The role of equipment and accessories in the early teaching of robotics

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ABSTRACT: Since robotics is attractive to students at middle and high school, several programmes of early teaching of robotics were developed to motivate them to decide on science and engineering careers. Educational concepts and aims significantly depend on the choice of equipment used in the robotics programme. Although the Lego Mindstorms robotics kit is the prevailing choice offering high-tech solutions, it has some drawbacks. Considering the criteria of low price, support for a wide range of robotics projects and a close relationship to the technology, reported in this article is the design and development of a robotics kit consisting of Fischertechnik construction bricks, all-purpose electronics components and a self-developed programmable controller module. The robotic kit was tested and evaluated during a summer camp in robotics in 2011 for participants aged 12 to 16 years. The level of projects accomplished by the participants, as well as the results of pre- and post-tests, confirmed the efficiency of the robotics kit for the early teaching of robotics.

INTRODUCTION

Robots feature in films and computer games, and are popular with youngsters. Furthermore, robots are used in medicine, industry and space exploration; they can help disabled people, and much more. Recently, they are becoming a part of everyday life through sophisticated devices being introduced even for housekeeping work. Since robotics is multidisciplinary, it can be used to integrate science and technology curricula for middle and high schools and before higher education [1][2]. Early teaching of robotics concepts can significantly motivate middle and high school students to enter science, technology, engineering and mathematics (STEM) careers [3][4].

Concepts and approaches for the early teaching of robotics are not straightforward. Various programmes differ in key topics, the methodology of teaching and the equipment used [5]. The use of hands-on equipment in robotics programmes is essential. The most established robotics kit for the early teaching of robotics is Lego Mindstorm. It is composed of construction bricks, RCX controller module, sensors, accessories and programming software. This robotics kit is intended to be used by students from 9 years up. However, the kit is also employed in colleges, as well as in higher engineering and science education, hence revealing its versatility [6][7].

An important reason for the popularity of Lego Mindstorms is its user-friendly platform with plug-and-play sensors and actuators. The disadvantage of this approach is that robotics projects using this kit, generally, do not include self-designed sensors, construction elements, actuators, etc. For example, Lego bricks for sensors use special connectors and a complex architecture. Standard motors have built-in gears and so it is not necessary to design more complex mechanisms. Some more opportunities for the straightforward exploration of the working of various mechanisms are offered by Fischertechnik construction bricks, but the sensors are still designed as black-boxes.

If the aim of the early teaching of robotics is to emphasise the integration of different engineering disciplines, then, commercial robotics kits are not optimal. Middle and high school students (age 12 to 18) can understand the operation of various electronic components, such as a switch or a button, photo sensors, such as light dependent resistors (LDR), light emitting diodes, electrical motors (DC, servo, stepper motor), etc. Such topics are a part of the curriculum for the elective subject named *robotics in technology* in middle school in Slovenia over the last two years. It is not appropriate to incorporate the concept of plug-and-play bricks into self-designed electronic circuits, motors, gears, etc.

In contrast to commercial robotics kits designed for the early teaching of robotics, there is an approach founded on the use of entirely self-made robots composed of all-purpose, general components. Robotics projects are carried out using electronic components, motors, construction materials and mechanical parts purchased in general stores. Such an approach provides a great experience for students since their projects are similar to actual industrial projects and help to develop a wider range of skills, including the crafts associated with material processing.

Self-made robots often cover a variety of robotic disciplines and are good at motivating students [8]. On the other hand, student robotics competitions limit projects using a variety of rules to make the competition fair. The consequence of teaching robotics for competitions is that students are encouraged to create special purpose solutions within rules, instead of developing and researching more widely [9]. Also, this way of making robot models can be more expensive because all of the components are self-made.

The authors, therefore, decided to design, test and evaluate a combination of commercially produced construction bricks, all-purpose electronics components and a controller module.

