Robotics for the Streets: Open-source Robotics for Academics

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***Abstract*—Open-source hardware are designs that are publicly available for anyone to modify, distribute, make, or sell. Open-source software is source code that anyone can access, inspect, modify, improve, and distribute. Open-source robotics builds upon the principles of open-source software and open-source hardware. The Open-Source Hardware Association (OSHWA) has a goal to encourage research and foster technical knowledge by making it more accessible and collaborative.**

The "Robotics for the Streets" project has a goal to expand open-source hardware in academia by documenting how to use it for service, teaching and research by making a library of resources for others to follow. There is a secondary goal of diversifying science, technology, engineering, and math (STEM) by using open-source robotics to increase access to and visibility of STEM technology for marginalized, minoritized, and under-resourced communities.

This paper will describe the design, creation and dissemination of the open-source mobile robot platform, Flower∞Bots. Flower∞Bots consist of three robots at the novice, intermediate, and expert levels including Lily∞Bot, Daisy∞Bot and Rosie∞Bot, respectively. These robots have the flexibility and modularity for modification based upon the user's needs. The benefits of this platform include the ability to be appropriate for any level and used for a variety of use cases. This research project is a unique, novel, and innovative practice for engineering education and research because it encourages diverse perspectives and voices to contribute to the creation and improvement of technology.

It was hypothesized that this educational robotics platform will serve as a model and pathway for teachers, professors, practitioners, and STEM enthusiasts, with limited resources to engage in robotics outreach, teaching, and research. The platform and guidebook will enable teachers and academics to meet their professional development goals at a low cost.

Keywords—mobile robotics, open-source hardware, open-source software, engineering education, robotics education

I. Introduction

Robotics is an ideal field for recruiting diverse populations to STEM due to its many multidisciplinary connections including science, technology, engineering, arts, math, sociology, and more. The intersectional nature of robotics means that it can be used by a broad community of users with diverse skillsets and interests. However, there are several barriers that inhibit some communities from being able to access the benefits of robotics. One disadvantage is that the technology can sometimes be cost prohibitive. Secondly, interested parties may lack the necessary skills and knowledge to know where to begin. Furthermore, it may be difficult to connect with the experts and learning materials to reduce the learning curve. Also, some platforms are overly prescriptive or restrictive and may not exactly meet the needs of the user. It becomes more difficult to achieve more advanced learning objectives, once all the provided learning resources are completed.

Open-source robotics attempts to address these needs and close the gap by evening the playing field. The features of open-source hardware include the design, production, assembly, and programming of some technology. This enables it to be inspected, modified, improved, and distributed. It is this unique quality that may enable increased access to these technologies by under resourced, marginalized or minoritized populations in STEM. Having the ability to update the robot platform to be used for service, teaching and research can elevate it from being seen as a children's toy to one used for creativity and innovation. The creation of a customizable platform affords the flexibility to allow the user to alter the platform as they see fit to meet their needs. Open-source hardware will also activate a larger community of support to contribute to the development and improvement of the platform by sharing use cases and documentation. In this way, the users crowd source the process to expedite the capabilities of the platform [1]. Research indicates that the best robotics systems are created when there is collaboration between diverse users and researchers. Therefore, it is vital to lower the barriers and create more opportunities for all people to work together to improve robotics technologies [2]. The creation of a low-cost, simple, intuitive, modular platform will enable users to learn about the fundamentals of robotics, programming, mechanics, and electronics without becoming overwhelmed with complex software or hardware.

The open-source mobile robot platform created for this research were the Flower∞Bots consisting of Lily∞Bot, Daisy∞Bot and Rosie∞Bot. These novice, modular and flexible platforms enable the user to engage with the platform based upon their skill level.

The goal for this research is to enable academics to meet their professional development goals with a low-cost, modular, flexible and accessible educational platform to engage in service, teaching, and research. There is also a secondary goal to democratize access to robotics technology for diverse populations. It is hypothesized that the creation of this platform will meet the following objectives:

- Educators will be able to use the Flower∞Bots platform for service to recruit novice users to get them interested and excited about STEM,
- Educators will be able to use the Flower∞Bots platform to teach electronics, software, programming, robotics, and design to intermediate students,
- Educators will be able to use the Flower∞Bots platform to teach advanced robotics concepts or conduct research with expert users.

