Educational Outdoor Mobile Robot for Trash Pickup

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***Abstract*— Machines in general and robots in particular, appeal greatly to children and youth. With the widespread availability of low-cost open source hardware and free open source software, robotics has become central to the promotion of STEM education in schools, and active learning at college/university level. With robots, children in developed countries gain from *technological immersion,* or exposure to the latest technologies and gadgets. Yet, developing countries like India still lag in the use of robots at school and even college level. In this paper, an innovative and low-cost educational outdoor mobile robot is developed for deployment by school children during volunteer trash pickup. The wheeled mobile robot is constructed with inexpensive commercial off-the-shelf components, including single board computer and miscellaneous sensors. It is remote controlled by children using smart phone app or video game controller. The robot is also equipped with air quality sensors to display air pollution levels to the children and public. The project can improve STEM education, environmental literacy and civic engagement among school children, while providing interdisciplinary service learning opportunities for college and university students. Results of a prototype mobile robot design, development, and deployment are presented to illustrate the effectiveness of the approach.**

Keywords*— *Mobile robot; STEM education; Environmental literacy; Human Robot Interaction; Active learning

I. INTRODUCTION

In the globally competitive economy of today and tomorrow, a well-educated, creative, and innovative workforce is essential for the success of nations. In the USA, the National Academy of Sciences' landmark 2005 report "Rising Above the Gathering Storm" and its 2010 update called for significant investments in science, technology, and education [1]. The 2009 National Academy of Engineering report emphasized the need for engineering education in schools (K-12), particularly focusing on the need to bring in more girls and underrepresented minorities into science, technology, engineering and mathematics (STEM) [2].

These steps are supported by extracurricular initiatives like US FIRST Robotics competitions for high school students, and FIRST Lego League competitions for elementary and middle school students. The ever decreasing cost of hardware (motors, sensors, microcontrollers, and computers) on the one hand, and its increasing versatility and power on the other has led to the popularity of robotics courses and projects in college and university engineering programs to motivate and retain students [3]. The *playful learning* potential of robotics (and the related field of mechatronics) means that college students could be involved in service learning through introducing school children to design, machines, robots, electronics, computers, programming, environmental literacy, and so on, e.g., [4], [5]. A comprehensive review of studies on introducing robotics in K-12 STEM education is presented by Karim, et al [6]. It concludes that robots play a positive role in STEM learning, and promote creative thinking and problem solving skills. It also identifies the need for standardized evaluation techniques on the effectiveness of robotics-based learning, and for tailored pedagogical modules and teacher training.

Children in developed countries also have the advantage of *technological immersion,* the exposure to the latest technologies and gadgets [7], and opportunities for *tinkering* and *making*, e.g., [8]. However, *passive learning* as exemplified by the *chalk and talk* model is still the norm in many developing countries including India, and sometimes in school systems in Western countries too [9]. Therefore, the emergence of inexpensive open source hardware and free, open source software leading to innovative Do It Yourself (DIY) robotics projects can be a boon to enterprising students, teachers, and school systems in developing countries, e.g., [10].

Another area in which the educational systems in developing countries lag is the limited outreach of research and higher educational institutions. In the USA, for example, leading funding agencies such as the National Science Foundation specifically mandate community and schools outreach as a secondary, *broader impact* of sponsored research projects [11]. National research agencies such as NASA, NOAA, and research wings of the Department of Defense too incorporate outreach in their research and development endeavors. Given the appeal of robots and machines to children and youth, university faculty and students can involve themselves in service learning, mentoring and community outreach by taking the robotics research test beds and educational systems from the lab to local schools, and to a broader audience using the power of the Web/cloud, e.g., [12].

In addition to being a catalyst for creative, hands-on education in schools and colleges, robotics is one of the disruptive technologies of our time and has significant linkages to other major technologies like autonomous vehicles, 3D printing, renewable energy, cyber-physical systems, Internet of Things, and so on [13]. Therefore, early exposure to and experience in robotics projects can contribute significantly to educating an innovative workforce of the future.

In this paper, an innovative and low-cost, outdoor mobile robot is designed and developed for interaction with school children, and to act as a roving trash can while the children are volunteering for trash pickup. The educational robot is constructed using commercial off-the-shelf materials and components, open source hardware, and free open source software. The instructions for interested school and college students to build their own robots will be made available online in future. Interaction of children with the robot takes the drudgery out of trash pickup activity and makes it a fun exercise collectively. It is hoped that the project will contribute to raising environmental awareness, help clean up the environment, and promote STEM and robotics education among children, while encouraging community service, service learning, and mentoring by college/university students. The mobile robot is also fitted with a low-cost air quality monitoring system so that reliable measurements of neighborhood air quality can be conveyed to the children and public.

