Bridging the Sustainable Digital Divide in Artificial Intelligence Enabled Robotics Education

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Abstract

This paper will examine and demonstrate the feasibility of an efficient, sustainable, and affordable educational platform for advanced robotics concepts, which is suitable for multi-robot, human-robot interaction, and autonomy research applications. It will also explore the need for educational resource support, and detail the platform's use in service learning projects intended to introduce advanced robotics concepts, wearable devices and applications at the undergraduate level. A brief comparison of available platforms with similar capabilities will be made in order to demonstrate how the significant economic investment required for more advanced pre-built robotics platforms capable of performing functions, such as autonomous behaviors and navigation, presents a significant obstacle. From an educational perspective, there are few sustainable and affordable platforms from which to base a curriculum needed to support the effort to bridge the digital divide, nor are there many complete informational resources available, which would allow inexperienced users to assemble, operate, and develop applications for these systems. A functional platform will be introduced, along with current efforts to develop educational resources and improve the overall capabilities, cost, and sustainability of the proposed platform.

Keywords

Robotics Education, STEM Education, Project Based Learning SLAM, Autonomy, ROS

Introduction

AI enabled multi-robot systems have started to become critical components in both commercial and advanced scientific efforts. Companies like Ocado, an online grocery retailer, have been making use of machine learning and swarm robotics in their warehouses. Their robot work force makes use of machine learning to optimize the flow of traffic during operations to prevent collisions and increase efficiency, as well monitoring the diagnostics of the swarm members to keep up with maintenance needs and prevent downtime[1]. Outside of the commercial sector, AI enabled multi-robot systems are being utilized for complex and dangerous tasks such as exploration. In its efforts to address the many challenges with robotic space exploration, The Nasa Jet Propulsion Laboratory has developed a unified modular software system called NeBula (Networked Belief-aware Perceptual Autonomy)[2]. NeBula has been implemented on a variety of robotic platforms (tracked, quadrupeds, wheeled, and flying robots) that made up heterogeneous teams and was used to win a DARPA subterranean challenge that focused on multi-robot autonomous navigation. Its use of machine learning and mesh communication among other things allows for adaptability and rapid operations in extreme environments.

While there is much interest in the development of multi-robot systems, for many, the cost of robotics platforms can be prohibitive. There are more affordable options such as the Turtlebot3 (Burger), but they lack many capabilities that researchers are interested in, such as the ability to support the growing computational demands for machine learning models, AI, or utilize computer vision. A brief comparison of platforms is made in Figure 1.

Platform	Open Source Software	Open Source Hardware	Approx. Price
TurtleBot3 (Burger)	Yes	Partial	~$559
TurtleBot3 (Waffle)	Yes	Partial	~$1400
ROSBot 2.0 (LIDAR only)	Yes	No	~$1700
ROSBot 2.0 (No sensors)	Yes	No	~$1300
MIT Racecar	Yes	Yes	~$2600
Clearpath Robotics Dingo	Yes	Yes	~$10000

	TurtleBot3 (Burger)	CARE-RP (Basic Model)
Single Board Computer (SBC)	Raspberry Pi 3	Nvidia Jetson Nano
Lidar	Yes	Yes
Wheel drop sensor	No	Yes
Light sensor	No	Yes
Bumper sensor	No	Yes
Omni IR Sensor	No	Yes
Wheel Encoders	Yes	Yes
Speakers	No	Yes
LED Digit Display	No	Yes
Price	$550	$407

	TurtleBot3 (Waffle)	CARE-RP (Full Options)
Single Board Computer (SBC)	Intel Joule	Nvidia Jetson Nano
Lidar	Yes	Yes
Wheel drop sensor	No	Yes
Light sensor	No	Yes
Bumper sensor	No	Yes
Omni IR Sensor	No	Yes
Wheel Encoders	Yes	Yes
Speakers	No	Yes
LED Digit Display	No	Yes
Cameras	Raspberry Pi Camera	Logitech C270 Webcam
IMU	No	Yes
GPS	No	Yes
Controller Support	Yes	Yes
Price	$1,399	$524

Figure 1. General platform comparison of features and cost (at time of comparison)

Another hurdle researchers and educators interested in exploring multi-robot systems face is that there is a lack of easily approachable open-source documentation for those without some background in the field. Furthermore, there is a lack of open-source documentation on implementing multi-robot systems in general. The majority of entry-level robotics documentation revolves around visualization and simulations (rviz, gazebo, etc.), which while useful, can lack key details needed for applied work or some hands-on learning activities. Much of the more comprehensive documentation that is available is targeted towards specific robot platforms rather than building a generic robot from scratch. There are a multitude of prerequisites (Python/C++, ROS, OpenCV, Linux/Bash, etc.) that need to be learned in order to work on an autonomous robot or analyze the data collected, and much of the documentation for these are outside of the context of robotics.

