Progress in Upcycled & Sustainable Robotics: Developing an Accessible, Flexible, and Environmentally Friendly Robotics Platform

Eric Williams, Michael Swindon, Jenario Johnson, Moshe Acvecedo, Elise Araiza, Bryan Garcia, Kendon Ricketts, Balasubramaniyan Chandrasekaran, Ercan Ellibol, Melissa Morris, Ryan Integlia

Florida Polytechnic University
4700 Research Way
Lakeland, Florida, 33805

ewilliams3590@floridapoly.edu, mswindon3602@floridapoly.edu, jjohnson3029@floridapoly.edu, macevedo5094@floridapoly.edu, earaiza7061@floridapoly.edu, bgarcia7415@floridapoly.edu,kricketts6237@floridapoly.edu, bchandrasekaran@floridapoly.edu, eelibol@floridapoly.edu, mmorris@floridapoly.edu, rinteglia@floridapoly.edu

ABSTRACT

The development of a sustainable, environmentally aware and accessible robotic platform to be used in multiple applications is detailed.. The robot utilizes upcycled components and serves as an economical and environmentally friendly robotic platform whose sensor loadout can easily be tailored for mission specific needs. The robot could serve as an intelligent system that might be applied to education, safety, environmental remediation, stewardship, physical impairment services, or in active sanitation applications. Some student projects using the platform are also discussed.

Keywords

Educational Robotics, Sustainable Robotics, Roomba, ROS, E-Waste Management

1. INTRODUCTION

1.1 E-Waste

Electronic waste, or e-waste, is a growing concern in our increasingly technological world. Discarded electronic devices present a significant waste management problem, with over 2.3 million tons of such refuse having been produced in the United States alone in 2009, and 44.5 million metric tonnes (equivalent to 49.3 US tons) produced worldwide in 2016.[2][3] This waste is often toxic -- electronics commonly contain heavy metals such as tin, lead, copper, and gold, along with other potentially hazardous materials such as flame retardants and the electrolytic compounds contained in batteries.[1][4][5]

E-waste is often exported to the developing world with deleterious effects on the health of the inhabitants, both due to the materials contained in the waste itself, and due to the methods commonly used to extract them -- methods that include the use of acid and open air burning of waste material to extract valuable metals. [2][4][5]

In order to reduce the environmental impact of electronic waste, we are looking into ways to extend the life cycle of existing electronics by repurposing and reusing them, rather than discarding or stripping them down to extract their component materials.

1.2 Sustainable Robotics

Robots are an example of a class of electronic devices whose sustainability has rarely been examined. Most of the discussion of the topic has been surprisingly recent, with the papers falling into two main categories: those focused on using robots in ways which directly and positively impact the environment, and those focused on making the robots themselves more sustainable.

In 2011, Bugmann, Siegel, and Burcin published a paper which talks about the sustainability of robotic modes of production in very general terms and as a new concept. Topics discussed included waste reduction via efficient automated processes, energy costs vs. labor costs, and improvements in production techniques which were discovered by use of robots, but which could be applied to manual labor in cases where labor costs allowed, as in the developing world. The specific example given for the last topic was the discovery that milk yields improved at dairy farms when cows were given around the clock access to a milking machine, with the increase coming from the ability on the cow's part to be milked as soon and as often as they were ready. This increase in production was discovered through use of a robot, but could be replicated with manual labor simply by ensuring a farm hand is always on duty at a milking station. [6] In 2016, Weisz et al. released a paper on the topic of benchmarking the energy efficiency of the software used to control robots, as a potential means of reducing energy usage.[7]

In 2018, several research groups independently published on various aspects of the topic. Grau et al. released a paper discussing a European Union funded project designed to encourage the use of robots for sustainability related tasks, in which teams from across Europe first competed to propose a sustainability related challenge which could conceivably be solved with robots, and then a second competition was held to design a robot to fulfil that task.[8] Bula, Hoxha, and Hajrizi put out a handful of papers discussing sustainable, waste reducing robots made out of discarded electronics.[4][5][9] These were similar in concept to a robot which our research group proposed in a paper that same year,[10] but they differed in that their robots were made from lower level components, allowing for a wider range of potential diverted waste streams, but also limiting the project's accessibility to a more highly skilled and educated group.