II. Affordable Robots for Education

Many of the commercial, off-the-shelf robotic kits used by children in affluent countries are generally far too expensive to be adopted on a large scale in developing countries. One fifth of the world population (1.2 billion people) lives on less than \$1 a day, and about half the world population (2.8 billion people) earns less than \$2 a day [14]. By comparison, the popular LEGO EV3 Core Set costs around \$500, an older LEGO Mindstorms NXT 2.0 kit costs \$650 or more, and a VEX Dual Control Starter kit costs more than \$800 (the actual prices in developing countries are much higher due to shipping cost and import duty).

In the above context, engineers, technologists, researchers, and educators need to pay special attention to the **4A**s of their technologies and systems for benefiting the population at the *bottom of the pyramid*, viz., Awareness, Accessibility, Affordability, and Availability [15]. In fact, several universities are now offering project-based courses on Design for Extreme Affordability, and competitions are conducted to encourage the design of ultra affordable robots for citizens of developing countries, e.g., [16]. Luckily, the widespread availability of low-cost open source hardware (microcontrollers, microcomputers and accessories), free open source software and increasing availability of and awareness about materials, tools, and electromechanical, electronic, computer, and networking components now facilitates building affordable robots, 3D printers, CNC machines, etc at a fraction of the cost of commercial machines using DIY and Build Your Own (BYO) approaches. While many of these systems may not have the accuracy or capability of commercial systems, they are quite sufficient for satisfying the needs of students, faculty and even researchers in both developing and developed countries, e.g., [17]-[19]. Several low-cost open source mobile robot platforms in literature are identified in [6], e.g., MIT SEG, Harvard Kilobot, etc. These robots are small in size and typically meant for indoor use. Outdoor and large-sized robots can also be more appealing for the children to interact with.

III. Educational Outdoor Mobile Robot for Trash Pickup

A major public health problem facing many developing countries, particularly India, is a lack of sanitation and uncollected trash littering the streets, roads, and sidewalks. Realizing the seriousness of the situation, the Indian Government has launched a *Clean India* (*Swachh Bharat*, in Hindi) mission on October 2, 2014. The goal is to make India 'clean' by October 2, 2019 (birthday of Mahatma Gandhi).

One of the authors has had experience in using underwater robots (remotely operated vehicles, ROVs) in promoting environmental education among school children [5]. In various Disney theme parks during 1995-2014, a radio-controlled trash can-shaped talking robot Push made rounds of the park and interacted with children and other visitors, promoting environmental conservation and recycling [20]. Similarly, several companies market licensed trash cans shaped like the Star Wars movie droid R2D2.

Autonomous trash collection robots have been considered a benchmark mobile robot design problem, e.g., for design competitions, as it involves several common tasks such as path planning, navigation, object detection and discrimination, obstacle avoidance, task sequencing, and, often, multi-agent coordination [21]. Yang, et al have developed a robotic trash barrel, consisting of a commercial mobile robot (iRobot Roomba) with a trash can mounted on top [21]. Their emphasis is on socially acceptable interactions of the robot in public spaces. Kulkarni and Junghare [22] have developed an autonomous wheeled vehicle with on-board manipulator for indoor trash detection and collection using ultrasonic sensors. An autonomous wheeled humanoid-type robot for home mess cleanup has been proposed by Ma, et al. [23]. It is equipped with two six degrees of freedom manipulators, and uses sensor fusion for localization and RFID for indoor navigation. An indoor toy mobile robot for encouraging children to tidy up their toys has been proposed in [24]. Yamaji, et al have developed a mobile robot as a *Sociable Trash Box* which interacts with children in the collection of trash [25].

