Development of constructionist robotics to facilitate learning in C programming course

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Abstract. Learning to program at a stationary computer for any programming course can be boring and demotivated especially when dealing with complex syntax details. A more hands-on approach utilizing robotic module will lead to a better task-oriented interaction between students and their real-life surroundings hoping to increase student engagement with programming. Thus, this paper proposed a constructionist robotic module to facilitate learning in C programming curriculum utilizing a microcontroller board known as FRDM-KL05Z. The module consists of several input and output components that can be utilized to establish human-machine interaction depending on the instruction code written by the students. A pilot survey was also carried out to assess overall impression of the student towards the proposed approach in teaching and learning activities. Results indicated that students were satisfied with the approach as it help to improve their understanding in C Programming.

1. Introduction
C-programming language is known as one of the most difficult subject to be taught and learnt especially for students [1]. It will normally been offered to the electrical engineering students during the first year of their study and has become very important due to the advancement of current technology especially on the embedded controller. C language provides the foundation for the diverse programming skills required in all areas of engineering and the fluency in C helps practicing engineers to solve much of their problems [4][5]. Most of the students who take textual based programming language course such as C felt very hard to understand as it comes with such a complex language syntax and programming structure [6]. For decades, console-based application has been used as a means of interaction between the written C language and the students. However, when it comes to engineering application, students are expected to develop a code that deals with actual input like sensor and also to be able to control real output such as lamp.

In order to overcome the issues raised, various educational training modules has been develop in order to enhance the effectiveness of teaching and learning activities particularly in programming class [7][8][9][10]. Authors in [11] incorporated the use of Lego Mindstorms in their programmed course to provide better engagement among students. Meanwhile, [12] utilized AVR butterfly board to develop a basic training kit module and practical exercises for C programming language. Other than that [13][14][15] creates a laboratory based C-programming course which expose learners with the
world of microcontroller, packed with hands-on and laboratory assignment aiming to increase their proficiency in both software and hardware development.

Meanwhile, the emerging of robotic technology in recent years had also captured researchers’ interest to develop educational robot to assist teaching and learning activities especially in C programming [16,17,18]. Authors in [19] studied on the use of reprogrammable mobile robot as an effort to improve students’ academic performance and motivation. Results indicated that educational mobile robot is a promising tool to enhance students’ engagement and motivation. In addition, researchers in [20] assessed the effectiveness and the impact of robotic-based exercises as opposed to paper-based exercises. Their results showed that the use of robotic set-up had improved the students’ attendance and enhance the ability to solve educational task which made their learning meaningful.

Thus, this paper presented the development of a simple robotic kit based on a low-cost and low-powered ARM-based controller board known as FRDM-KL05Z. Apart from that, several teaching modules have been proposed to offer a better learning experience to the students in C programming class. The development of the proposed robotic kit is described in the next section.

2. The Robotic Kit

Figure 1 depicted the block diagram of the proposed robotic kit. It consists of a FRDM development board as its central processor to interpret code instruction and sensor input. The robot employed two DC motors as its drive mechanism which will be separately driven to establish differential drive motion.

![Figure 1. Block Diagram of The Robotic Kit](image)

2.1. FRDM-KL05Z Development Platform

An ultra-low-cost development platform known as FRDM-KL05Z was used in this project. Empowered by the Kinetis L Series on 32-bit ARM Cortex-M0+ processor, it became a powerful tool for both embedded systems prototyping and production. It offers easy access to MCU input/output peripherals, low power operation, a built-in debug interface for flash programming, a standard Arduino-form factor and is supported by both NXP and third-party development software [21]. Detail specification of the board were populated in Table 1.

| Attribute         | Attribute Value                                      |
|-------------------|------------------------------------------------------|
| Core              | 32-bit ARM Cortex-M0+ 48 MHz operation               |
| Memories          | 32 KB flash, 4KB SRAM                                |
| Clock             | 4 MHz and 32 KHz internal reference clock            |
| Analog Peripherals| 12-bit DAC, high speed comparator                    |
Timer | Periodic Interrupt Timer, Real time clock
---|---
Human-Machine Interfaces(HMI) | General Purpose input/output controller, Capacitive touch sensor, accelerometer