Initially, the authors were primarily interested in experimenting with multi-robot systems and cooperative robotics. However, it was determined that there were no suitable platforms that had the capabilities desired for a low enough cost that multiple robots could be purchased. Because of this, the project evolved into the development of the Cost-effective Autonomous Robotics Education and Research Platform (CARE-RP), designed to be suitable for applied research while maintaining affordability (see Figure2 a,b). The initial criteria laid out for the platform were that it needed to be capable of performing SLAM in order to experiment with autonomous behavior, a capability to train neural networks and apply machine learning models was required, there needed to be some way to apply computer vision, and there also had to be a way to network between robots.

The development of a project-based learning approach for robotics education and STEM outreach, that makes use of CARE-RP, began shortly after the completion of the first functional prototype[3, 4]. The undergraduate and graduate student engagement is enhanced through the use of project-based learning in the development of the platform, applications, and evolution of the platform. The collegiate engagement would involve peer learning and mentoring along with potential course development. The outreach as service learning would engage high school (secondary) students with hands-on activities applying the platform and primary education engagement through demonstrations[5]. Additionally the educational aspects of this effort could extend to discovery challenges, competitions, games, AI enabled robotics acclimation and extending the reach and availability of the platform, while enhancing its sustainability[6, 7, 8].

Only open-source software was used in the project, in an effort to keep the costs as low as possible as well as creating a suite of resources that support education and research. Additionally, the hardware selected supports this open source strategy, and promotes the sustainability of the platform with upcycled devices. This is intended to allow for more community engagement and collaboration. Currently work is being done on documentation for the open-source software and upcycled hardware used in the platform so that it can be applied in the project-based learning curriculum and related service learning efforts.

Design

During the planning and design, the use of the i-Robot Roomba as a base was inspired by the Roomblock project as a low-cost option with the additional benefit of reducing e-waste[9]. Some advantages to using the Roomba as a base were that it already had multiple sensors and wheel encoders built-in that were usable through existing open-source ROS packages. This was seen as a significant time-saver as well because any other desired hardware simply needed to be mounted to the Roomba. The robots built utilized recycled Roombas, but if no functional Roombas were available, a Create 2 programmable robot from iRobot could also be used with minor software configuration changes.

The Nvidia Jetson Nano was selected to run ROS on the robots. The ability to deploy machine learning models while maintaining a small form factor with a low power draw were the main factors that lead to choosing the Jetson, as well as the relatively low price(at time of purchase). An uninterruptible power supply (UPS) with four 18650 batteries was used to power the Jetson Nano and the sensors connected to it while the Roomba and its sensors ran off of its own internal battery.

The version of ROS chosen was Melodic because it will continue to be supported until April of 2023 and is a mature version having had 10 years for documentation to be created[10]. In order to perform SLAM, an RPLIDAR A1 planar laser scanner was selected because of its low cost and ROS support. Gmapping was the SLAM algorithm chosen and utilized the RPLIDAR A1 laser scans and the odometry information published by the Roomba's wheel encoders to successfully map out complete floor plans in different university buildings(see figure 2e)[11, 12]. Gmapping was chosen for its performance during testing as well as the ability to integrate the use of global positioning system (GPS) and inertial measurement unit (IMU) data in the future. An object avoidance and lane centering python program using a proportional-integral-derivative (PID) controller was implemented as well to demonstrate a very low level of autonomy. Currently, the work being developed is to enable higher levels of multi-robot autonomy and human computer interaction (HCI) to encourage both a more personalized learning experience, and student engagement in learning activities.

In order to implement the multi-robot communication, a wireless mesh network was created with each robot acting as a node in the mesh. The Jetson Nano lacks wireless capabilities without the use of an external module, but because of availability, Raspberry Pi 3B+'s were used to create a wireless mesh and act as bridges for the Jetson Nanos to access the mesh. Batman-adv was used to implement the mesh network on the Raspberry Pis. Batman-adv is an implementation of the Better Approach to Mobile Ad-hoc Networking (BATMAN) routing protocol on network layer 2 in the form of a Linux kernel module. A multi-master architecture is implemented in ROS which enables a multi-robot system.