II. Literature Review

A literature review was performed by searching for open-source hardware, open-source software and open-source robotics in engineering education. The goal was to identify what others had done to compare and contrast with the Flower∞Bots platform. The literature found was separated into open-source robots primarily used for research or education.

A. *Open-Source Robotics for Education*

The first platform was WitBot, an open-source, low-cost, and user-friendly robot designed to be highly customizable [3]. It aimed to provide alternatives to existing educational robots, which are either very expensive or very limited in features. The robot was compatible with a wide range of programming languages and expandable with additional parts or software. Like the Flower∞Bots, it had a price point of approximately $50. It used a 3D printed chassis for simple assembly and flexibility. However, this project had a primary goal to teach programming to elementary school children, thus a more limited audience than Flower∞Bots.

Mondada et al. [4] designed Thymio, an open-source educational robot with a compact, durable design and a wide variety of sensors and actuators. Similar to the WitBot, these authors had the goal of solving the problem of limited access, limited flexibility, and the high cost of educational robots. At a slightly higher price point of $130, Thymio aims to offer educational resources for all ages and skill levels. To achieve this goal, there were options for programming including visual, graphical, and text based. Thymio used injected-plastic mechanical parts with a printed circuit board for electronics. However, this model does not offer the hardware flexibility or potential for building circuits that the Flower∞Bots provide.

Darrah et al. [5] at The Institute for Software Integrated Systems at Vanderbilt University developed an open-source robot to teach an AP Computer Science Principles curriculum and Computational Thinking concepts. The authors proposed that educational robotics promote STEM learning for students. However, similar to Mondada et al., they found that the most popular educational robotics platforms were LEGO® and VEX. However, these kits are expensive, proprietary, and limited. For the platform designed here, students interacted with the robot on a testbed through a GUI application or more advanced interface through a terminal and remote desktop or direct connection. Programming was completed using Python since this was the standard for Raspberry Pi®. There were limited details on the design of the educational platform although the physical platform for the robot was to drive it on a combination of a physical and virtual workspaces. Based upon a user study with a small sample set, they were able to demonstrate that it is possible to use a robot-centric model to teach computational thinking and computer science.

B. *Open-Source Robotics for Research*

One of the most well-known organizations in open-source robotics is Willow Garage [6]. Willow Garage creates open-source robotics platforms to enable scientists to collaborate by sharing resources and replicating experiments. Their work attempts to reduce the barriers of incompatible hardware, proprietary software, and intellectual property in two ways. They provide the PR2 robot platform programmed with ROS (Robot Operating Systems). The PR2 is a two-arm mobile robot designed to be used for mobile manipulation, research, and applications. ROS has become one of the more well-known middleware for creating a level of abstraction for lower-level robotics control to enable users to implement more advanced software quickly on their chosen platform.

The PyRobot is an open-source robot built on top of ROS [7]. The goal for this robot is research and benchmarking by controlling different types of robots. The use of ROS and PyRobot creates an abstraction of some low-level control so that researchers can focus on high-level artificial intelligence. PyRobot can also be used to control robots in Gazebo as part of a simulation. Since it is hardware independent it may be used to create a hardware and educational ecosystem. The open architecture makes it beginner friendly for teaching with hands-on instruction. It also allows for collaboration and iteration more efficiently on high level algorithm implementation. The key difference between this platform and the Flower∞Bots is that there was not a goal to abstract away the lower-level robot controls but rather to use that as a learning opportunity.

Herbie is an open-source robot developed as a part of a computer science course at Cal Poly State University [8]. It had multiple purposes including research, social engagement and recruiting more students to STEM and for STEM education. It was one of the few platforms with a multifaceted purpose, similar to the Flower∞Bots. It ran on ROS and was created from a Robotics Teaching kit developed by NVIDIA. An Arduino Mega was used as the offline computer for counting the encoder ticks on the drive wheels. The robot brain was provided by an on-board NVIDIA Jetson TX2 computer. A color stereo camera was used for localization and detecting obstacles. For the robot's odometry, an IMU (Inertial Measurement Unit) as well as the encoder were used. The ROS middleware was used on Linux to create a level of abstraction for managing the sensors and actuators and provide an interface for drivers. All the robot navigation was done autonomously by using SLAM (Simultaneous Localization and Mapping) that used the RGB-D camera. Similar to the PI's, this school was primarily undergraduate, and the initial work was to get the platform working at a basic level and then recruit students to develop modular projects to enhance the functionality of the robot.

