The Design and Implementation of an Open-source Programmable Bot for Educational Purposes

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Abstract. The ubiquity and an established framework for using open-source electronics and 3D prototyping platforms have enhanced the ways educational robotics (ER) is introduced. Low entry-level, a wide range of peripheral modules and 3D designs alleviate approaching the subject. Nevertheless, the relative ease such systems aim to provide tends to obscure the underlying machinery and basic principles. In this regard, the present article describes designing and implementing a simple programmable Arduino-based bot with a particular accent on the underpinning principles' exposition.

Keywords: Educational Robotics, 3D-modelling, STEM, Arduino.

1 Introduction

The widespread availability of electronics prototyping platforms like Arduino, Raspberry PI, micro:bit has a decisive impact on a simplified adoption of a wide range of entry-level skills in the ER and STEM in general (Brand, Roy, Ray, Oberlin, & Oberlix, 2018; Kalelioglu & Sentance, 2020; MErino et al., 2018). Since the seminal work of Eguchi (Amy Eguchi, 2010), researchers have continuously explored the ER field in view of its inherent closeness to the principles of computational (Amy Eguchi, 2016; M. Tramonti & Dochshanov, 2018) and algorithmic thinking (Evripidou, Amanatiadis, Christodoulou, & Chatzichristofis, 2021; Matyushchenko, Zvereva, & Lavina, 2020), problem-solving (Caballero-Gonzalez, Muñoz-Repiso, & García-Holgado, 2019; Kamga, Romero, Komis, & Mirsili, 2017) and project-based learning methodologies (Cocota, D'Angelo, & de Barros Monteiro, 2015). In addition, following the latest trends in IoT, AI and machine learning, ER offers enough room to enter the fields as well (A. Eguchi, 2022; Mariescu-Istodor & Jormanainen, 2019), thus bringing closer the achievements of the current technology to education (El-Hamamsy et al., 2021).

Rooted in fundamental disciplines like physics and mathematics, ER enables students to embrace the underlying concepts faster (Datteri, Zecca, Laudisa, & Castiglioni, 2013; Ospennikova, Ershov, & Iljin, 2015). Moreover, being goal-oriented, it forms a solid base for related knowledge convergence and scaffolding (Istikomah & Budiyanto, 2018; Mikropoulos & Bellou, 2013). In fact, the educational community has largely contributed to the revealing of the science delivery effectiveness through robotics, demonstrating its fruitful impact in the context of physics (Luciano, Fusinato, Gomes, Luciano, & Takai, 2019), mathematics (Zhong & Xia, 2020), biology (Cuperman & Verner, 2013), and chemistry (Verner & Revzin, 2017).

Important to note that the latest developments in machine learning and AI ground on a solid mathematical foundation, therefore, pure algorithmic and computational thinking alone cannot substitute the clear understanding of mathematical principles lying behind (Deisenroth, Faisal, & Ong, 2020). The same is valid for electronics, where one's capacity to program Arduino may be erroneously interpreted as an awareness of what physically happens in the circuits at a component level (Williams, 2014). Being the last entry point for the electronics of tomorrow, a gradual shift from black to white box perspective may be beneficial for the students.

Since their inception, open-source electronics prototyping platforms have significantly lowered the entry threshold (Banzi & Shiloh, 2022), permitting one to concentrate efforts on the idea rather than getting lost in technicalities. Nevertheless, a simplified yet deepened exposition of the underlying concepts may serve as a valuable guideline for the students' future professional self-orientation and general outlook integrity.

In particular, when providing the first experience in robot coding using the simplified approaches the modern instruments generously offer, it would be reasonable to keep the underlying machinery transparent wherever possible while keeping its exposition close and natural to the basic concepts of physics and electronics. The same approach is feasible when approaching the development of tangible artefacts using 3D technology. When it comes to its use in the educational context, the continuous development of technology gradually leads towards the seamlessness of the overall process (Alcock, Hudson, & Chilana, 2016). As a result, the student's major effort naturally shifts to the virtual space of 3D model development (Bicer et al., 2017). Similarly to the previous aspect, the current entry-level of resources enabling one's effort in the field has been significantly lowered (e.g. Tinkercad). As a downside, the plethora of models for free download may turn the first experience of actual 3D printing into a sort of a game that risks remaining without stimulating further interest for independent and contextualized 3D-development.

