Materials for Enabling Hands-On Robotics and STEM Education

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Abstract

We describe our approach to enabling hands-on experiential robotics for all ages through the introduction of a robot programming handbook and robot test-bed. We describe the vision and motivation for the project, and then the details of the robot hardware, software, and the accompanying handbook and textbook materials. Together, the resources are aimed at providing free, detailed, and readily accessible materials to K-12 and early university educators and students for direct immersion in hands-on robotics.

Introduction and Motivation

It has long been recognized that experiential, hands-on education provides superior motivation for learning new material, by providing real-world meaning to the otherwise abstract knowledge. Robotics has been shown to be a superb tool for hands-on learning, not only of robotics itself, but of general topics in science, technology, engineering, and math (STEM). Given the current shortage of student interest in STEM topics, and an undersupply of a trained workforce in those areas, increasing attention has been paid to developing innovative tools for improved teaching of STEM, including through robotics.

A broad spectrum of avenues for pursuing robotics at the pre-university level exists; the most visible are FIRST (FIRST 2006) LEGO Mindstorms (LEGO 2006), and Botball (Botball 2006). Increasingly, high schools across the country are providing elective robotics courses as well as after-school programs. Slowly, middle schools are starting to get involved as well. However, significant barriers still exist to making robotics accessible to pre-university students and teachers.

In this paper, we describe our vision for making robotics accessible to all pre-university K-12 ages, as well as the materials and tools we are developing toward making that possible.

Vision and Mission

To open a child's mind to the breadth of career choices, including those in STEM areas, it is known that the critical period begins much earlier than high school. Popular culture, misconceptions, and peer pressure begin to exert their strong influences from the very youngest stages of a child's cognitive and social development. Thus, it is critical to provide engaging hands-on education to all children as early as possible.

With regard to robotics specifically, it has been shown that no age is too young for being engaged by robots. Toddlers express deep interest in active machines and toys; even children with special social and cognitive needs are motivated by robots (Werry *et al.* 2001). Unfortunately, in most cultures that interest is nurtured very inconsistently, resulting in girls and under-privileged students having little if any access and a plethora of subtle discouragement from a continued interest and pursuit of robotics. These and other social and economic forces push children away from free choice of interests and educational pursuits.

To truly engage a child's interest in STEM, it is necessary to make creative, accessible, and affordable educational materials available from elementary school on in a continuous fashion. In the case of robotics, several challenges stand in the way of this vision:

- Lack of teacher time
- Lack of teacher training
- Lack of age-suitable academic materials
- Lack of ready-for-use lesson materials
- Lack of a range of affordable robotic platforms

Each of the above must be addressed in order to make effective robotics education possible.

Teacher time and training can be achieved through funding; as long as funding is available, teachers can be compensated for additional work involved in learning new pedagogical material, such as that required for teaching robotics.

It is critical that training and educational materials be created by robotics educators, ideally at the university level. Commercial vendors of robotics kits provide a tool, but are neither qualified nor motivated to provide principled pedagogical educational materials.

Because of the astounding range of backgrounds and training levels of K-12 educators who teach robotics, it is critical that ready educational materials be provided for guidance. Teachers are best prepared to innovate when working from a solid foundation, prepared by robotics educators (as per above), not when starting *de novo.*

Finally, in spite of the slowly growing numbers of robotic platforms and kits on the market, the lack of a range of *affordable* robotic platforms persists. To reach the full spectrum of pre-university students and schools, such materials must truly be *cheap*, as they must be acquired in significant numbers and be replaced regularly due to the natural wear-and-tear of hands-on education.

We envision a future in which elementary school-aged children play with programming simple robots, middle school-aged children engage in teams in local contests in designing robots, high school-aged students compete in national contest to design robots with societally relevant themes (fire fighting, emergency response, health care), first-year university students work with humanoid robots to learn about complex natural and synthetic systems, and begin research toward technologies of the future. In that vision, the sky is the limit by the time these students graduate.

In this paper we outline the concrete steps we have taken to help make this vision a reality.

Approach

In the last few years, we have been working with K-12 schools to help them develop robotics programs and, in the process, to learn what their real needs are (Matarić 2004). In collaboration with middles school teachers, we developed robotics courses as well as science courses that use robotics to teach middle school-level science; all lesson plans are freely available from: http://robotics.usc.edu/interaction/k-12/ Most recently we have begun development of similar materials for elementary school-aged students.

