Robotics in STEM Education: a Multiperspective Strategy Case Study

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Abstract

The widespread availability and prevalence of such platforms as Arduino, LEGO Mindstorms, Raspberry Pi, and auxiliary electronic plug-and-play modules and shields enable students to enter rapidly into different aspects of robotics design and prototyping. Nevertheless, a significant part of in-class robotics related activities at the current level of technological development has naturally shifted towards coding, placing a large part of fundamental issues to the background. While at the professional level this situation can be regarded as natural, given the complexity of tasks a modern robot supposed to perform, whereas at the introductory level, this approach appears to be as unreasonably one-sided, hiding much of inter-, multidisciplinary connections and basic fundamentals. From this perspective, the work provides an example of how the modern customary instruments, usually used in robotics classes could be supported through the use of additional means to preserve and cultivate its' truly multidisciplinary character and mindset.

Introduction

Being inherently multidisciplinary, robotics education provides a flexible platform with a great potential to help young pupils to enter the field of modern technologies [Ben12], [GES04], including electronics and electrical engineering, mechanics, coding, mathematics and physics[KM15], get accustomed to scientific literacy [Sul08], systems [CN17] and computational [TD18] thinking. Nevertheless, the continuous sophistication, the actual complexity and widespread availability of the electronic components (in particular, modules and shields) used generally in such courses tends to shift the Robot construction towards the assembling of ready-to-use pieces and subsequent coding, without any particular insights into the basic electronics even.

Different kinds of modules, shields together with the diversity of platforms (LEGO Mindstorm, Arduino, Raspberry Pi etc.) bring a lot in terms of choice, permitting introduction of the robotic design starting from primary/elementary schools [CRP06], and even earlier [SB16], [Joh03]. But the basic idea lying behind, in most cases, is constrained to assembling and coding of a pre-defined structure, which is absolutely acceptable in case

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of children, but is insufficiently justified at the secondary school and especially engineering high-school level [PCOMS16].

From one side the concept of multidisciplinarity itself presumes a uniform coverage of disciplines co-involved in a contextualized fashion, i.e. at a level, sufficient to understand deeply enough the issues lying behind the subject [WEG+01]. From the other side, given the actual situation described above, it is clear, that without going too deeply into the detailed consideration of the electronic part for example, but possessing the vast capacities of coding ("soft soldering iron") and a long list variety of pre-engineered sensors, one is able to develop much more complex and fascinating robotic projects, never thought before, see e.g. [PPJ14].

Thus, the emerging dilemma is how deeply one is supposed to go into a certain discipline topics' coverage while preserving at the same time the multidisciplinary point of view onto the robotic major or, in other words, to combine micro- and macro level thinking tools [CN17]. In this regard different paths have already been proposed in a literature. Authors [PCOMS16] start their course with the introduction of Arduino with subsequent deeper understanding of its framework and parameters configuring. After the students focus on the microcontroller without any reference to Arduino platform and learn the principle features of its architecture. Authors observed that structured in this way course has helped to increase the students' skills and motivation. Despite of the possible use of Arduino platform the curriculum proposed in [GR12] covers adequately all the related issued in a highly calibrated and multidisciplinary manner.

The robotics course organization and description provided in [WWK+05], represent not only an optimally organized structure and topics coverage but accentuate the group dynamics and skills necessary for interaction with people in different disciplines within multidisciplinary teams. A problem-based learning project, described in [Has14], represents another successful application of a multidisciplinary PBL approach, when a successful treatment of the problem required knowledge of other five courses, and as consequence was possible only after the organizational changes of the course.

Being complex in a nutshell, robots are comprised of an assortment of integrated components treated within multiple disciplines. As consequence, the development of such systems has inevitably shifted from isolated single components design to the fully cross-functional in team development encompassing the variety of expertises. In this regard, multidisciplinary vision, capacity to interact with peers inside a team, is of an utmost importance [WWK+05]. Moreover, as authors [WEG+01] have pointed out, while the curriculum in any specific area of study tends to narrowly focus students on that area, real-world systems tend to integrate electrical, mechanical and computing components. Therefore, to provide a formal guidance, the described experience of the Multidisciplinary Project Action Group [WEG+01] represents another successful example of the methodological and pedagogical solution. A different feasible approach has been outlined in [MJ10], where authors proposed that courses might attempt to ensure that graduates are able to work effectively in cross-discipline teams, rather than try to produce robotics graduates who are skilled in each and every sub-discipline.

As can be seen the problems of robotics education are faced from different perspectives. Certainly, the multidisciplinary character of the discipline is basically at the root of the methodological problems. Following the concern of the authors [FTFS17] that the use of kits in most of the cases meets educational needs, the best results, nevertheless, can be achieved when using task oriented materials. Thus, the work aims at providing the example of such methodological approach, which can be useful in the organization of robotics classes at different levels.