In general, while a growing number of researchers are thinking about and working on both making robots themselves more sustainable and taking advantage of the features which differentiate robots from more traditional sources of labor and modes of production in order to make various tasks more sustainable, this is still a developing area of research, and there is still much more work to be done.

2. THE DEVELOPMENT OF AN AFFORDABLE, SUSTAINABLE EDUCATIONAL ROBOTICS PLATFORM USING REPURPOSED E-WASTE AND INEXPENSIVE COMPONENTS

Last year, we presented a paper on the subject of a proposed sustainable robotics platform built around the iRobot Roomba robotic vacuum cleaner.[10] The remainder of this paper discusses our progress in the ongoing development of this platform, and then describes a handful of projects that are in development which take advantage of the platform.

2.1 The Base Platform

For the chassis of the robot, we are using the iRobot Roomba. This is an automated vacuum cleaner which has a significant number of advantages as the base of an educational robotics platform, and which, as a popular piece of consumer electronics equipment, is discarded commonly enough that used models with the appropriate feature set are not in short supply. For this project, we have been purchasing used Roombas listed on E-bay as "for parts or as is," but ideally in the future we could partner with recycling centers, waste management companies, or possibly even iRobot themselves to intercept Roombas which would otherwise be headed for the landfill, at either zero cost or very low costs.

This said, even purchasing the units on E-bay is surprisingly cost effective. Almost all models produced since 2005 have had a serial port which allows for complete control over the robot's features and full access to the data from the built in sensors.[11] Units with this feature, when purchased from for parts or as is listings on ebay, can be easily found for around $50 each at the time of writing. In our experience, most of the time the only problem with the unit is that it needs a new battery, at a cost of around $20. In a minority of cases the old battery will have corroded the battery terminals, necessitating a cleaning, and occasionally a sensor will be damaged, necessitating repair, replacement, or an application which does not require the use of that particular sensor. However, as the Roomba is first and foremost a home appliance, repair guides and spare parts are both readily available, and in the relatively common case of a bump sensor which has been damaged due to the robot having been dropped, new parts are often not even needed -- it can often be fixed simply by bending an internal leaf spring back into shape. These are, on the whole, simple troubleshooting tasks which, for example, a class of high school students working on a class or club robotics project could easily be trained to handle.

2.2 Expanding the Unit's Capabilities

Once a functioning Roomba has been acquired, the task becomes one of extending its functionality. The serial port is part of what makes this a surprisingly feasible task, even for high school or college undergrad students. The other part is the general robustness of the platform itself. The Roomba is a sturdy platform which can easily hold a full sized laptop paired with additional sensors and whatever additional peripherals, such as USB hubs and battery packs, are required. This opens up a wealth of possible expansion options, and also provides another opportunity for diverting e-waste from landfills. Specifically, we have discovered that many five to ten year old laptops are capable of running an appropriate Linux distribution and software stack for our purposes. Such laptops are generally worth very little, tend to be landfill bound, and can often be acquired for free or for next to nothing. They are, in other words, another e-waste stream which can be diverted to make these robots more sustainable.

Figure 1: The Assembled Robot

Currently, our hardware platform consists of a roomba paired with a laptop, a serial to USB cable, an RPLidar A1 LIDAR (light detection and ranging) unit, and a Sparkfun Razor IMU (Inertial Measurement Unit). Additionally, a wireless video game controller is used to allow a human operator to assume direct control of the robot. Depending on the number of USB ports on the laptop, a USB hub and, potentially, a power source for the hub may be needed. We currently use common off the shelf USB power banks to power the hubs when needed, but the serial port on the Roomba includes power and ground pins which tap directly into the Roomba's 14.4 volt battery, so with appropriate power regulation hardware, it should be possible to use that power source instead. Other sensors, such as cameras, light sensors, or microphones, could easily be integrated if necessary for a specific mission profile.