However, working with one school at a time, which highly productive, is a slow means of making broad impact. To address as many teachers as possible, we have teamed up with iRobot Corporation (http://www.irobot.com) to develop **a detailed handbook of robot programming exercises with illustrations and solutions**. The handbook will be freely distributed on the web, and possibly available in hardcopy form for purchase as well.

The handbook will be a stand-alone resource, but will dovetail with ”The Robotics Primer” by M. Matarić, an introductory robotics textbook being published in 2007. The textbook is aimed at K-12 teacher training, high school and early university students, as well as any level of reader interested in a 1st academic reading on the subject. The textbook fills a currently open niche that will serve the K-12 population: a pedagogical introduction to robotics that covers the key concepts and principles but is written in a fully accessible style.

To produce a robot programming handbook, one must commit to a robot platform. We aimed for a real robot that was affordable and generally available. This lead us to the selection of the iRobot Roomba, which can be purchased at an academic discount for approximately $150. The handbook contains exercises with the off-the-shelf Roomba, but also provides hardware and sensor add-ons that greatly extend the capability of the Roomba in an affordable and fully explained and illustrated fashion. In this way, the testbed can be used to teach a full spectrum of robotics concepts, from the very basic introductory notions of sensor state and uncertainty to more complex topics including planning, learning, and multi-robot control.

In the remainder of this paper we briefly outline the Roomba robot programming testbed that is at the heart of the robot programming resource we are developing.

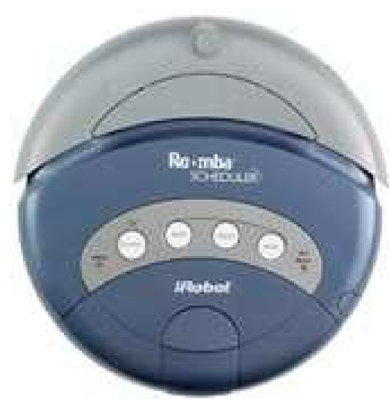


Figure 1: iRobot Roomba vacuum cleaner robot.

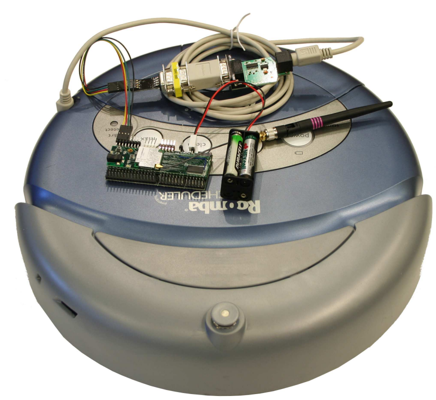
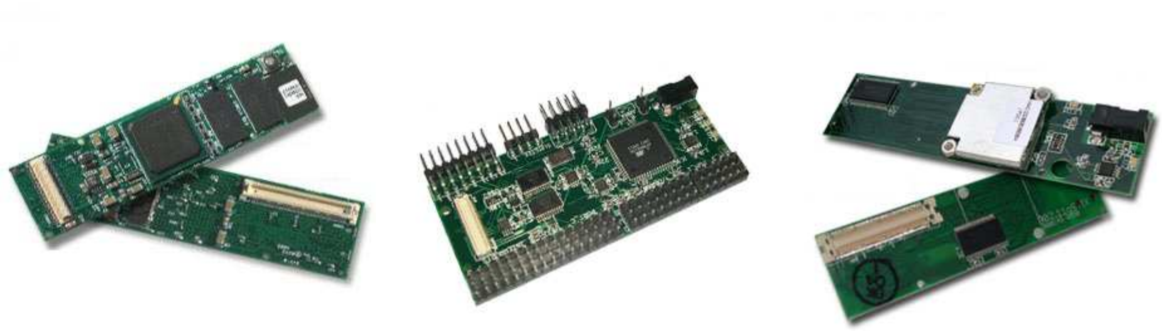


Figure 2: iRobot Roomba vacuum cleaner robot attached to a Gumstix computer.

Hardware and Software

Two limiting factors for placing robots in a classroom setting are the hardware costs an experience constructing a robot. These two factors can usually be considered reciprocals, where a high hardware cost equates to low construction knowledge and vice versa. Our goal is to limit both the hardware costs and construction knowledge so that students and teachers have ready access to a robot platform.

