A Review of Robotics Kits for Tertiary Education

Marco Ruzzenente[1], Moreno Koo[1], Katherine Nielsen[2], Lorenzo Grespan[1], and Paolo Fiorini[1]

[1] ALTAIR Robotics Lab, Dept. of Computer Science, University of Verona, Italy
[2] CHEER, Dept. of Education, University of Sussex, UK
marco.ruzzenente@metropolis.sci.univr.it

Abstract. The purpose of this paper is to present a survey of the currently available kits for tertiary education in robotics. Our selection criteria are (i) modularity (ii) re-usability (iii) versatility and (iv) affordability. We focus on toolkits that allow ease of re-use to teach in different curricula (such as electronics, programming, or human-robot interaction). We also considered the interoperability with libraries and open-source frameworks. Finally, we present an overview of our contribution in the form of a robotic manipulator built with LEGO Mindstorm NXT and its integration with Matlab and the ROS robotic framework.

Keywords: robotics education, robotics kit, teaching robotics

1 Introduction

Pedagogical challenges in the 21st century require a new balance between traditional academic fluency with an ever-evolving technological fluency. Technology is changing how we learn, how we interact, how we think. Consequently, there is an increasing concern in teaching interdisciplinarily, focusing on a particular subject or problem by simultaneously incorporating learning from multiple, traditionally separate, disciplinary perspectives. The incorporation of robotics into the curriculum facilitates the curiosity of both the educator and the student alike. For example, educational robotics can be incorporated into the traditional disciplinary learning activities envisaged in mathematics, computer programming, electronics, and physics [1] but also philosophy, language development [2], history [3], and literacy [4] curricula at the primary [5], secondary, undergraduate [6], and postgraduate levels [7].

Educational robotics offers educators a hands-on educational program which engages students' imaginations and may inspire them to continue further studies, thereby increasing declining science, technology, engineering and mathematics (STEM) enrolments [8]. In order to accomplish this, it is imperative to offer children, and indeed university students, the opportunity to play at robotics, and gain confidence and self-esteem as a result. Such activities will, hopefully, also encourage girls to continue in tertiary STEM courses as a result of positive learning activities [9]. In this paper we will specifically examine the tools that are available to incorporate robotics into curricula and pedagogy employing a combination of

Proceedings of 3rd International Workshop
Teaching Robotics, Teaching with Robotics
Integrating Robotics in School Curriculum
Riva del Garda (Trento, Italy) April 20, 2012
ISBN 978-88-95872-05-6
pp. 153-162

software and hardware. Our target is educational robotics in a higher education context (i.e. universities); we will give an overview of those kits that are in our opinion suited for such activities, including where available the price and the key components.

2 Past Work

Educational robotics is pedagogically grounded in a constructivist approach to learning because it inherently incorporates traditional, individualized problem-solving with social activities. As a result, educational robotics enables students to: learn about specific issues and design their own projects to address those issues, share their findings with their local communities, explore those issues experientially using real objects and problems, identify those social and technological challenges which are significant to their lives, and reflect on the implications of these lessons for themselves, their community, and their world [10]. In this sense, educational robotics becomes both the tool for teaching specific subjects but also offers students a way to apply that learning and share it with others [11]. Educational robotics offers educators a tool with which to broaden and integrate educational subjects in a fun and exploratory fashion, hone cognitive skills, expand perceptions and inspire the imagination of students [12].

There is an ever-increasing myriad of educational robotic technologies and curricula available for purchase or as open-source materials on the Internet which educators can make use of at every educational level. Within higher education contexts, universities engage and inspire students to learn about robotics through the incorporation of laboratory exercises that incorporate computer science, engineering, mechatronics, and automation components. Some institutions have already designed courses around a robot rather than a textbook, and evaluate student success in the course not only in terms of an exam, but also through understanding their problem-solving techniques, their programming skills, their creativity, social collaboration, and presentation skills [13]. By fostering friendly competition, teamwork, problem-solving skills, and enjoyment student retention might increase [14], [15].

3 Educational Robotics

The principle aim of this investigation is to supply a panoramic survey of robotics kits which are commercially available, paying particular attention to such aspects as: modularity; re-usability; versatility; and the price of various kits (when available)

Robotics is an area of study that incorporates elements from mechanical engineering, electrical engineering, and informatics. Through the fusion of these disciplines, it can be understood how robots constitute an optimal instrument for the study of various basic theories and, through laboratory activities, students are permitted to do experiments in different areas of technology using sensors, measurement systems, control systems, and microprocessors. In recent years research in the area of educational technology has brought to our attention new environments

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and instruments for the teaching and learning of robotics. This area of interest is called *educational robotics*.