In general, the plethora of online resources, the abundance of social networks and video-sharing services capable of providing an immediate and multi-opinion answer on virtually any "how-to" inquiry inevitably puts the educational community in front of the problem of coexistence with the "virtual content" and teaching effort optimization (Liu, 2010; Moghavvemi, Sulaiman, Jaafar, & Kasem, 2018). Substantially, the underlying dilemma that arises is the search for a reasonable perspective to concentrate one's effort. In this view, the simplifications brought by technology, both in hardware and software development, offer a wide space for a combined endeavour towards the more substantial and complex effort.

Thus, to provide an example for such an effort, the article shares the experience of designing and implementing Arduino platform-based programmable bot. In particular, the details regarding robotics artefact development and the examples illustrating the variety of the relevant electronics components introduction in the class are provided.

The 3D-model as well as a detailed component list with assembly guidelines are available for download on Thingiverse.

2 Bot Chassis 3D-development

The 3D model of a bot was developed using freely available DesignSpark Mechanical software. The ease of software use in creating sophisticated 3D geometries and detailed online educational resources makes the option particularly convenient in school.

The bot chassis was designed considering the linear dimensions of the electronics components at disposal without compromising the overall compactness of the structure (Figure 1). The parts to be placed inside are the following: DIY-control panel PCB, LED indicator, a couple of stepper motor controllers (ULN2003A), two standard stepper motors (28BYJ-48), Arduino UNO board, and 18650-type battery holder. The fundamental difficulty in geometry development lies in the spatial distribution of all the elements while keeping track of their available mounting holes and the corresponding supporting columns' synthesis of the hosting structure.

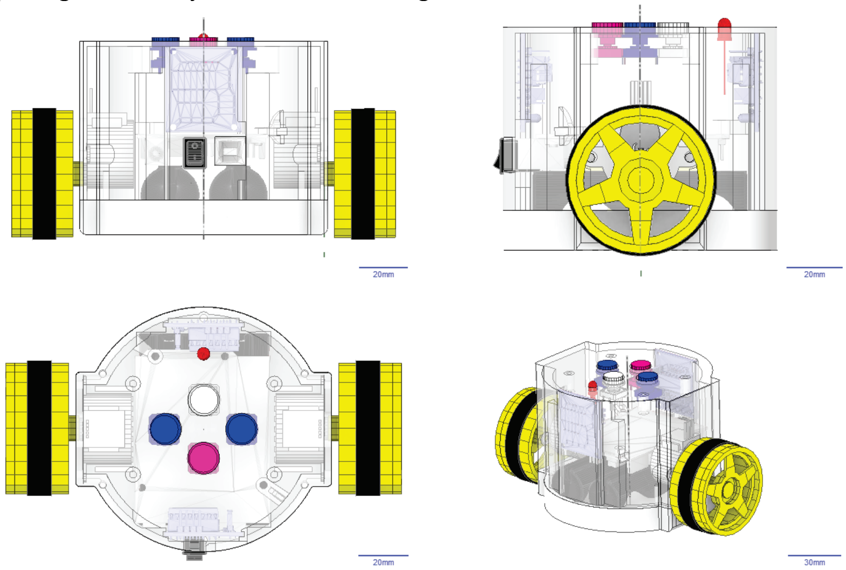

Fig. 1. The 3D-model of a bot developed in DesignSpark Mechanical software. (The model of the chassis is available for free download at https://www.thingiverse.com/thing:5880820)

3 Circuitry

In Figure 2 the functional scheme of the bot is shown. The system is composed of two primary elements: control and actuation. The control circuitry comprises the control PCB, Arduino microcontroller, and step motor controllers. The actuators are: a couple of step motors and the state-LED used to discern between the modes of the bot operation.

The control PCB is composed of 4 pushbuttons soldered on standard perforated PCB-board. The standard low-cost 28BYJ-48 step motors with a ULN2003A Darlington array-based controller are used for movement actuation.