The focus of this research is *humanitarian*, in the sense of design and development of affordable and accessible, interactive, educational and environmentally beneficial mobile robots for deployment and dissemination in developing countries (though the robots could be adopted for use with developed country school children too). An autonomous system design is avoided as it minimizes *control* by children, leaving them as bystanders. The children will find it more fun and have a sense of accomplishment by interacting with, and remotely controlling, the much less expensive and less complex non-autonomous or semi-autonomous mobile robot. Where Wi-Fi access to the Internet is possible, for example in the vicinity of the school, children can even *teleoperate* the robot over the Web [12], [26]. Further, autonomous outdoor mobile robots will become prohibitively expensive with the need for multiple sensors – such as inertial measurement unit, radar and lidar – and control systems for fail-safe navigation and real-time obstacle avoidance. Moreover, the outdoor environments like typical streets and roads in a country like India are often quite *unstructured* (e.g., due to potholes, uneven construction and slopes, etc) making it difficult for autonomous mobile robots to navigate effectively.

At the simplest level, a mobile robot – whether on land, in air, or underwater – is a mechanical base or platform actuated by electric motors. Therefore, our mobile robot platform is constructed with a simple circular wooden (plywood) disk of 12 mm (1/2”) thickness, with two 12-volt geared DC motors at the rear and two casters at the front. The highly geared motors reduce cost and complexity of power transmission, and are directly coupled to 5” rubber wheels. A commercial, cylindrical stainless steel trash can (14” diameter, 32” height) is mounted on top of the wheeled platform. The electronics for air quality sensing, control, data acquisition, and interaction with children are mounted inside the cylinder at the bottom. The trash can used comes with a set of tiny holes for air circulation near the bottom, which conveniently helps in the cooling of the electronic circuits and control computer, in the hot outdoor environment.

A schematic of the system for trash pickup by school children interacting with the outdoor mobile robot is shown in Figure 1.

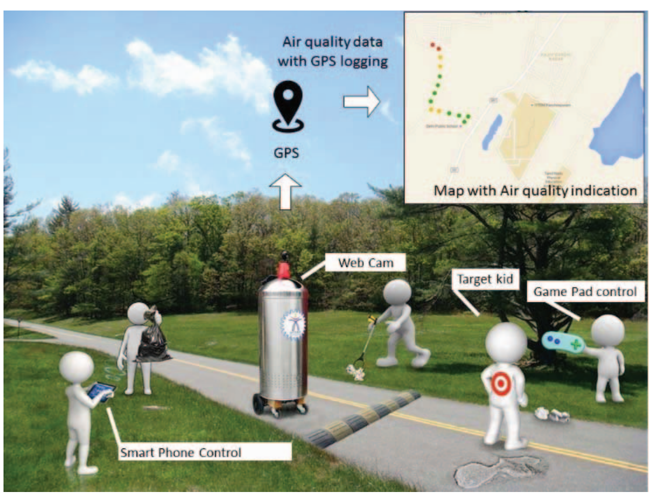

Figure 1. Schematic of mobile outdoor robot trash pickup by school children

The trash can robot developed is shown in Figure 2. A custom-made rotating beacon light, with high-intensity LED lights for low power consumption, is mounted on the top of the robot along with a USB webcam (VGA, 30 fps). HD webcams with higher resolution video and frame rate could also be used, but the display monitor size is fairly small so a low-cost webcam provides acceptable quality.

A portable 7” LCD display is mounted on the lid, to display air quality sensor data, broadcast environmental awareness messages (including animations), as well as display images of children within the range of the webcam.

Figure 2.View of trash can mobile robot

Multiple modes of teleoperation are provided for navigating the mobile robot to enhance the user experience: control with a wireless video game controller, control with a smart phone/tablet app, and semi-autonomous following of a person with a target on dress. The robot serves as a roving trash can on wheels. In future, IR sensors will be used so that once the can fills up, the robot sends visible and audible signals for replacement of the trash bag within.

Figure 3 shows the architecture of the computer control, interaction and measurement system of the outdoor mobile robot for assisting children in trash pickup.

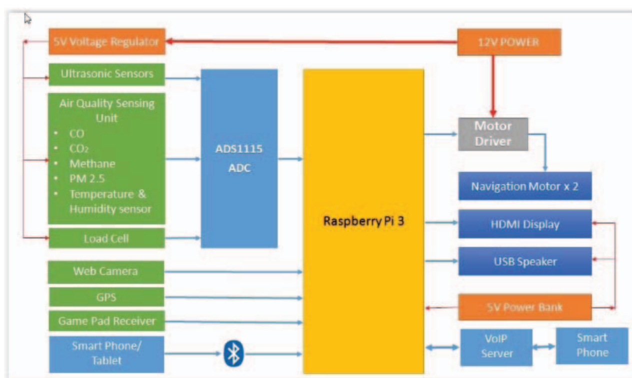

Figure 3. System architecture for control, measurement, and interaction

The robot is controlled by a low-cost, Raspberry Pi 3 (RPi) single-board microcomputer which comes with built-in Wi-Fi and Bluetooth, and so can be readily controlled using a smart phone/tablet or over the Web. Multiple ultrasonic sensors are used to avoid collision with the children and onlookers. Data from the ultrasonic sensors and the webcam can be used to automatically sense obstacles like non-standard speed breaks or potholes, so that the robot can slow down and stop and request manual assistance to navigate the barriers (to be implemented in future). A load cell is used to keep track of the weight of the trash filled up by the children in real-time.