Table I provides a comparison of the Flower∞Bots to several other educational and research platforms. It is evident that the proposed platform is not only more cost-effective but has more flexibility.

TABLE I. TABLE TYPE STYLES

Device	Open-Source	Modular	Education Level	Tutorials	Price ($)
Flower∞Bot	Y	Y	Elementary – Graduate+	Y	50
WitBot [3]	Y	Y	Elementary	Y	50
Thymio [4]	Y	N	Elementary – Graduate+	Y	130
Lego®	N	Y	Elementary	N	360
PyRobot[7]	Y	Y	Graduate+	Y	4,548

III. DESIGN OF THE FLOWER∞BOTS

The two main goals for the design of the Flower∞Bots were affordability and adaptability. All design choices were made with these goals in mind, so widely available materials were used for all components while maintaining modularity.

Three different designs were developed to meet different goals. Although similar in concept, they have key features that allow them to adapt to specific needs. The three models are Lily∞Bot, Daisy∞Bot, and Rosie∞Bot. Each model increases in size and complexity. Lily∞Bot is the smallest of the family and is targeted towards middle school, high school, and first-year college students. It is meant to introduce robotics to someone with no prior knowledge of robotics, programming, or electronics. Daisy∞Bot is the middle sibling and is oriented towards higher education. This robot can be used for upper-level college courses where it can execute a variety of behaviors and allow students to explore the capabilities of mobile robots. Finally, Rosie is the biggest model aimed at research in graduate school or beyond. This model is the most complex and best equipped for frontier research in mobile robotics. To make Flower∞Bots adaptive and expandable, the team decided to use a modular design. Additionally, it was designed as an educational platform with an open architecture that enables users of various skill levels to learn by seeing each component.

Figure 1 shows the 3D-model for Lily∞Bot, which was representative of all the robots. All Flower∞Bots have a lower chassis and an upper chassis, both circular. One benefit of the circular design was to enable ease when turning or avoiding getting stuck in corners. However, this design also meant that it was necessary to provide labels to indicate the front of the robot. In fact, the design included several text guides to assist users in identifying the robot parts such as breadboard, wheel, battery, controller, etc. The two chassis were connected by four square standoffs. The benefit of having the two levels on the robot was that it allowed the platform to be organized based upon power and controls as well as meeting the open architecture requirements. The bottom chassis included the battery holder and wheels. The top chassis was equipped with a microcontroller, breadboard, and peripherals (sensors, gripper, camera etc).

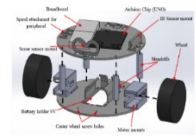

Fig. 1. 3D-model for the Flower∞Bots educational robotics platform

The chassis of the robot, motor mounts, battery pack holder, standoffs, and sensor mounts were all 3D printed with Prusa MK3S+ and Mini printers. The parts were designed in either TinkerCAD or SolidWorks and printable g-code files were generated in PrusaSlicer. There were multiple reasons that we decided to 3D print these parts. First, this allowed for a versatile design that would also be cost-effective. Furthermore, it made it simple to share with any institution or individual that has access to a 3D printer. Finally, it gave users the freedom to change or replace any part as they see fit. All the screws used were standard 3mm machine panhead screws, which are widely available. Each robot had two DAGUXXXX motors along their diameter where the baseline was through the center of rotation. For robot stability, there were also two ½" metal roller ball caster wheels in the front and back.

A. *Lily∞Bot*

Lily∞Bot was designed for novice users, including children at the middle or high school level. With parental supervision, it could also be used by elementary school children as well. This platform enables the user to engage in basic CAD (Computer Aided Design) design, 3D printing, electronics, and programming. It is the smallest of the three robots with a width of 9 inches (6in chassis + 3in wheels) and a height of 3.5 inches including the wheels. Since it was the smallest model, it had the least number of attachments. The attachments included a 4AA battery pack that was later changed to 6AA or 9V battery pack. It had space for 4 peripherals on the top chassis: front, back, left, and right. It included an Arduino Uno microcontroller and two tiny breadboards. This hardware allows for a lot of simple behaviors such as motion, sounds, obstacle avoidance, and much more.