CHOOSING CONSTRUCTION BRICKS

The criteria considered in choosing the construction bricks were price, ability to construct various types of projects, integration of engineering disciplines and the capacity to combine bricks with all-purpose electronic components. An overview of commercial construction bricks shows that the basic parts used to construct models are relatively inexpensive.

On the other hand, the prices of electronic parts (bricks), such as motors and sensors and other devices, are much more expensive than all-purpose components that can be purchased in a store. Moreover, those bricks are adjusted and optimised for the whole kit, so it is easy to plug them into appropriate place but it is difficult to explore their working details.

One such task is to explore how the direction of rotation of a DC motor shaft depends on the polarity of a DC voltage source. Another task is to design a light sensor consisting of a light dependent resistor (LDR) and a linear resistor wired as a voltage divider. Without such details it would be hard, for example, to empirically determine the optimal value of the resistance of a linear resistor.

After filling-out a checklist and making some practical tests, it was decided to employ the Fischertechnik construction bricks called Mechanic+Static [10]. These include a number of basic parts (bricks, gears, wheels, pulleys, bush-chain, etc) relevant to the assembly of various mechanical constructions. Also these construction bricks can be easily combined with all-purpose components, which were added to the robotics kit. Such components are presented on the left side of Figure 1.

There are two servo-motors, a DC motor, an alpha-numeric LCD, two potentiometers to measure the rotation angle, an infrared (IR) distance sensor and some basic electronics components (light dependent resistors (LDRs), thermistors and some linear resistors). Moreover, students can include their own adds-on by buying components and constructing materials using general tools available in schools.

Combining those components with the Fischertechnik bricks is done by dismantled bonds, which is very important to maintain the reusability of the constructed parts. An example of combining those parts with Fischertechnik bricks can be seen on the right side of Figure 1, where the model of a robotic arm is shown.

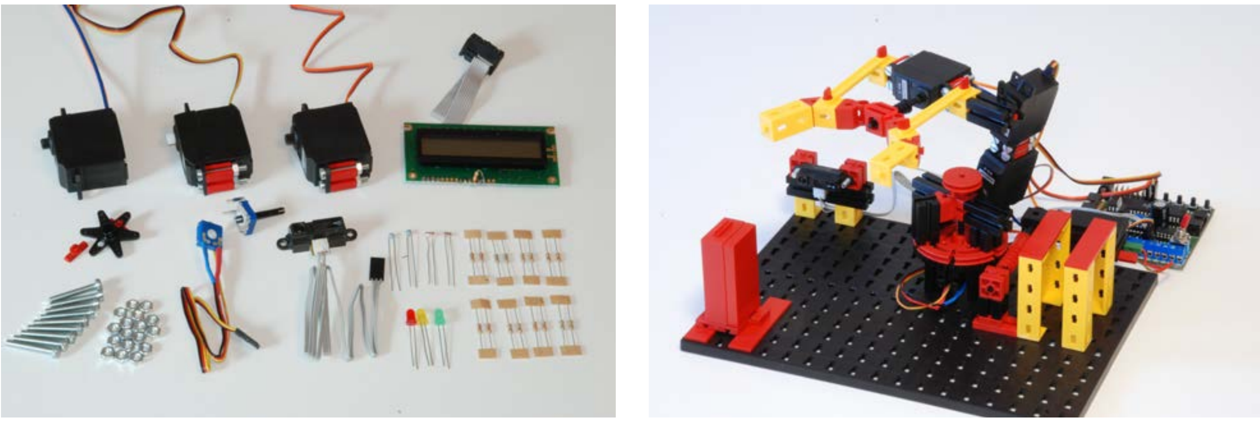


Figure 1: Examples of combining all-purpose components with Fischertechnik construction bricks.

CHOOSING THE CONTROLLER MODULE

Perhaps the most significant component in the robotics kit is the programmable controller module. It is a kind of *brain* of the robot, which is supposed to enable easy connectivity with motors, sensors and construction bricks. Lego and Fischertechnik controller modules are optimised for connectivity with their other components, especially sensors.