The rules of artificial cognition in the construction of consciousness have been highlighted by Seymour Papert [16] as the development of tests and resulting in the construction of concrete principles. In addressing these ideas, robotics kits have been developed to permit the realization of an *artificial creation* using, for example, the need to resolve a concrete task in a real situation. To allow adaptation to new circumstances and problems it is necessary to transpose a vast range of sensor information relative to the environment in which the robot is found into a *model* of such environment. Robot kits are hence true objects of active learning that reflect general cognitive integration through simple simulation and the construction of modeling.

It should be noted that the success of laboratory activities and close ties to simple instruments are used in diverse activities. Therefore, a course of robotics education should take into account (i) a mechanical construction kit that does not require particular mechanical knowledge; (ii) an environment that is easy to use and does not require complex administrative tasks to set-up; (iii) a collaborative learning environment.

Following the work of [17], robotics kits have been divided into five categories:

1. Building Body Kits: kits that permit the creation of a mechanical skeleton of a robot, such as LEGO Technik, FischerTechnik, and Meccano.
2. Electronic Components: this category is focused on microprocessors, electro-mechanical components and sensors.
3. Software Kits: development environments (such as Microsoft Robotic Studio or Gazebo) that often include simulation environments to allow testing and development of specific firmwares;
4. Programmable Robots: kits where the robot offers no flexibility in terms of hardware and electronics expansion but allows the user focus on the reprogramming of their firmware.
5. Complete Starter Kits: this category includes all robots that allow flexibility in terms of body design, electronics, mechanics and software functionality.

In the course of this survey, we will concentrate on the fifth category, given that the others do not satisfy the requirements of a course on robotics at the tertiary level. In fact, Building Body Kits are more targeted to the mechanics aspects and leave out all the informatics and strictly computer science curricula; for the same reason, Electronic Components are aimed at courses in applied electronics and electro-mechanics. Software Kits do not address the development of the physical body and purely Programmable Robots do not allow a learner to exploit the design of body parts to achieve a particular task.

4 Hardware: Complete Starter Kits

Complete Starter Kits can be divided into two classes: versatile (Lego-like kits designed around basic building blocks) and non-versatile (such as industrial robots, household robots, robotic aircraft and humanoid robots). Versatility is valued because: (i) it allows the possibility of morphological changes to the robot; and/or (ii) whether it allows the possibility of expanding the hardware.

In this section of the paper we list kits that either have been used in robotics education courses or that, given their price, could be used in such courses. We do not list hardware that is no longer manufactured or sold. We highlight whether the kit supports the ROS framework (Robotic Operating System), which "provides libraries and tools to help software developers create robot applications" [18].

4.1 Non-versatile kits: Manipulators

This type of kit allows the user to experiment with manipulators with different degrees of freedom (DOF).

Servobotics RA-02 Robotic Arm [19] The RA-02 Robotic Arm is an assembled manipulator that costs EUR 235. The kit includes servomotors, body parts, a PCB board and proprietary software to communicate with it.

Robot Arm Trainer [20] This manipulator is constructed for teaching basic robotics. It has five DOF and it is possible to interface with a PC using proprietary software. It costs approximately EUR 80.

Lynx [21] The Lynxmotion Arms of the AL5xx series is a robotic arm made of anodized aluminum and plastic; it has five DOF and a clamping tool. Control is done through proprietary software. Stand-Alone programming is available to adequately control a microcontroller (PIC, Arduino). The cost of this arm is approximately EUR 250.

4.2 Non-versatile kits: Household Robots

Pioneer Robot 3DX [22] The Pioneer 3DX is a differential drive vehicle, with two-wheeled motors, each implemented by a continuous current electric motor. It is equipped with an array of eight series sonar, arranged around the perimeter. The management of the sensors and the motors comes from an integrated microcontroller, which also assists the communication with an elaborate remote, which can be mediated with a serial cable or a connection via radio-modem. Programming the robot is possible using the ARIA library. The programming language is C/C++. There is also a vast range of accessories, such as stereoscopic cameras, magnetic compass, pliers, tilt-position sensors, laser sensors, etc. Even though there is no publicly available information on its price, an educational price lists can be obtained upon request (however, to date the producer has not replied to our requests for such info). Numerous simulators and ROS support this robot.

Khepera III Robot [23] The Khepera III robot, developed by K-Team includes a mounted DsPIC processor which can be programmed in C or C++, 4KB of RAM and 66 KB of flash memory. It is possible to expand computational potential by installing a KoreBot card. The robot also has proximity sensors, infrared, and sonar with a range from 20 cm to 4 m. The card uses the Linux operating system that allows for the easy development of applications through access to particular libraries such as SysQuake (containing optimized computational algorithms). The price of this robot ranges from

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Riva del Garda (Trento, Italy) April 20, 2012
ISBN 978-88-95872-05-6
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EUR 2,850 to 5,300 . It is not supported by ROS; it was included in this survey for its wide use in previous educational curricula (see for example [24] for an example of the use of a Khepera and an evaluation of it).