2.2. Online Debugger – mbed
Freescale Kinetis L Family adopted sophisticated open-standard serial and debug adapter (OpenSDA) debug interface to link between USB host and target processor. It offers ‘drag and drop’ programming feature through its mass storage device (MSD) programmer as a quick way for loading different code instruction and application. A web-based ARM mbed integrated development environment (IDE) was used in this project. The IDE is an open source C/C++ microcontroller software platform, free for use with mbed enabled hardware including FRDM board with free software library, online tools, without any installation and restrictive license. Besides, the platform is also supported by a pool of skilled developers and helpful online community.

The programming process begins with the code editing in C language using the web-based compiler. The compiler works with C/C++ and pre-configured to allow hassle-free code editing, compilation and execution. Students were required to register to get their own private compiler workspace. The compiler uses the industry standard ARM RVDS 4.1 compiler engine [22] and the generated code can be freely used for both commercial and non-commercial purpose. Upon successful compilation, a binary file with extension .bin will be generated. The execution of program can be done by simply transferring the generated file into the FRDM KL05Z board and restarting the board.

2.3. I/O Shield
A modular printed circuit board (PCB) comprise several I/O peripherals was developed as shown in Figure 2.0. Also known as shield, it can be stacked on top of the FRDM board to instill it with extra functionality. The proposed shield consists of a variable resistor and a light depended resistor (LDR) to provide analog response. Besides, a DC motor drive module based on L9110S H-Bridge was also embedded on the shield to control the DC motor movement. A Bluetooth module, HC06, was used to provide wireless communication link between the robot and user for debugging and monitoring.

![Figure 2. I/O Shield](image)

2.4. Robot Platform
The robot platform consists of two DC gear motors mounted at the back of a 3D-printed PLA platform (Figure 3). The robot movement is based on the relative speed of the two separately driven wheels attached on either side of the robot platform.
3. Teaching Module

Various teaching modules utilizing the robotic platform were developed to teach first year student of Diploma in Electrical Engineering and other targeted participants in Universiti Teknologi Mara, Terengganu, Malaysia. This includes Introduction to C Programming course, ECE126. Upon completion of this course, students are expected to be able to describe program structure and syntax of C Programming Language (CLO1) and apply the knowledge in C programming language to program a simple system (CLO2). The duration of ECE126 course is 14 weeks with two-hour lectures and two-hour laboratories each week. The course assessment comprises tests, quizzes and mini project.

3.1. Module 1: C programming using FRDM-KL05Z

The introductory task given to the students deals with the familiarization of FRDM board, registration of the online web-based IDE and the process of editing, linking, compiling and execution of a program. Students were taught on application of basic syntax and I/O in C programming using `scanf` and `printf` function. The execution of the program was observed via smartphone apps known as “BT Term” developed by Futaba Inc. as shown in Figure 4.

![Figure 4. BT Term apps to observe code execution through smartphone](image-url)
3.2. Module 2: Selection statement based on user input

The second module intended to expose students with the application of selection statement such as if-else and switch-case in C language. Thus, the hands-on exercise involves the activation of the robot upon receiving commands from user’s smartphone. To perform this, students need to use scanf function to read the input given by user and implement if-else selection statement in C programming in order to perform a decision-making process. For example, as depicted in Figure 5, if the input given was ‘1’, then the robot shall move forward direction, if the robot received ‘2’ or ‘3’, it shall turn right and left respectively. By doing this, students will be able to observe the immediate effect of the if-else and switch structure in real life application.