Implementation of remote control of the mobile robot with video game controller and smart phone/tablet (Android) is implemented in a straightforward manner with the RPi using programs written in Python language. In the semi-autonomous mode, the robot follows a *navigator* wearing a dress with a target on the back, or a specific colored dress. Here, object detection and tracking system is implemented using open source OpenCV libraries on Linux platform for RPi. As the video captured by the camera is in RGB format, each frame of the video is processed for detecting the object. Each color in the image is represented by a combination of RGB values, and so the object is detected on the basis of color. The RGB color space is converted to HSV (hue, saturation, value) so as to separate the colors easily for object detection [27]. The person following mode can be extended to generalized cases, instead of a specific color of dress, e.g., [28]. The ultrasonic sensors used for detecting barriers can be used for obstacle avoidance and to avoid collision with the enthusiastic children milling around the robot, by slowing down or stopping completely.

The LCD touch screen display is used for showing the progress in trash collection, displaying air quality values at the location of the robot, playing basic education games, displaying animated images, and so on (Figure 4). A graphical user interface (GUI) program to display the air quality parameters is developed using QT C++ on Linux platform. The software reads the sensor data from an Arduino microcontroller or an ADC and displays them on the GUI on the display connected to the RPi. The software plays audio files, giving educational information about the harmful effects of the air pollutants and green house gases, propagating messages about cleanliness and not littering, and so on. The on-board microphone and speaker will be used in future to interact with the children using basic voice-to-text recognition, converting the text messages to robotic voice, and so on.

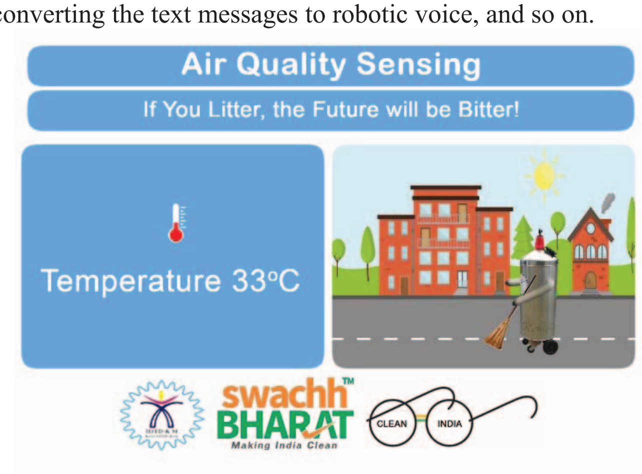

Figure 4. Typical screen display of mobile robot

In this work, presently voice over Internet protocol (VoIP) technology is used for bidirectional communication between the robot and an operator, who acts as proxy for the robot imitating the responses of the robot to questions and comments from the children. He/She uses a smart phone for listening to the microphone input from the children, and to respond in a modified robotic voice. The smart phone voice output is received by the mobile robot and broadcast over the on-board speakers. The secure, open standard Session Initiation Protocol (SIP) is implemented using elements of the hypertext transfer protocol (HTTP) and the simple mail transfer protocol (SMTP). A private branch exchange (PBX) is set up using the Asterisk open source communication server on the RPi. RasPBX, a special version of Rasbian OS with Asterisk and FreePBX which is a web-based open source GUI for configuring Asterisk, is installed on the RPi for this purpose. The audio output of the RPi can be converted to robotic voice using HT8950 voice modulator IC.

IV. Mobile Air Quality Sensing System

Outdoor and indoor air pollution are a major public health hazard around the world, especially in the developing countries due to rapid economic growth and the use of fossil fuel sources like coal. A recent study by the International Energy Agency estimates 6.5 million early deaths annually due to pollution [29]. Pollution levels are expected to rise in future unless major investments are made in clean energy and pollution control measures. Though pollution is a major killer, the solutions to reducing pollution are low-cost and well-known [30]. Therefore, raising environmental literacy and awareness through *Citizen Science* movements and outreach activities can help in improving local environments, in addition to government action.