1 "Black" And "White" Box Dilemma

Ideologically based on the constructivism theory [Pia64, Pia73b, Pia73a], robotics education presumes an active involvement of the students into a process when learning takes place as a result of mental construction by a learner [KM15]. An understanding gained through personal conceptualizations, knowledge and problem-solving upon a direct interaction with objects and events substantially furnish the essential features of the major and constructivism itself. In such an approach, "a learner is actively constructing new understandings, rather than passively receiving and absorbing 'facts'" [JW06]. Emerged as a unique learning tool, educational robotics can offer hands-on, fun activities in an attractive environment feeding students interest and curiosity [Egu10].

With this in mind, nowadays, robotics educational community, nevertheless, is facing a dilemma outlined in [Ali13] as "Shifting from "black box" to "white box" paradigm: learners as "makers" rather than just consumers". The last basically appeals to the robotics industry which mainly aims at humans using pre-programmed and pre-fabricated robots. In addition, it is worth noting that the diversity of available platforms and different additional auxiliary pre-engineered sensors and shields does substantially eliminate a great deal of difficulties the professional robot developers are supposed to face. Therefore, all these pieces are becoming a sort of "black boxes" ready to be connected together and programmed.

Further, as authors [Ali13] specify, the main reason behind these solutions is based on the perception that construction and programming of a robot is a highly demanding task, especially for children. Although, the difficulties of robotics tasks perceived have been found as attributed to deficient design rather than learners' cognitive difficulties [BK13].

Apparently from the "black box" approach, constructivism/constructionism methods require the transition to the design of "transparent" ("white-box") robots, where learners can deal with robots from scratch and have a deeper manipulation with the basic artefacts rather than just consume pre-engineered pieces [Ali13]. In addition, this approach is capable of generating a lot of creative thinking and involvement in learners [RBE00].

Of course, depending on the purpose sought, the "white box"-only approach might be considered as retrogressive too. Especially if one looks onto the technological innovations that are being introduced continuously. But, by providing the pupils with "black box" perspective alone, one may risk to narrow down not their world view only, but a vibrant need for underlying/hidden or basic, therefore fundamental issues discovery.

Needless to say, that by using only the Robotic kits available, despite of their enhanced functionality, pupils become the recipients of pre-determined paths in building a robot. Without any particular insights onto the basics of their functioning, the whole experience of work is reducing to digital/analog read or control. Of course, we cannot neglect the fact that today's most sophisticated robots rely heavily on software, but the future advancements in robotic performance are still inevitably attributed to a further progress in sensors and actuators technology. The lasts, in its turn, are the issues dealt within the major of material science and electronic engineering.

Moreover, by the time today's children will have grown, the design, development, installation and maintaining of robotic systems might be completely automated. Therefore, for a robotics course to remain both modern and essentially appealing to the issues demanded in the future an adequate coverage of fundamental topics is not to be overlooked.

In addition, it seems natural, that from a teenager's point of view who is generally younger than Arduino itself, this platform and all the auxiliary pieces are basically perceived as something integral, ground zero all-in-one. As consequence, a significant part of the underlying fundamental issues remains inevitably hidden or missed. And such an approach, based exclusively on the application of ready-to-use pieces, consisting in one-sided, identical and, in many ways, superficial organization of Robotic classes, may potentially keep a teenager away from entering the related area in the professional future, only because a certain argument was not covered fully enough.

Thus, as one of the possible strategies combining "black" and "white" box approaches in robotics classes, here below the combination of different variants of a widely known line-follower robot model and concept, with particular accent to "in-hardware" realization, is given and discussed.

2 Line Follower

As an example for balancing between "black" and "white" box dilemma a well-known model of the line follower robot seems perfectly adapted. The choice is basically governed by a widely-known principle and diversity of both "in-hardware"/micro-controller free [BAM+05] and Arduino-based [CESPC14] platform realizations. The detailed description and strategies to build a line follower robot are beyond the scope of the article and can be found elsewhere [MBV10, MNP11, PS09, HK11].

2.1 Arduino Variant

The core elements of a slightly different Arduino-based line-follower robot realizations remain the same, namely IR sensors or array of IR sensors, responsible for the crossing-the-line moment detection with the subsequent reaction of the guiding motors [PSR10]. Consequently, the basic difficulty is related to an appropriate sensors' calibration and the corresponding feedback control of the motors [HK11, PSR10].

Thus, in addition to the attractiveness and relative simplicity of realization [CESPC14], the approach, nevertheless, represents in many ways an insufficient basis for the full grasping of the problem and understanding what really happens at a low level. Apart from dealing with sensors and developing the code, method basically permits to deal with "the top of an ice-berg", enabling interaction with the pre-engineered pieces and substantially treating them rather as the digitalized values within the code, than the concrete measurable physical entities.

Of course, if the purpose presumes nothing but to attract or intrigue pupils with its simplicity and showiness of the final result - it's in the bag. But, generally, to provide an audience with a larger and deeper understanding of the phenomena lying behind, it would be advisable to take into account another variant of the line-following Robot as well, in order to furnish a class with multi-perspective view of the issue. The advantages of this additional approach involvement are outlined in the next section.

