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 workbook 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 workbook and textbook materials. Together, these resources are aimed at providing free, detailed, and readily accessible materials to K-12 and 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; some of the most visible are FIRST (2) LEGO Mindstorms (5), and Botball (1). Increasingly, high schools across the country are providing elective robotics courses as well as after-school programs. Gradually, 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 vision possible.

Vision and Mission

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 in order to open their minds to the breadth of future career choices, including those in STEM areas.

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 (8). 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 pursuit of robotics and related STEM topics. 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:

- 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 *inexpensive*, as they must be acquired in significant numbers and be replaced regularly due to the natural wear-and-tear of hands-on education materials.

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 contests 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 (6). 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, while 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) and Microsoft Research (http://research.microsoft.com) to develop **a detailed workbook of robot programming exercises with illustrations and solutions**. The workbook is freely distributed on the web, at: **http://roboticsprimer.sourceforge.net/workbook** Parts of the workbook have been made available as of January 2007, and the rest will be available with the publication of an accompanying textbook, described next.

The workbook is a stand-alone resource, but is written to dovetail with "The Robotics Primer" by M. Matarić, an introductory robotics textbook being published in mid 2007. The textbook is aimed at K-12 teacher training, high school and early university students, as well as any reader interested in a first pedagogical 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 workbook, as a stand-alone resource or as a companion to a textbook, 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 (4) and Create (4) platforms, which can be purchased at an academic discount for approximately 150 USD. The workbook contains exercises with the off-the-shelf Roomba/Create, 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.

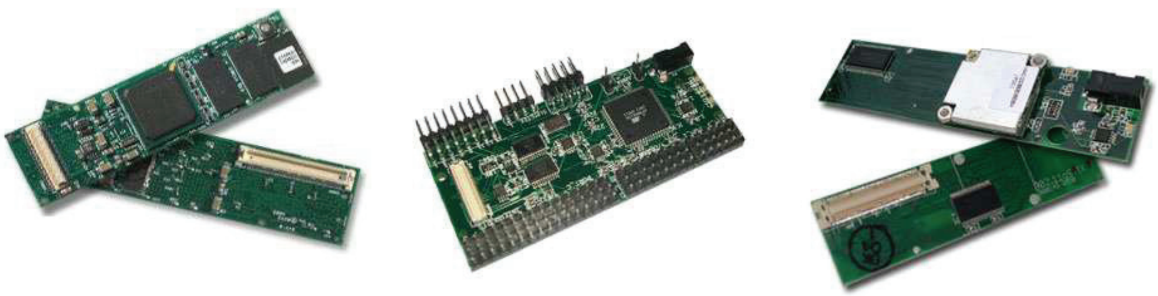
In the remainder of this paper we briefly outline the Roomba/Create robot programming testbed that is at the heart of the robot programming resource we have developed.

Figure 1: iRobot Roomba vacuum cleaner robot.

Figure 2: iRobot Create programmable robot.

Hardware and Software

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



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

Figure 4: 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.

Figure 3: iRobot Roomba vacuum cleaner robot attached to a Gumstix computer.

Item	**Distributor**	**Prices (USD)**
Create	iRobot	130.00
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		**315.19**

Table 1: Hardware parts and cost

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 such fully constructed robots, which can cost upwards of 3,000.00 USD, a price point considered beyond the reach of most users.

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. They are 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. Two such mobile robots, produced by iRobot Corporation, meet our needs. The first is the popular autonomous vacuum cleaning robot called the iRobot Roomba, shown in Figure 1. The Roomba comes in various models, with prices ranging from 150.00 USD to 350.00 USD. All models are built on the same mobile platform; we used the lowest cost version.

The second robot is very similar to the Roomba. In fact it is essentially the Roomba without the vacuum, and is called the iRobot Create, shown in Figure 2. This recently released platform has a few advantages over the Roomba. Without the vacuum cleaner, the battery life on the Create lasts longer, and the cost is lower, at 130.00 USD. In place of the vacuum cleaner is a payload bay convenient for attaching various electronics. The most important difference is that the Create can be programmed using the iRobot Command Module, a unit that plugs into the Create and contains a microcontroller and numerous external ports. The Create and Command Module combination can be used for many of the workbook exercises. However, the limited amount of computation on the Command Module does somewhat limit the number of exercises that can be completed.

In contrast to the Create, the Roomba lacks an accessible onboard computer. Adding such a computer involves satisfying several constraints: 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 satisfied by the Gumstix (3) computer, and the Robostix (3) and Wifistix (3) expansion boards. The Gumstix computer can also be used on the Create in place of the Command Module. iRobot openly encourages third party development and has released the API specifications for the Roomba and Create. With this API, a user can control the Roomba's motors and access its sensors. Consequently, with the Gumstix and either the Roomba or Create, all the exercises in the workbook can be completed.

The Gumstix, shown in Figure 4(a), is a very small (80x20 mm) Linux computer. There exist various versions of the Gumstix; we chose the Connex 200xm, whose mother-board 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 4(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., infra red, sonar, and heat) and servos, and control the Roomba/Create. The board is 80x26 mm in size, equipped with a Atmel ATMega128 microcontroller, and costs 49.00 USD. The Robostix provides a low cost solution for expanding the capabilities of the Roomba/Create.

The Wifistix, shown in Figure 4(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/Create. 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/Create. The Roomba/Create 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. Consistent with our philosophy of accessibility, 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 (7) level shifter and mini-DIN cable which is plugged into the Roomba/Create. 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 3 shows the Roomba/Create and Gumstix combination.

The total hardware cost for the materials, consisting of a mobile robot base and an extensible general-purpose Linux computer described above is 335.19 USD, as shown and itemized in Table 1. This configuration was chosen not only to minimize cost 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, education, and hobby communities 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/Create API is incorporated into Player, including drivers for controlling the Robostix break-out ports.

This workbook also offers the newly developed Microsoft Robotics Studio (http://msdn.microsoft.com/robotics) as an alternative to Linux. The Microsoft Robotics Studio takes a service-oriented approach toward robot control. It leverages the .NET framework for asynchronous programming, real-time robot monitoring, the creation of modular services, and a 3D dynamic robot simulator. This Studio will create a comfortable learning environment for students accustomed to the Windows environment, while still exposing the core challenges associated with controlling robots.

Summary

We have argued that barriers to making robotics accessible to students at all levels, as well as educators, include the lack of availability of readily accessible robot programming exercises with solutions, which operate on affordable robot platforms. Toward addressing this problem, we have developed a public-domain free robot programming workbook, found on the Web at: **http://roboticsprimer.sourceforge.net/workbook**

The workbook is a stand-alone guided peagogical resources for teachers, students, and hobbyists, based on the iRobot Roomba and Create robot platforms. The workbook is also designed to dovetail with "The Robotics Primer", an introductory robotics textbook by M. Matarić, which is itself targeted to the same audience and requires no background prerequisites.

Acknowledgments

The workbook development was supported by iRobot Corporation. The integration of the Microsoft Robotics Studio into the workbook was supported by Microsoft Research.

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