However, it is not an easy task to connect the controller with self-designed sensors and all-purpose components. The controllers are based on a new generation of 32-bit microcontrollers, which are powerful and capable of controlling complex devices, such as secure digital (SD) memory cards, touch screens and other sophisticated sensors and actuators.

The most straightforward way to program such controllers is to use the programming environment included in the robotics kit.

Using general programming tools is not easy because 32-bit microcontrollers have very complex architectures [11]. On the other hand, there are seemingly obsolete controller modules based on 8-bit microcontrollers. There are several such *open-hardware* solutions already broadly used; for example, Parallax from the Board of Education [12] and Arduino Uno [13]. Both are based on the AVR 8-bit microcontroller, which serves their purpose but does not optimally satisfy requirements here. Therefore, the authors developed a controller module, eProDas-Rob1, with power outputs and the ability to control motors, as well as offering direct microcontroller signals to aid further development and experimentation [14].

EPRODAS-ROB1 CONTROLLER MODULE

The eProDas-Rob1 is one of the results of a project named ComLab-2 (http://e-prolab.com/comlab) carried out within the EU programme Leonardo Da Vinci. It is built around the AT-Mega16 microcontroller. The microcontroller is intended to be affordable for hobbyists or learners, either beginners or those who have some knowledge of programming and electronics. Since eProDas-Rob1's characteristics are versatile, this controller module is not only applicable in the early teaching of robotics but also can be used in engineering applications similar to other industrial controllers.

On the controller board there are eight digital high-current outputs that are deployed via screw-equipped terminals and ready for use with different kinds of motors and other actuators. Although their functionality is digital, the output voltage can be set from 6 to 24 Volts. The controller also contains four onboard keys, which are mainly used for interaction with the user when operating off-line. Sensors can be screwed on to screw terminals or plugged into 3-pin connectors.

Responses can be read from eight digital or analog channels with 10-bit resolution. In addition, the controller also has eight TTL-compatible digital signal lines that can be used as inputs or outputs (I/O). These signal lines are intended to be used for further development and experimentation. The controller printed circuit board (PCB) is shown in Figure 2.

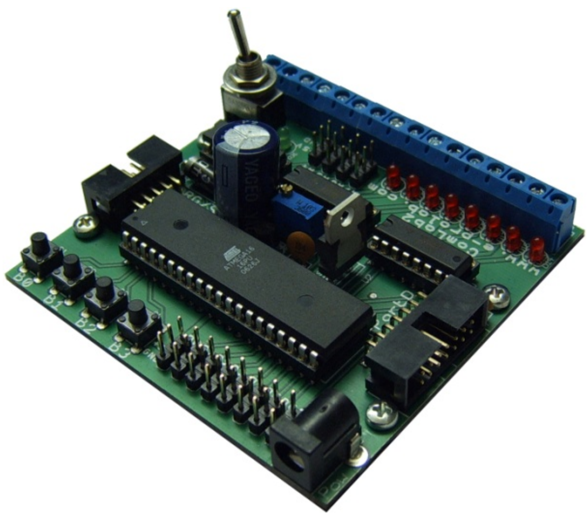
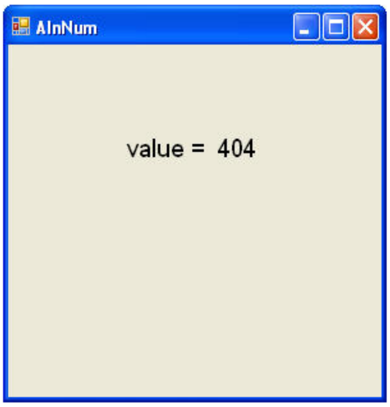


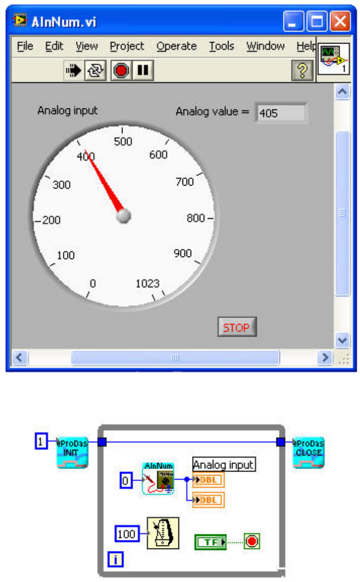
Figure 2: eProDas-Rob1 controller module.