B. *Daisy∞Bot*

Daisy∞Bot was aimed at college students, where it could be implemented as part of the robotics curriculum. It allowed students to have hands on experience with a real robot where they get to interact with digital and analog components. This gave them the opportunity to test theoretical concepts on a physical robot at a low cost. Furthermore, it provided the opportunity to redesign any parts of the robot and intgrate a wide variety of sensors. Daisy∞Bot was larger than Lily with an 11-inch width (8in chassis + 3in wheels) and 4 in height including the wheels. This allowed Daisy∞Bot to carry the Arduino Mega instead of the Uno and hold one half-size breadboard. Furthermore, it had space for 8 sensors on the top chassis and 6 more on the bottom, for a total of 14 peripherals distributed on the perimeter every 45 degrees. To power Daisy∞Bot, an extra 6V (4 AA batteries) was added to power the motors, while the 9V battery was reserved for the sensors.

C. *Rosie∞Bot*

Rosie∞Bot was built for research purposes and was the biggest robot of the family, targeted towards graduate research or experts. The increase in size to 15in (12in chassis + 3in wheels) allowed it to house a total of 22 sensors (12 on the top and 10 on the bottom). It is relevant to mention that the increase in size prevents some of the pieces from being printed on smaller 3D printers. The increase in size also made it feasible to attach more complex items such as a gripper without losing the stability of the platform.

D. Design Modifications

During the engineering design process, there was continuous improvement on the educational robotics platform. Changes were made based upon use and preliminary prototype user feedback. This section will summarize some of the more relevant updates. It provides an example of how flexibility, functionality, and cost were balanced.

The design of the peripheral attachment was a good example of how flexibility was implemented into every part of the model. Figure 2 shows how peripherals were attached to the chassis in the first version. The attachment head can be introduced and pressed into the rectangular hole. All peripherals have the same attachment head, allowing users to switch peripherals quickly and easily even after the robot was fully built. However, it was not able to hold the attachments securely enough. A second version of the design was created that used a spiral to hold the mount more securely and this is shown in Figure 3.

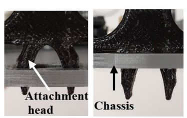

Fig. 2. Old peripheral attachments

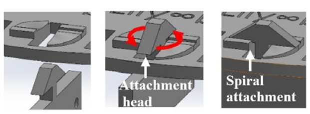

Fig. 3. New spiral peripheral attachment

The battery holder was also redesigned to hold more types of batteries and hold them more securely. Figure 4 on the left shows the first design which was dual lock. It worked for a variety of batteries and held them securely but was very difficult to remove. The second version for the battery holder used a Velcro cinch strap as shown on the right side of Figure 4. This mount allowed easier access to the batteries, and it also accommodated various sizes. However, it did not hold the battery pack as securely and would fall out or slide as the robot moved. Therefore, the battery pack was designed again. The third and current version was designed to address those performance issues (see Figure 5). This design consisted of a hole on the bottom chassis with a structure to fix the battery in place. Underneath the hole there was a cover that was screwed into the bottom. This last design kept the battery tightly attached. Since it required removing screws to change out the batteries, it was also a safer design for children. It should be noted that although there was some loss in flexibility, this design still worked for multiple battery packs as required on the various robot platforms.

The motor mounts were redesigned to be more secure so that the robot would drive straight. The initial design was like the clip in attachment in Figure 2. This was not secure and was later changed to the spiral design shown on the left side of Figure 6. Although this was an improvement, it still was not strong enough to withstand the torque of the wheels. The third version moved away from the spiral attachment. As shown in the right side of Figure 6, this mount surrounded the motor completely and used two screws to firmly attach it to the lower chassis.

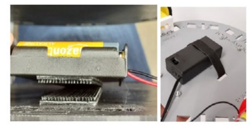

Fig. 4. Original battery holder with dual lock attachment (4AA) and version 2 of the battery holder with cinch strap (9V)

Fig. 5. Version 3 of battery holder with screw cap for 9V and AA batteries (top view on left, bottom view on right)

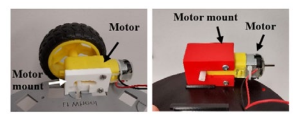

Fig. 6. Original and re-designed motor mounts to improve security

E. Instructional Labels

To aid the novice user, instructional labels were imprinted labels on the chassis to guide the robot assembly. These small hints were meant to educate the user while they built the robot. As shown in Figure 7, these labels showed where each of the components fit on the chassis (motor, wheels, breadboard, caster wheels, microcontroller, etc.). They familiarized the users with the robot and allowed them to rebuild or switch out components.