2.3 The Software Stack

The software stack is built around ROS (Robot Operating System) running on Lubuntu, a light weight variant of Ubuntu, which is a common, user friendly Linux distribution.[23] Despite the name, ROS is not an operating system, but an extensible, open source software suite which consists of a master program and various packages which, together, handle all of the tasks involved in controlling and automating a robot.[24] For package compatibility reasons, we are specifically using ROS Kinetic and Lubuntu 16.04. These are not the most up to date versions of either platform, but they were the newest long term support versions at the time the project started, and we have not updated yet for reasons of time and potential compatibility issues with certain ROS packages. The ROS packages we are using consist of roomblock, which provides drivers for the Roomba itself; razor_imu_9dof, which provides a driver for the IMU; rplidar, which provides a driver for the Lidar unit; teleop_twist_joy, which is used for directly controlling the robot via a game controller; and hector_slam, which provides a simultaneous location and mapping (SLAM) algorithm which uses the LIDAR and IMU data to generate a map of the robot's surroundings and find and keep track of the robot's location within it. While the robot is not currently autonomous, this is a natural extension of this work, which the hector_slam package will be key to.[13][14][15][16][17][18]

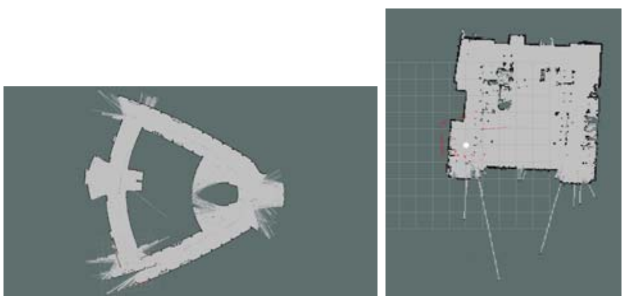

Figure 2: Maps generated by the robot using Hector SLAM. Loop closure problems on the left hand image were caused by a damaged USB hub losing and regaining connection; the right hand image has a completed loop, with the only significant artifacts being distant reflections caused by the lidar reflecting objects across the hall through a glass window.

3. ONGOING AND PROPOSED PROJECTS UTILIZING THE PLATFORM

While the platform is still under active development, it is far enough along in the process that it is already being used for student projects and educational outreach, and plans are being made to use it for prototyping a companion robot system which expands on the sustainability aspect of the project. Brief descriptions of some of these efforts follow.

3.1 Wearable Integration

The robots have been used in support of an ongoing project which focuses on the use of wearable sensors in health and wellness related applications.[25] Biometric and kinetic sensors, including a forehead mounted EEG (electroencephalograph) sensor, a wrist, leg, or upper arm mounted EMG (electromyograph) sensor, and a wrist, leg, or upper arm mounted IMU, are attached to the body and used for various wellness related purposes, primarily serious gaming applications which use a video game interface for training users in proper exercise form, tracking results, and keeping track of big picture mental state in relation to the exercise -- particularly, whether the user is calm or agitated. This has various potential applications in physical therapy, physical education, and wellness improvement for the elderly and disabled.

Figure 3: Some of the wearables in use

In the case of the elderly and disabled, a companion or service robot could be used for purposes similar to a service animal. To, for example, act as a seeing eye dog, or assist a physically disabled individual in carrying heavy objects. Our robot was used for some preliminary testing in using gesture recognition to give commands to such a robot by means of a wearable device. At this early stage the gestures were simple motions which prompted the robot to start moving forward or to stop moving, but the concept has significant room for expansion.