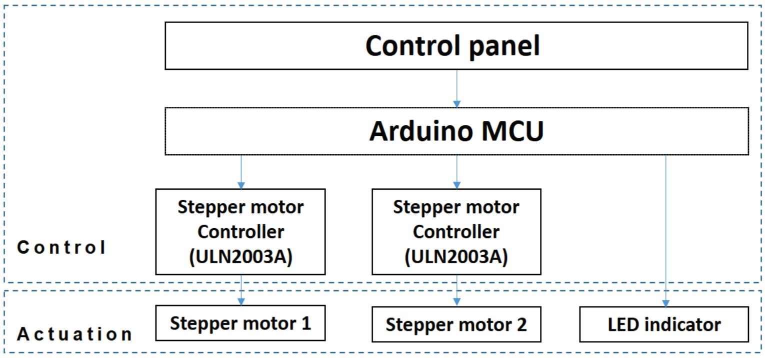

Fig. 2. The functional scheme of the bot.

In the current version, following the standard logic, the controlling pushbuttons were connected to 4 digital inputs of the Arduino board. But to enhance the students' vision of the variety of possible solutions, the controlling function may also follow the variant presented in Figure 3.

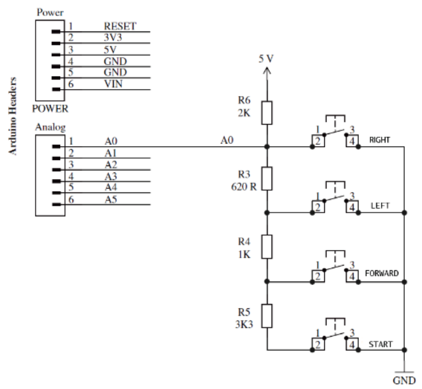

Fig. 3. Using a single analogue input instead of 4 digital to perform the control function of the bot (adapted from (Scherz & Monk, 2013)).

As can be seen, the solution not only resolves the task at hand but may be an efficient introduction to a voltage divider. Simultaneously, extending the solution space and figuring out the interplay between digital and analogue processing principles.

4 Code

The flowchart of the general algorithm of the bot is provided in Figure 4. As can be seen, two core elements correspond to the data input and output. The first is the control sequence set of the movements through the selection of the corresponding options (LEFT (L), RIGHT (R), FORWARD (F)). Once the START button is pressed, the data processing part is responsible for the sequential reading of the rowset components.

In detail, by arbitrarily choosing an option for the moving sequence (L,R,F) user thus forms the controlling string, which at the beginning is declared as empty (gov = “"). with every option checked (L, for example), the value of the gov string changes accordingly (e.g. gov=gov+L) until the START button is pressed. Once the START button is activated, the bot executes the movement sequence formed by the pre-START moment. Every movement (L, R, F) met in a sequence is associated with the subroutine for a corresponding pairwise stepper motor actuation. For example, moving to the left presumes left motor to turn backwards and right – forwards.

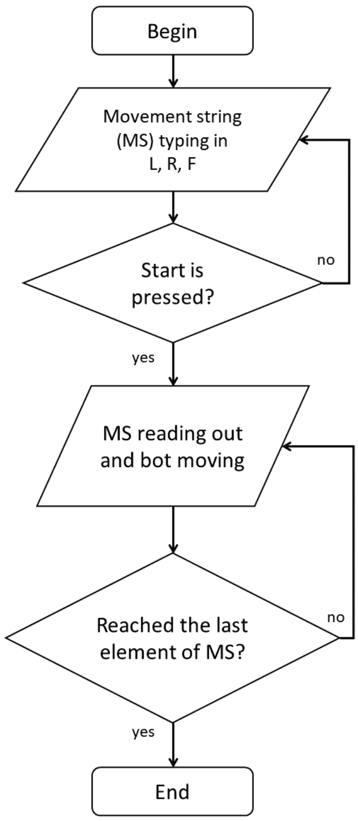

Fig. 4. The flowchart of the general algorithm.