Societal Impact and Ethical Considerations

There are several important ethical considerations that have been made during the development process of the platform. Because one of the primary goals is to increase participation in the robotics and machine learning fields, accessibility is a high priority. The current plan to achieve this is by creating open source education materials that cover all of the necessary prerequisite information while remaining approachable to someone with no background in the use of computers or electronics. Another key barrier to inclusion is the availability and affordability of hardware. To this end work has been ongoing to reduce as much of the costs as possible while maintaining a robust set of capabilities. In order to accomplish this the authors have been working on designs capable of utilizing upcycled components at reduced costs and improved availability, as well as cheaper components that can be purchased if needed. This is an ongoing process to implement more open source hardware as well as sustainable component alternatives to reduce e-waste. Some materials under consideration are sustainable 3D printed filaments and green PCBs. One prevalent issue discovered in development is that it is possible to create open source hardware that can be 3D printed but many people will not have access to a printer, and will benefit more from a design that utilizes more easily recycled components. However scavenging components from otherwise working devices can contribute to increased e-waste as well as creating a reliance on hardware that may be proprietary. The many ethical considerations that must be made to balance sustainability, inclusion, availability, and affordability often require trade offs and so all efforts have been made to make as flexible of a platform as possible.

Conclusions/Future Work

The goal of this work was to create a multi-robot platform for education with enhanced affordability and availability that was still capable enough to be used for applied research purposes, as well as creating the documentation for how to build and use such a robot system. While the current robots meet much of the basic design criteria there is much that can be done to refine the platform in general. Standardization of the mounting of sensors and the optimization of configurations are currently in progress. There are also plans to extend the autonomous capabilities of the platform beyond simple object avoidance and lane centering through the use of computer vision and machine learning implementations. Some parallel ongoing efforts involve edge-AI implementation with the Nvidia Jetson nano devices, along with exploring supplementary cloud resources for the platform that will allow for more future growth in its functionality and learning potential supporting common development environments for students Another important ongoing effort is the continued development of educational resources for use in coursework that covers Linux, Python, ROS, OpenCV, and networking concepts. Some efforts besides general functional improvements that can be worked on in order to refine the platform would be to further address the sustainability of the components needed to build it as well as developing open source hardware for parts that are not able to be sourced reliably through the up-cycling of electronics. This could entail the use of more environmentally friendly materials as well as reworking designs to make use of easily salvageable components that would have otherwise contributed to e-waste. Currently the majority of mounting solutions are non-standard across the different robots that have been assembled in an effort to encourage the use of items that are generally available but this will likely cause issues with the repeatability. Work is being done to standardize the design in a way that it is still able to make use of upcycled components for which sources and safe methods of extraction have been identified. The use of alternative materials in the 3D printing of parts is being explored, as well as the designing of green pcbs (printed circuit boards) that can be released as open source files.

Long term goals for this project are the development of an inclusive community that can be utilized to spread awareness of AI, ML, and robotics, while promoting cooperative efforts to develop sustainable designs and applications. Given the appropriate resources an increase in public awareness can be accompanied by the creation of more educational resources and opportunities to help transition skilled workers, create better informed policy makers, as well as inspiring new community leaders during a period of increasing automation.

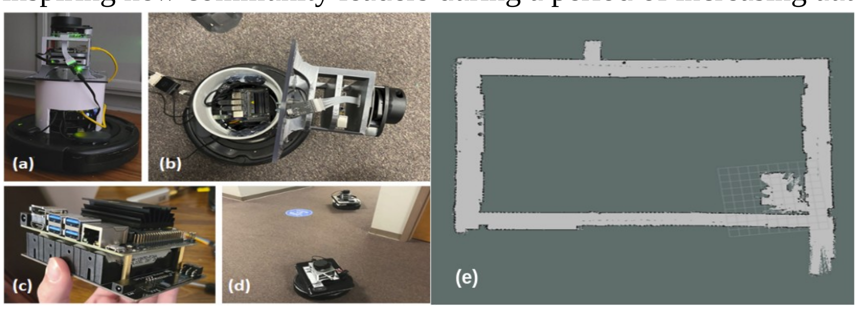

Figure 2. (a) Full-body view of CARE-RP. (b) View of CARE-RP with top hatch open. (c) Jetson Nano with UPS. (d) Alt. models cooperatively mapping an area. (e) 3rd Floor of Grimsley Hall at the Citadel.

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