3.2 Smart Garden Automation

Figure 4: Mockups of the robots in their smart garden configuration

Another project which our robots are being used for is a smart garden automation project. The basic idea is to use the mobile base and various sensors to better attend to the needs of a potted plant sitting on top of the robot. A light sensor combined with data about the needs of the specific species of plant can be used to maneuver the robot to a position in which the plant is receiving optimal sunlight, a soil water sensor can be used to detect when the plant needs water, and provide it accordingly -- either through means of a built in servo actuated water reservoir, or through the robot maneuvering to a watering station, and soil nutrients can be tracked to some extent through the use of, for example, PH sensors. Visual sensors, such as visible and infrared cameras, might also be used to track plant health via leaf color and infrared emission. A touch screen interface could also be attached, allowing visitors to the garden to view interactive information about the status of each plant.

Currently the additional hardware needed for this project has been purchased, and students are ready to begin working on integrating the new hardware and software with the existing system.

3.3 High School Outreach

We have been in contact with the school board of St. Lucie County, Florida. Students, teachers, and county officials have visited the university on a handful of occasions, and they are interested in utilizing the platform we have developed in high school level STEM (science, technology, engineering, and math) programs. We are working with them to put together kits which can be used to replicate and build on our existing work.

3.4 Sentiment Based Lifecycle Extension

One final project which we plan on using the robots for is a concept based on the very human tendency to empathise with and anthropomorphize animals and inanimate objects. In 2008, Sung et al. released a study on how roomba owners interacted with their robots, and found that many of them anthropomorphized their robots to various degrees. Many of the subjects ascribed a gender to the robot -- consistently referring to it as a he or a she -- slightly fewer gave it a name, and small minorities even reported ascribing a personality to the robot, talking to it to greet it, praise it, and so on, and dressing their robots up in costumes for, for example, halloween.[22] These behaviors indicate that at least some people get emotionally attached to these robots, almost as if they were a pet, despite a roomba without additional attached computing equipment as described in the rest of this paper having almost no intelligence -- for the most part, they drive around more or less at random, reacting only to sensor input and only in basic, pre-programmed ways by, for example, turning when the bump sensor is triggered by a collision with a wall.

In an e-waste reduction context, this human tendency to get attached to inanimate objects could be a powerful force for good. If some people get attached to and imagine a personality for a robot with less intelligence than an insect, how might the average person react to a robot which actually has a personality of sorts and can, in its own limited way, interact with and react to them? And if the software running on the robot was able to, in a more personable way than your average computer update, keep track of its own hardware and software repair and update needs, would it make a difference? Could a robot which lets its user know when an improved version of a sensor or other user replaceable device it relies on has significantly dropped in price convince that user to purchase and install the upgrade, thus improving the robot's capabilities and keeping the system as a whole relevant for a longer period -- thus extending the time between the initial purchase of the robot and its inevitable trip to a landfill?

In light of the overall goals of this project, it seems to at least be an area worthy of further research. Internet scraping software such as Scrapey or Beautiful Soup[20][21] could be used to track component prices and availability from various online retailers, and natural language processing technology[19] could be used (with the user's consent) to monitor the user's tweets and facebook wall posts to monitor their mood and adjust behavior accordingly. In the case of the wearable technology connected companion and service robots described above, this system could even conceivably be extended to interact with the wearables, particularly the EEG sensor, allowing a companion robot to attempt to comfort its user when they're upset, to keep its distance when they're angry, or to perform some sort of entertaining trick when they're in a good mood.

4. Conclusion

To conclude, E-waste is a growing concern, and robots, like all technology, are a source of it. Awareness of specifically the sustainability issues related to robots is starting to grow in the scientific community, but research in that area is still in its early stages, with significant room for innovation in the near future. Our upcycled Roomba and laptop based platform is an example of such an innovation.

5. ACKNOWLEDGMENTS

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