5 An example of the In-depth Exposition of the Underlying Fundamentals

When it comes to the whole project's idea delivery in the class, the relative simplicity of the code can be balanced through a deeper exposition of underlying machinery. For example, the stepper motor controlling circuitry treatment can be started from the inner scheme of every particular driver, i.e. Darlington pair (see Figure 5a). Further, depending on the audience specialization or age, the treatment of the argument may be reasonably started from a higher level of abstraction (Figure 5b), thus shifting the attention towards an even higher level. Should the argument be treated in the school context, a possible further extension of the stepper motor control principle exposition can be done using the scheme represented in Figure 5c.
In short, whereas the approach to the argument starting from Darlington pair and further may be reasonable in the case of electronics engineering students, an immediate start from the simplified block diagram of the stepper motor controller may be an appropriate starting point for software engineering scholars.

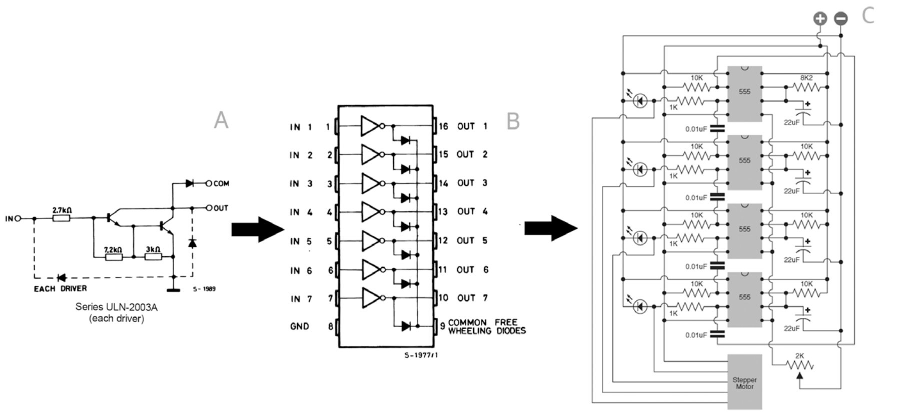

Fig. 5. Three levels of abstraction in the stepper motor control treatment: a) Darlington pair; b) simplified block diagram of ULN2003a; c) an example of stepper motor control using 555 timers (for a detailed exposition, refer to (Platt, 2009)).

According to the authors' experience (Alden & Tramonti, 2020; Dochshanov & Tramonti, 2017; Michela Tramonti, Dochshanov, & Zhumabayeva, 2023), such an extended exposition of the underlying principles does contribute significantly to the students' understanding of the background concepts and, particularly, to their relation with the upper-level abstraction, i.e. coding. In this regard, in our view, today's technology teacher's effort optimization can be seen as providing this "vertical" perspective through the different level concepts' interrelation and dependence.

6 Future Evolution Directions

As to the future evolution of the robot, the authors propose using additional hardware and introducing software changes. In the first case, the bot may be equipped with additional sensors, e.g. accelerometer, to improve further bot's in-space orientation and movements' precision. In addition to the pre-programmable principle of control, extra options like Bluetooth, and IR may also be added.

Generally, the design of the chassis proposed can be easily changed depending on the functionality one wishes to add. For the software part, depending on the student's age, it could be reasonable to optimise the code, gradually shifting from Arduino's digitalWrite and digitalRead functions to AVR's PORTx and PINx commands correspondingly. Fortunately, the currently available online resources do facilitate such a transition.

7 Conclusions

Ongoing technological development has manifested through the widespread availability of open prototyping electronic platforms and 3D printing technology that has naturally entered the educational context. When combined, the instruments may significantly enhance the educational process, enabling students to develop such learning abilities of the 21st century as critical thinking and problem-solving, creativity and innovation, communication and collaboration. The last, being undoubtedly crucial for future professionals, should not support the idea that the innovation is attributed exclusively to one's high-order thinking skills but rather to a deep understanding of the fundamental concepts and effortless transition between macro- and micro-vision instead. Therefore, an example in the article aims to foster such combined skill set development. Where the higher-order perspective (Arduino code in this case) is underpinned by lower-level considerations (such as stepper motor control) seen from different points of view (Darlington pair, stepper motor controller, 555 timer variant). In other words, every level of a problem, whether from hardware or software, always offers enough space for creativity and ways of in-class delivery.

To conclude, the authors hope that the multilevel interplay between functional and aesthetic aspects provided herein may serve as a fruitful example to be inspired by or to adopt in the context of ER classes.

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