![Figure 5. Robot movement based on user input](image)

3.3. Module 3: Repetitive action and movement

Module 3 emphasized on the use of repetition statement such as do-while, while, and for, to replicate certain robot action or movement pattern. The tasks include moving the robot in forward direction for two seconds, freeze for one second and repeat the action for three cycle recurrently as illustrated in Figure 6. During this module, students also taught on how to use suitable increment, decrement or assignment operators. In addition, the use of break and continue statements were also demonstrated to alter the repetition action of the robot.

![Figure 6. Robot repetitive movement](image)

3.4 Module 4: Functions based on robot movement

The fourth module utilize the concept of function to organize the programming statements and handling of I/O components. For instance, they learnt how to create numerous robot movement patterns and group the instructions within a set of function. Table 2 indicate the list of useable functions created to for the robot.
| Function     | Description          |
|--------------|----------------------|
| Buzzer_ON( ) | To activate buzzer   |
| Lamp_ON( )   | To activate on-board LED |
| Forward( )   | To move forward direction |
| Right( )     | To turn right direction |
| Left( )      | To turn left direction |
| Stop( )      | To stop the DC motor  |

4. Students’ Experience

Based on the observation, students’ participation throughout the semester were excellent (Figure 7). Students in the first year of EE111 Diploma in Electrical Engineering program are generally had little or no programming experience at all. Despite their lack of experience, they managed to undergo all the exercises successfully with minimum assistance. They succeeded to use online mbed IDE to write code, debug and execute the program using the proposed robotic platform. The participants for the initial implementation of the robot was 25 students. Although the number for the pilot testing was small, feedback from the participants provided meaningful insight for future improvement.

The final task was given in a form of competitive activity to make the learning session more interesting. Students were divided into eight teams and each team was asked to move their robot to a specific ‘transit station’ and perform special task upon arrival at the desired ‘transit station’ (Figure 8). Remarkably, each team added some additional features that was beyond project requirement to show off their increased understanding and to make their project more interesting. Three of the teams included password verification procedure embedded into their robot utilizing array and pointer concept. One team made use of the on-board RGB LED to produce fancy light effect when the robot moved towards the desired station. Others made some melody using buzzer upon completion of the given mission.

![Figure 7. Hands-on activities using robot](image-url)
Written response from the students was also taken using open ended questions done at the end of the semester. Based on the comments given, students felt that they could appreciate the real-world relevance of C programming and they gained more from the hands-on approach. Among the quotes included:

“*It is fun to control actual hardware such as lamp, motor, and microcontroller*”

“*C programming is an exciting subject to learn*”

“*Programming course has been more fun, user friendly and entertaining*”

Besides, overall students’ impression about the course was also studied based on the UiTM students’ feedback online (SuFO) as represented in Figure 9. Results indicated that the students’ confidence level have increased upon completion the course with mean value 3.75/4. Each team were seen to exhibit significant enthusiasm in order to complete the given project. Meanwhile, the assessment method implemented in the course was also believed to enhance their learning ability (3.71/4). Other than that, most of the students also realized that the course content was related to their field of study (3.83/4) and had increased their knowledge (3.67/4) as they were engaged with the hands-on project.
Besides, Figure 10 demonstrates the students’ view on the aspect of teaching and learning activities. Based on the figure, it is clear that the question regarding to the teaching style obtained high mean value with 3.67/4. They felt that the delivery was also challenging (3.75/4), interesting (3.67/4) and engaging (3.83/4).

5. Conclusion
In this paper, the development of a modular robotic platform to facilitate teaching and learning activities in C programming course (ECE126) is presented. Active engagement of the students can be seen through the visual observation during the completion of the activities and based on their written feedback. It is believed that the proposed robotic platform will provide a strong positive influence that will motivate student to explore and implement C programming knowledge in real-life context. Future works will focus on the study on the effectiveness of the approach towards several motivational constructs included intrinsic and extrinsic motivation, interest, competence and attainment value using Motivated Strategies of Learning Questionnaire (MSQL) mode [23]. Finally, by introducing freely available and open source software tools such as mbed compiler IDE, it will help to educate students the significant role of open source community towards the development of computer resources to further aid the learning process.
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