Primary air pollutants are sulfur oxides (SOx), nitrogen oxides (NOx), particulate matter (PM 2.5 and 10), carbon monoxide (CO), volatile organic compounds (VOC), ammonia (NH_3) and ground-level ozone (O_3). Two other variables of public interest are the key greenhouse gases, carbon dioxide (CO_2) and methane (CH_4) which contribute to Global Warming. CO_2 levels also provide a measure of vehicle emissions in an area.

Recently, a mobile outdoor air quality monitoring system was proposed in [31], using low-cost air quality sensors installed in automobiles such as school/college buses which are widely used in cities and towns in India. In the present work, an air quality sensing kit is installed on the mobile robot trash can so that children can be informed of the pollution levels in the neighborhoods where they collect trash with the aid of the robot. As a result, in addition to STEM education using the robot, the children can be educated on the need for environmental monitoring, awareness and stewardship [32].

A schematic of the air quality monitoring unit installed inside the trash can at the bottom is shown in Figure 5. The unit is mounted on a plywood disk along with the rest of the electronics and battery. Presently, the air quality variables being sensed are carbon monoxide (using a low-cost MQ9 sensor), carbon dioxide (MQ7), particulate matter less than 2.5 microns diameter in size (PM2.5), and methane (MQ2). Strictly speaking, the MQ-type low-cost air quality sensors provide acceptable readings for indoor air quality, but their readings correlate reasonably well with outdoor air quality, and so they are used as a proxy for much more expensive outdoor air quality sensors. A low-cost temperature/humidity sensor is also used, as temperature and humidity have an effect on air pollution, e.g., via emissions from building materials. In future, it is planned to add SOx, NOx, VOC, O_3 and NH_3 sensors to the system to provide a more complete picture of outdoor air quality and pollution levels in the areas where the mobile robot is used by children for voluntary trash collection. The values from the CO, CO_2, and PM2.5 sensors have been calibrated against values from commercial meters.

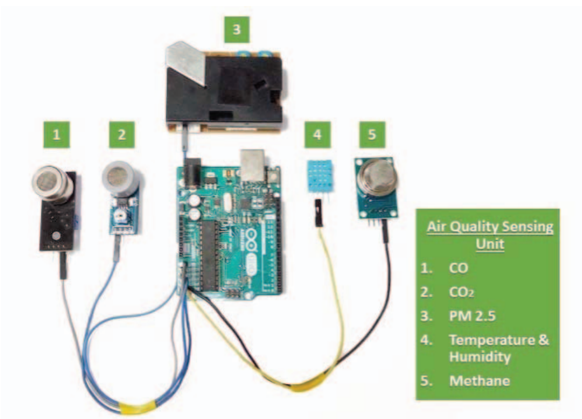

Figure 5. Schematic of air quality monitoring unit

As the RPi does not have built-in analog-to-digital converters, an Arduino Uno microcontroller board was initially used to read the analog air quality sensor and temperature/humidity data. More recently, cheaper 4-channel, 16-bit analog-to-digital converter ADS1115 IC was used to reduce cost and power consumption. A real-time clock and a GPS receiver are interfaced with the RPi so that the trash collection data and the air quality data can be tagged with geospatial and temporal data (latitude/longitude coordinates and date/time). The data will be provided to the schools of the children, so that they can analyze and understand the air quality of their neighborhood. Similar to schools outreach programs like MIT Sea Perch where children can upload water quality data collected with their DIY remotely operated vehicles [33], in future an online database will be developed where children can themselves upload the air quality data on the Web. As in [31], an air quality geographical information system (GIS) of whole neighborhoods can also be developed from the trash collection expeditions by school children. It is hoped that publicizing the implications of the results among parents, teachers, children, and the public will raise awareness of air quality and pollution issues, leading to local level action and remedial measures.

V. Deployment and Discussions

The educational robot for assisting in trash collection has been deployed by local school children (belonging to Delhi Public School, Chennai). The children were instructed in safety precautions for handling trash, provided gloves and trash grabber tools, and given instructions about the remote control of the mobile robot trash can (Figure 6).

The air quality data, data on robot navigation (e.g., distances traveled and areas covered) as well as amounts of trash collected in a given amount of time will be stored in a public database to encourage cooperation and friendly competition among schools in cleaning up the environment and to provide motivation for participation. The data will also hopefully encourage teachers and students to analyze the data about comparative air quality and pollution levels in different neighborhoods.

