple sequence of elementary commands to infinite loops to navigate the environment based on sensor readings with nested for and if statements).

- Define metrics to evaluate the execution of the block sequences.
- Test and evaluate the sample block sequences. Use the feedback to debug and re-engineer the hardware and software design until all metrics are maximized.

Composition of Team:

2 Electrical Engineers & 2 Computer Engineers.

Skills Required:

Electrical Engineering Skills Required:

- Embedded programming
- Experience with fast prototyping
- Familiarity with computer architecture
- Familiarity with robotics or concurrent enrollment in ELE456.

Computer Engineering Skills Required:

- C and embedded programming
- Familiarity with software architecture and organization
- Experience with embedded systems and Arduino
- Experience with complex systems and/or machine language and/or computer architecture design is a plus.

Anticipated Best Outcome's Impact on Company's Business, and Economic Impact

The developed robotic kit will serve as a prototype for a final product that will be produced and delivered to Rhode Island schools. Achieving the ABO will assist the ICRobots lab in its mission to bring robotics, programming and STEM in the communities that needs it the most. By doing so, the ICRobots lab will be able to inspire a generation of Rhode Island students, establishing itself as the center of robotics in Rhode Island. In the long term, this will attract a diverse population of high-quality local students to the ICRobots lab.

Broader Implications of the Best Outcome In Rhode Island:

Providing early childhood access to STEM education is considered as one of the most effective tools to foster social equity among underrepresented communities. A successful outcome of this project will help bringing robotics and programming in the most diverse K-5 schools in Rhode Island. On the one hand, this will improve early education in STEM in Rhode Island. Students within this program will take the first step towards a successful career in high-paying tech jobs that will allow them to improve the economic condition of their communities. By partnering with the COE, the ICRobots lab is planning to reach out to the communities that are underrepresented within the tech industry, in order to create a more diverse environment and foster social equity. On the other hand, establishing the ICRobots Lab and URI as a recognized international research facility in robotics will allow those very same local students to continue their education and career in Rhode Island. Eventually, the synergy between these two effects will allow Rhode Island to position itself as an international hub in the tech industry and improve its economic foundations.