One can define two general categories of robots, pre-built and do-it-yourself (DIY). Pre-built robots are generally found in research labs, industry, and the military. All of these places have significant funds with which to purchase these fully constructed robots, which can cost upwards of



(a) Gumstix linux computer (b) Robostix expansion board (c) Wifistix expansion board

Figure 3: The Gumstix is a linux computer based on the Intel Xscale processor. The Robostix contains an Atmel microcontroller with break-out ports, and the Wifistix provides wireless communications.

Item	Distributor	Prices (USD)
Roomba Red	iRobot	150.00
Gumstix	Gumstix	109.00
Robostix	Gumstix	49.00
Wifistix	Gumstix	79.00
4-pin serial conn.	Acroname	11.75
Roo232 + cable	RoboDynamics	41.94
Battery pack	Acroname	3.50
Total		**335.19**

Table 1: Hardware parts and cost

3,000.00 USD. This price point is considered beyond the reach of most high school and undergraduate classes.

The alternative, DIY robots, are much less expensive than their pre-built counterparts. These robots tend to cost less than 1,000.00 USD, and in many cases less than 500.00 USD. This price range is more suitable for high school and undergraduate classrooms. However, the DIY robots require significant experience with hardware and electronics. This type of robot is not a suitable starting point for robotics education as many students and teachers may not have the required know-how.

Our approach is to use a low-cost pre-built mobile robot in conjunction with open-source software. The mobile robot we use is an iRobot Roomba, see Figure 1. The Roomba is an autonomous vacuum cleaner with a minimal cost of 150.00 USD. iRobot openly encourages third party development and has released the API specifications for the Roomba. With this API, a user can control the Roomba's motors and access it's sensors. The Roomba therefore meets our needs as low-cost robot platform.

The Roomba however lacks an accessible onboard computer. Without a computer to process sensor data and control motors the Roomba cannot function as and autonomous robot. However, not just any computer is suitable. It must be low cost, small enough to place on top of the Roomba, have minimal power requirements, and have expansion ports to add additional sensors and motors. These specifications are met with the Gumstix computer, and Robostix and Wifistix expansion boards.

The Gumstix, see Figure 3(a), is a very small, 80x20 mm, linux computer. There are numerous versions of the Gumstix, and the one we have chosen to use is the Connex 200xm. This motherboard utilizes a 200 MHz Intel Xscale CPU, 16 MB flash memory, and has two expansion ports. The Gumstix Connex 200xm is currently priced at 109.00 USD.

The Robostix, see Figure 3(b), is an expansion card that attaches directly to one of the ports on the Gumstix. With the Robostix we can attach numerous sensors (e.g. infrared, sonar, and heat) and servos, and control the Roomba. This board is 80x26 mm in size, equipped with a Atmel ATMega128 microcontroller, and costs 49.00 USD. The Robostix provides us with a low cost solution for expanding the capabilities of the Roomba.

The Wifistix, see Figure 3(c), is another expansion card that connects to the second Gumstix port. As its name implies, the Wifistix provides the Gumstix with 802.11g wireless communications. With this expansion board desktop PCs and laptops can communicate and control the Roomba. This board is 80x20 mm in size, uses the Marvell 88W8385 module and open-source driver for communication, and costs 79.00 USD.

A small set of miscellaneous hardware is necessary to power the Gumstix and connect it to the Roomba. The Roomba utilizes a TTY mini-DIN port for serial communication, and the Robostix uses a TTY 4-pin serial header. Connecting the two devices requires either making a custom cable, or using a set of off the shelf parts. Sticking with our previous strategy, we used the off the shelf parts method. Starting with Robostix, an Acroname serial interface connection, part S13-SERIAL-INT-CONN, is connected to a 4-pin serial header. This is followed by a Roo232 level shifter and mini-DIN cable which is plugged into the Roomba. The Roo232 level shifter and mini-DIN cable are available from RoboDynamics and cost a total of 41.94 USD. The Acroname serial interface costs 11.75 USD. Finally, the battery pack holds four AAA batteries and is available from Acroname for 3.50 USD. Figure 2 shows the Roomba and Gumstix combination.

The grand total hardware cost is 335.19 USD, see Table 1. This minimal cost provides one mobile base and linux computer. This configuration was chosen not only to reduce costs and use off the shelf parts, but also to maintain compatibility with Player, an open-source network server for robot control. Player is widely used in the research on hobby community for robot control, sensor processing, and communication. It has been in constant development for over five years, and can be considered one the most robust and feature rich robot development libraries. Support for the Roomba API is incorporated into Player, and drivers for controlling the Robostix break-out ports are currently under development.

Acknowledgments

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