2.2 Microcontroller-Free Variant

The principle scheme of in-hardware line-following robot realization is presented in Fig. 1. A well-known structure can be found in a commercially available DIY-kit as well, in case if teacher or students have no enough time to assemble the robot with discrete elements. Naturally, that in this case, the basic principle lying behind

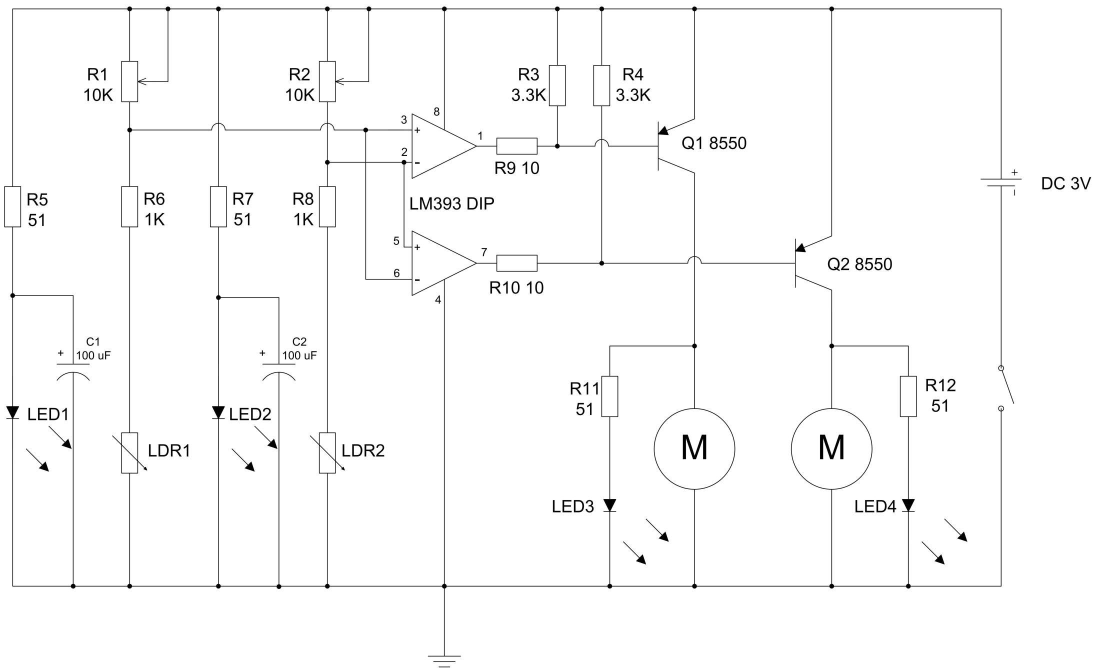

Figure 1: Circuit diagram of the line-follower robot based on LM393 dual differential comparator

the line-follower robot, when compared to the microcontroller-based realization, is translated into the terms of voltages, feedbacks, signal amplification and comparison. All this, as the basic elements of the alphabet of every electronics engineer, becomes "tangible" and evident. Being deprived of add-on microcontroller, the introduction of this version may bring the following topics for an eventual in-depth study:

- a deeper level of the overall function understanding due to a system view at a low-level;
- the contextualized introduction of the hardware feedback control;
- work with discrete sensors (LDR - light dependent resistors);
- role of the potentiometer;
- setting the gain factor for operational amplifier;
- comparator working principle as the introduction to the analog-to-digital conversion;
- LEDs;
- amplifying characteristics of transistors;
- motor coil issues (Lorentz' force, stall current etc.).

The list presented is by no means intended to be exhaustive. But as can be seen, the variety of additional themes for in-depth elaboration may be of essential support to be used both alone and as an auxiliary tool for the Arduino-based realization. In such a way students are provided with a more comprehensive and enhanced perspective, that advances their reasoning through the qualitatively new categories involvement.

3 Discussion

Both approaches described above possess both strong and weak points. In Arduino case example, we have a direct attack of the task through the code development without going in particulars of hardware organization and principles lying behind. Leaving a great deal at the back stage, pupils obtain an immediate but rather superficial tackling of the problem in spite of all the possible difficulties faced at the software level.

Whereas the second variant, despite of its partially regressive character due to leaving the add-on microcontroller issues outside, provides an essentially enriched and integrated perspective of dealing with the problem. The last, in its turn, permits to widen the pupils' perception and understanding of the purely electronics issues, thus concretely promoting the multidisciplinary mindset.

Certainly, the choice of a strategy to apply is basically driven by the goals and interests of students and a teacher. Nevertheless, to authors' mind, the best solution would be to follow a combined path trying to escape any one-sidedness in material presentation.

4 Conclusion

The methods discussed in the article basically represent the variants of "black" box and "white" box approach. Naturally, that the widespread diffusion and openness of Arduino and similar platforms in the last decade multiplied by the numerous well-established communities have built a solid ground for a rapid initiation of the practical activities in the field. Based on the microcontrollers and user-friendly IDEs (integrated development environment), the method, nevertheless, is tending to obscure an essential part of electronics lying behind, and conditionally is being handled as a "black box" approach.

Whereas the transparency and elemental character of the second approach ("white box") might be considered not as the complete replacement for the "black", but rather as a supplementary one. In this regard there should be no any dilemma between "black or white", because only the combination of both permits to enhance the effect of two methods reciprocally.

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