Hemisson [25] The Hemisson robot was specifically designed for robotics education. Equipped with diverse sensors and with an 8-bit MCU microprocessor, this robot is able to avoid obstacles, detect the intensity of a light and follow a traced line on the pavement. The kit also includes software that allows for the simulation of programs. This software enables the user to debug their work before installing it on the internal firmware of the robot. It is possible to program the robot in C using the API, which comes with the product. It is not supported by ROS.

iRobot Create [26] iRobot Create is a robot designed for educational robotics and is derived from the commercial product iRobot Roomba, a completely autonomous vacuum cleaner. It is equipped with 30 sensors that can capture both internal and external events, and is expandable with another 25 pins of electronics. The price is approximately $300. Numerous simulators support the robot and it can be used in ROS. Two projects spawned from the iRobot Create: the Bilibot Project [27] and the TurtleBot [28], both ranging around USD1200-1500. See [29] for an example of using an iRobot Create kit in a robotics laboratory educational context.

MiaBot [30] MiaBotPro is a robot developed by Merlin Robotics. Programming is done using the appropriate developer kit and the robot communicates via wireless and Bluetooth. The kit is sold with optional accessories that integrate on a printed circuit various sensors (infrared, light). It also comes with separate sensors such as sonar, intelligent camera, magnetic compass, and pliers. It is supported in ROS and the price is approximately EUR 800.

WowWee Rovio [31] The WowWee Rovio is a mobile robot equipped with a webcam that can be used to pilot the robot from a distance using a computer or cellular phone. Created strictly as a commercial product, it is not intended for educational purposes but presents features that make it a good educational tool: it integrates an adjustable neck with a camera on top, a LED illumination system for vision in low light conditions, a microphone, a loud speaker, and it can link to a PC via Wifi or USB. Out of this project the PyRovio [32] library was created, an API implementation in Python language, thus allowing a user to write programs for a more fine-grained control of the robot. The price of the robot is approximately EUR 200 and it is supported in ROS.

E-Puck [33] The E-Puck is a circular robot 75 mm in diameter, produced by the École Polytechnique de Lausanne (EPFL). Despite its relative simplicity, this kit seems to have a good success for its uses in education [20]. The programming language is in C and the price of this robot is EUR 700. It is supported by ROS and simulators (Webots) and seems well suited to provide a student first-hand experience in signal processing, automatic control, behaviour-based robotics, distributed intelligent systems, odometry and path finding (see [34] for an example).

4.3 Non-versatile kits: Robotic Aircrafts

Skybotix's Coax Helicopter [35] The Coax helicopter kit consists of a micro-UAV project for the research market and educational robotics. This small helicopter weighs

320 grams and includes one IMU, 1 revolving propeller towards the base and 3 optional propellers revolving for altitude, a pressure sensor, colour camera, and communication through Bluetooth, Xbee, or Wifi. It is possible to request options such as the Gumstix Overo board (Linux OS) so that it can be operated using ROS. This project is completely open-source and the API also includes the low-level firmware, which is available under GNU LGPL license.

Parrot AR. Drone [36] The AR. Drone is a 4-propellered helicopter designed with the use of materials that are particularly light and resilient. The principle structure is formed of carbon-fibre tubing and plastic parts are reinforced with PA66 plastic. This helicopter weighs 380 grams and its noteworthy features are a CMOS camera with 60 frames/second for orientation and stabilization and integrated altimeter and ultrasound sensors. The drone has already been integrated with the ROS platform and the price is from EUR 300 per unit.

AscTec Quadrotor Pelican [37] This helicopter is developed for commercial markets for research purposes. It is completely open-source and open-hardware. Noteworthy features are an autopilot based on an IMU composed of a 3D magnetometer, a 3D gyroscope, a 3D accelerometer; pressure sensors, GPS sensors and 4 brushless motors. This project is supported by ROS; given the open hardware nature of this robot there is no price tag attached to it.

4.4 Non-versatile kits: Humanoid Robots

Aldebaran Robotics Nao [38] The robot, 50 cm tall, is completely programmable and extremely versatile. Relevant features are 2 speakers, voice synthesizer, 2 webcams as eyes and 25 DOF (in the more advanced model). Its behavior can be completely personalized thanks to the programming interface called *Choregraphe* (an iconic programming interface developed in the LEGO style). It is possible to program the robot using C, C++, URBI, Python and .Net. There are various versions of this robot, which ranges from a simple robot with 2 DOF (ideal for the student of visual interactions and hearing) and a robot with 25 DOF. Despite its price, which varies from USD 4,200 (for a basic model composed of a robotic head only) to USD 16,000, we included this model because it is the only current humanoid robot marketed for educational purposes. The robot is developed and supported for ROS.