The eProDas-Rob1 controller can be programmed in off-line or on-line mode. Off-line mode means that the program is developed on a PC, uploaded to the microcontroller via a USB connection, after which the module can be unplugged form the PC. This off-line operation is suitable for autonomous control applications, such as for mobile robots or data acquisition stations where the connection to a PC is not desirable or impossible. The controller can be programmed with any programming tool that supports 8-bit AVR microcontrollers, such as Bascom, which is suitable for beginners or AVR Studio for advanced users.

Slightly more specific is on-line programming where the controller needs to be permanently connected to a computer; this is not usually supported by open-hardware controllers. However, the authors' experience has shown that this type of programming is more than welcome in the first steps of robotic programming. At the PC side one needs to install a dynamic link library (DLL) called eProDasHL.dll, which can be imported into most programming environments, such as Microsoft Visual Basic or C++, Borland Turbo Delphi or even more specific programming environments, such as LabVIEW from National Instruments.

The Windows program initialises the communication between the PC and the controller by uploading a firmware code to the microcontroller. The DLL contains procedures to support communication for either output data to, or to read data from, the controller. On-line programming has the advantages of a real time interaction, user friendly graphics user interface (GUI) and easy debugging. Figure 3 shows two on-line applications developed in different programming environments, including the program code.






```
Private Sub Timer1_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles Timer1.Tick
Dim AInValue As Integer
AInValue = AIn10bNum(ADC.No0)
Label1.Text = "value = " + Str(AInValue)
End Sub
```

Figure 3: Programming eProDas-Rob1 controller in Microsoft Visual Basic (left); and in NI LabVIEW (right).

TESTING AND EVALUATION AT THE SUMMER CAMP

The robotics kit composed of Fischertechnik construction bricks, an assembly of all-purpose electronics components and an eProDas-Rob1 controller was tested during robotics and electronics summer camps. The first robotics summer camp was carried out in 2007, and continued for the past three consecutive years. Summer camps for electronics and robotics have been held as presented in Reference [15].

The summer camps lasted seven days at a different location each year. Besides having approximately seven school hours of workshops a day, the participants had sports and social activities and visited one nearby hi-tech company. The camp will acquire an international character in June 2012 due to its inclusion in the EU project named InFiRo (http://metodika.phy.hr/infiro/).

The robotics workshop was divided into two parts; the first part was based on guided exercises, while the second part was project-orientated. Guided exercises lasted 25 hours (about half of the programme). The first task was to assemble and program a model of a parking barrier equipped with light signals and safety sensors. The second task was to make a model of a mobile robot, which can drive along a black line on a white surface while avoiding obstacles. In the second part of the programme, participants working in pairs designed, performed, documented and, finally, presented their projects to parents. Sample photographs from the projects are shown in Figure 4.

Figure 4: Children at a robotics workshop while researching (left); and when finishing the project (right).

In 2011, the authors performed a pre-test and post-test survey of 12 participants attending the robotics workshop. Their knowledge and capability to implement different components and the basic I/O functions of the controller module were tested. The results are presented in Figure 5.

It turned out that the students already knew much about the implementation of a bulb, switch and somewhat less about a DC motor. Therefore, for these components, progress during the workshop was not so essential. For the rest of the components and especially for the I/O functions, progress was significant. For example, a good post-test result was achieved in understanding how the light sensor works and the students were even able to construct it from basic parts with a linear resistor and a light dependent resistor.