Figure 6. Children volunteering with trash can mobile robot

Transition from joystick/mobile app control to semi-autonomous mode is incorporated to ensure that the robot operation is reliable and safe when navigation obstacles are encountered. If the display is replaced with a tablet computer, it is possible to develop and incorporate mobile games to improve environmental awareness using the data collected [34].

In future, the air quality map will be shown in real-time on the display (presently, it is sketched offline, see Figure 1, inset), with color-coded display for air quality at the location of the robot: green indicates good, orange means medium, and red means poor air quality or high levels of air pollution.

Figure 7. Demonstration of robot at neighborhood zoo

The mobile trash can robot was also demonstrated to the visitors at Vandalur Zoo, in Chennai, which is India's largest zoological garden and attracts more than 1.8 million visitors a year (Figure 7).

The school children involved in the trash collection activities were observed to be very enthusiastic and excited in their interactions with the mobile robot. For *most* of these children, this was their first encounter with a physical robot. The children expressed curiosity about the construction and operation of the robot. In future, it is planned to conduct quantitative evaluations of the effectiveness and impact of their experiences with the robot system in terms of school- or self-directed activities in environmental stewardship, learning of robotics, computers, programming, and so on.

The materials and components used in the construction of the mobile robot system and their costs are listed in Table I in Indian Rupees (INR). The total materials cost of the project is less than US $250, which amounts to a very significant value added in comparison to commercial mobile robots and imported educational mobile robot kits. With further iterations in design, the cost of the system can be brought down further. For example, by replacing the RPi 3 with a $5 RPi Zero (not yet available in India), using a user smart phone for remote control, and broadcasting the sensor readings via speakers instead of using LCD display, it is expected that the cost of the system can be brought under INR 10,000 or $150. Higher cost accessories such as HDMI display, video game controller and HD webcam can be used as optional add-ons for interested users.

Table I. Bill of Materials for Educational Robot

Component & Quantity	***Specification***	***Cost (INR)***
Trash can	D:355mm, L: 812mm	1,700
Materials	Wood, nuts & bolts, etc.	200
Wheels (2) & casters (2)	D:124mm, W: 31.75mm D:76.2mm, W: 25.4mm	1,100
LED strip (1 m)	12V, 24W, 2A	100
LCD screen	7 inch, 5V	3,000
USB Speaker	5V, 5W	300
DC Motors, 2	12V, 100RPM	2,500
Motor driver	24V, 5A	200
Battery	12V, 7Ah	800
ADC	4-channel, 16-bit	400
MQ7 sensor	5V, 150mA	300
MQ2 sensor	5V,800mW	200
PM2.5 sensor	5V,90mA	750
DHT11 sensor	5V, 2.5mA	100
Raspberry Pi 3	1.2GHz Quad-Core ARM	3,050
USB webcam	VGA (640x480)	320
Game controller	2.4GHz Wireless	2,150
TOTAL		**17,170**

Additional improvements can be made to the effectiveness of the system, e.g., as the center of gravity of the robot is located fairly high, a low-cost inertial measurement unit (IMU) consisting of 3-axis accelerometer and 3-axis gyroscope can be used to slow down and avoid fall of the robot on steep slopes or in rough terrains.

To enhance the practical impact and effectiveness of the project, it is planned to publicize online the mechanical design, control and navigation software, system integration details, and mobile and web applications developed. Thus, for others interested in development of similar outdoor mobile robots, there is no need to *reinvent the wheel*. It is also hoped to *crowd source* the future development of the project, so that similar to the highly successful OpenROV project, improvements and adaptations can be made rapidly, cost-effectively and *globally* [35].

Projects such as the present work provide valuable service learning and mentoring opportunities to college and university students. Such involvement and active learning can in turn lead to future (social) entrepreneurship possibilities in robotics and related areas like IoT, mobile and networked hardware and software systems.

VI. CONCLUSIONS

This paper has presented an affordable and innovative educational outdoor mobile robot for use as roving trash can by school children during volunteer trash pickup. The system design and development are based on popular open source hardware and free open software tools, and low-cost off-the-shelf components. It includes an air quality monitoring system to increase environmental awareness of the children. The system has been deployed and tested with school children and public, and produced encouraging results. It has the potential for widespread deployment and further improvements.

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