4.5 Versatile kits

Boe-Bot [39] BoeBot is a robot produced by Parallax. Albeit a bit dated in terms of hardware, it is still used for the versatility of its on-board electronics that can be easily upgraded. The price is approximately EUR 150 and is not supported by ROS.

Stingray Robot [40] The Stingray Robot from Parralax provides a mid-size platform for a vast range of robotic projects and experiments. This robot can be controlled via a proprietary programming language. The price is approximately EUR 335 and is not supported by ROS.

LEGO Mindstorm [41] LEGO Mindstorms are a line of product from LEGO, which combines programmable bricks with electric motors, sensors, LEGO bricks,

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Riva del Garda (Trento, Italy) April 20, 2012
ISBN 978-88-95872-05-6
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and the LEGO Technic parts (such as gears, axes, and pneumatic parts) for the construction of a robot and other automated systems. There is a larger and well-developed community of professionals and amateurs of every kind involved in the sharing of projects, programming techniques, and other ideas about LEGO Mindstorms. Initially LEGO Mindstorms were limited to the RCX platform, which later evolved into the NXT models: this new version of the kit is composed of 3 servomotors (a tactile sensor, a light sensor, a sound sensor, an ultrasound proximity sensor, and the NXT brick which functions as the core. The Mindstorms NXT contains 4 input ports and 3 outputs ports, but has a digital connection through which it is possible to increase the external modules. The connectors are different from the old RCX but it is possible to control the RCX sensors via adaptors. There is also a vast range of extra accessories such as 3 axes accelerometer, magnetometer (providing the direct angle of orientation) and infrared sensors. The project is completely open-source and programming language applies the same considerations as for the RCX platform. LEGO NXT is integrated with ROS [34]. The price tag is around EUR 300 for the basic kit. See [42] for an example of integration of this kit into an existing curriculum, or [43] for an online resource from Carnegie Mellon University.

VEX [44] The Vex Starter Kit costs EUR 300 and contains more than 500 pieces, a configurable frame, a programmable microcontroller, 3 variable-speed motors, a servomotor, gears, 2 sensors for the bumper, various types of wheels and a radio controller for wireless control of the robot. It is also possible to acquire additional optional sensors, such as ultrasonic sensors and high-precision encoders. The VEX processor can be programmed used the easyC language. It is not integrated with ROS. See [45] for an online educational resource from Carnegie Mellon University.

FischerTechnik [46] FischerTechnik is a division of the Fischer Group, which proposes solutions for the teaching of scientific topics for diverse academic levels, from primary levels to university graduate studies. The implemented models can be transformed in automated robotic systems mediated through their sensors (pressure, light, distance, temperature, etc.), motors and lights. These elements are connected to a programmer controller interface. This kit is relevant for industrial automation as it proposes several solutions ranging from the transportation of tapes with work islands combined with mechanical arms. It is basically the first kit which allows students a direct interaction with a PLC-like based system. It is possible to program in C and there are numerous interfaces (Java, Python), which allow students to program the robot without requiring previous knowledge of programming languages at advanced levels The cost of this kit is EUR 325 but it can vary depending on the contents of the basic kit.

Qfix [47] Qfix proposes a starter kit called *crash-bobby*. The electric parts are organized into a nodular manner, and the connectors are made through an I2C bus. Qfix provides two resources to program the robot: a C/C++ library and software called GRAPE. The price of this kit is about EUR 300 and it is not integrated in ROS.

5 An Integrated Robotic Lego Manipulator

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As an example of the versatility of the LEGO Mindstorm NXT kit, we developed our own robotic manipulator and integrated it with Matlab/ROS for a higher education robotics course taught at University of Verona. Our requirements were:

1) The students do not need to have previous knowledge of electronics or mechanics;
2) Possibility to re-use algorithms and filters developed using Matlab in other courses (i.e. Machine Vision, Signals, Human-Machine Interaction);
3) Students must be able to test the accuracy of their kinematic models with limited access to a physical.

The result is visible in the following figure: the manipulator is controlled from a Matlab script, which sends commands to the robot through ROS. Using *rviz* (a ROS data visualization tool) one can also see the kinematic model move in sync with the actual robot. If the robot were not present, the ROS commands would go directly to *rviz*, thus allowing for the debugging of the entire robot model without the need to access the hardware itself.

Further detail on this architecture and the outcome of a robotics course will be published in a future paper.

Fig. 1. Our LEGO robotic manipulator shown in real life and visualized through *rviz*.

6 Conclusions

In this paper we introduced a brief overview of the literature on the topic of robotics education and we reviewed a list of kits built or marketed for higher education courses. We compared the kits that are still currently available on the market based on their versatility, modularity and price; we also highlighted which kits are compatible with the ROS framework.

Finally, we presented a robotic manipulator built with a LEGO Mindstorm NXT and integrated with Matlab and the ROS framework.

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