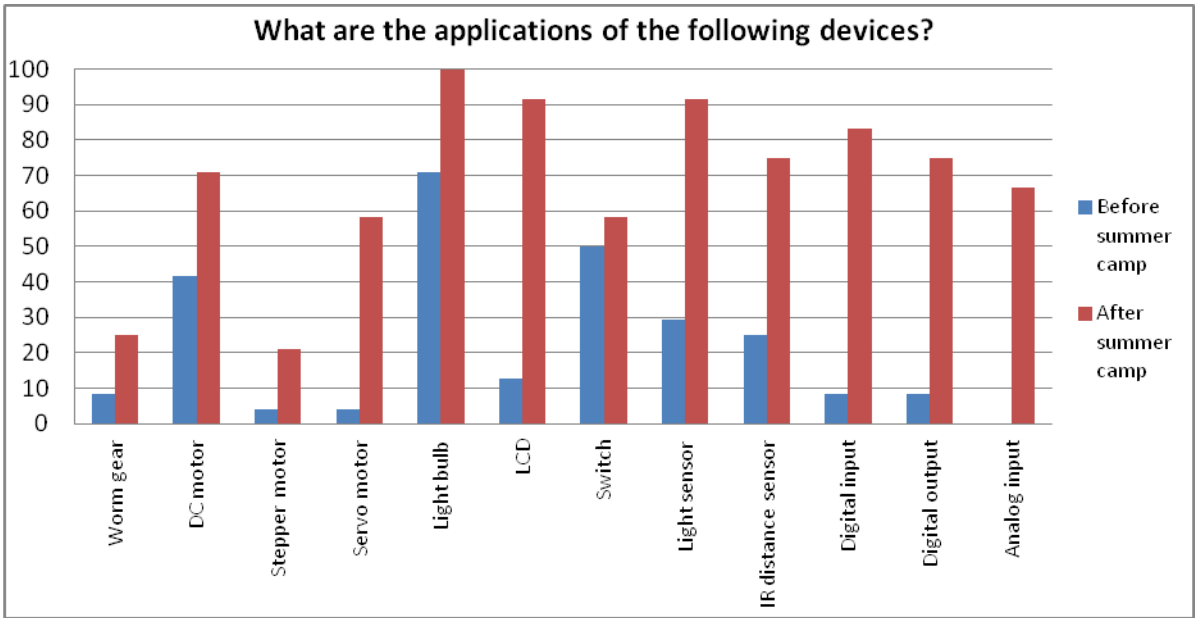


Figure 5: Comparison of results before and after summer camp of robotics.

Clearly, learning results were not achieved so successfully when using the commercial robotics kits based on sensor bricks. However, knowledge about the worm gear and stepper motor had relatively poor results as revealed by the pre-test and post-test survey. While this is understandable for the stepper motor since it is a relatively unknown and rather complex device, this is not the case with the worm gear. Various gears are a part of a compulsory subject of the Slovenian middle school curriculum at 7th grade (age 12-13). This is consistent with a much bigger survey carried out in Slovenia on the national assessment of knowledge of engineering and technology topics at the end of middle school, which also revealed weak points in the knowledge of mechanical systems [16]. Since the progress of participants on this topic was not as expected, this is a challenge for the next summer camp.

CONCLUSIONS

Robotic kits composed of construction bricks, all-purpose electronics components and self-developed controller modules not only have the benefit of low price but also bring some educational advantages. Early teaching of robotics concepts becomes better associated with the real technological challenges, and school students get more transferable knowledge, skills and experiences. They become able at searching for a solution in the wider circumstances that they have in everyday life. The students who participated in the summer camp demonstrated an ability to develop, investigate and evaluate different ideas when they were constructing their projects.

The students proposed several solutions for a best line-following robot and put them to the test and made further improvements. The authors' report on the results achieved by participants in developing electronic circuits show that they learnt how to construct a simple light sensor and understand the role of the resistor in a voltage divider - such tasks are not even considered elsewhere in their education.

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