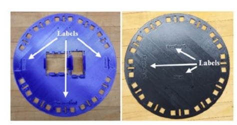

Fig. 7. Instructional labels on top and bottom chassis

IV. Curriculum and Educational Activities

To make the open-source robotics platform accessible to users with a wide range of abilities, there was a multifaceted approach used to document the work. This included blog posts and video blogs on a professional website with topics such as innovation, creativity, debugging, troubleshooting, scholarship reconsidered, and the engineering design process. The Flower∞Bots were designed in TinkerCad and SolidWorks and the modifiable files were placed in GitHub. Videos were created to demonstrate building, testing, and programming the robot for various use cases and placed on YouTube. Electrical diagrams were created in Fritzing and TinkerCad and integrated into tutorials on HacksterIO and Instructables.

Ideally, each user will use the platform in the way most suitable for their needs. However, there will still be some basic examples and use cases created to foster creativity and encourage enhancements. Furthermore, to assist users in determining their entry point into this platform, a learning road map was created (see link).

A. Educational Activities for K-12

For users who have never done robotics, electronics or programmed before, the Lily∞Bot is for novice users. The first task is to 3D print and acquire all of the parts and assemble the robot. Next, there would be an electronics introduction by learning to wire a breadboard and programming and Arduino Uno to flash an LED (Light Emitting Diode). This is typically considered the "Hello World" activity for electronics. Next, the user would play sound on a buzzer or read a pushbutton attached to their robot. The final task would be to use motion control with the TB6612 motor controller to get the robot moving. A stretch goal would be to attach a sonar sensor and get the robot to avoid an obstacle.

B. Mobile Robotics curriculum for Intermediate Students

The curriculum for the intermediate level users will use the Daisy∞Bot and build upon the introductory activities. The following list describes some recommended activities:

- Obstacle avoidance with bang-bang, proportional control
- Wall Following with PID control
- Behavior-Based Control
- Control Architectures (Hybrid, Reactive, Deliberative)
- Braitenberg Vehicles (light, temperature sensing)
- Line Following
- Color Tracking

C. Artificial Intelligence for Advanced Users

The curriculum for the expert level users such as graduate students to perform research would be implemented with the Rosie∞Bot. It also builds on the Daisy∞Bot curriculum. Examples of activities would include the following list:

- Localization
- Mapping
- Path Planning
- Simultaneous Localization and Mapping
- Computer Vision
- Color Tracking
- Teaming/Swarming
- Human-Robot Interaction

V. Conclusions and Future Work

In conclusion, open-source robotics is an ideal tool to illustrate multidisciplinary connections, recruit diverse populations to STEM, and enable resource-limited academics to engage in service, teaching, and research. This paper summarizes the design, implementation, and documentation of a set of open-source robots referred to as the Flower∞Bots. They were designed to be low-cost, modular, and flexible but also accessible to recruit more diverse communities to STEM.

To assess the usability of the open-source robotics platform, it was built and shipped to various users for evaluation. The participants were recruited from social media and several communities including Black in Robotics, Black in Engineering, Future of Mechatronics and Robotics Engineering Education, African American Roboticists, and African American PhDs in Computer Science. There was a total of 44 robots (22 Lily∞Bot, 22 Daisy∞Bot) shipped to evaluators in the United States, Canada, Africa, Barbados, Colombia, and Turkey. Due to the expedited timeline, the Rosie∞Bot was not used in the user evaluation.

Participants were asked to complete several tasks including robot assembly, motion control, illuminating LEDs, playing sounds with a buzzer, obstacle avoidance using sonar, and light tracking using a photoresistor. After completing their evaluation, users responded to a survey about their experience.

Future work for this project includes evaluating the survey results for a future publication. Also, using the results to improve the Flower∞Bots platform and continuing to create use cases and learning resources for users.

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