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Diamond: the DC motor drive module in the GEMS Erasmus+ project

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***Abstract*—Mechatronics is an interdisciplinary field that requires students to possess knowledge and skills from multiple domains. Theoretical learning can provide students with basic knowledge. However, it is not sufficient for applied engineering knowledge. It is essential for students to learn with a suitable platform, including hardware and software. Moreover, the platform should also be equally accessible to all students.**

This paper describes the DC motor drive module developed in the context of the GEMS (Graceful Equalising of Mechatronics Students) Erasmus+ project. The designed module is open access and a part of a mechatronics platform, which allows students who are interested in mechatronics to learn from scratch.

***Index Terms*—mechatronics hardware, DC motor drive, educational platform**

I. Introduction

Mechatronics is a key component of modern industrial science and technology. It is an interdisciplinary field that encompasses computer science, mechanical engineering and electrical engineering [1]. It is easy for students to find the resources to study the related theoretical knowledge. However, challenges arise when applying this knowledge in practice. Although many courses and teaching aids have been developed to help students work on real hardware [2]- [6], many students still cannot find suitable methods and tools to study mechatronics systematically. Moreover, these platforms are mainly for universities and have specific application scenarios. It is not suitable for high school students who are interested in mechatronics. In the Netherlands, high schools implement platforms to help teach and engage students, such as LEGO and BEP robots. These platforms are easy to buy and students can quickly get started with the tutorial. However, these platforms are usually expensive. For those who want to study further in the future, these platforms cannot fully support DIY and tutorials contain insufficient theoretical knowledge. This will also influence the recycling and reuse of the hardware. The printed circuit board (PCB) waste contributes about 6% of the total electronic waste by weight and the percentage is still growing [7]. This issue should be taken into account during the platform design process.

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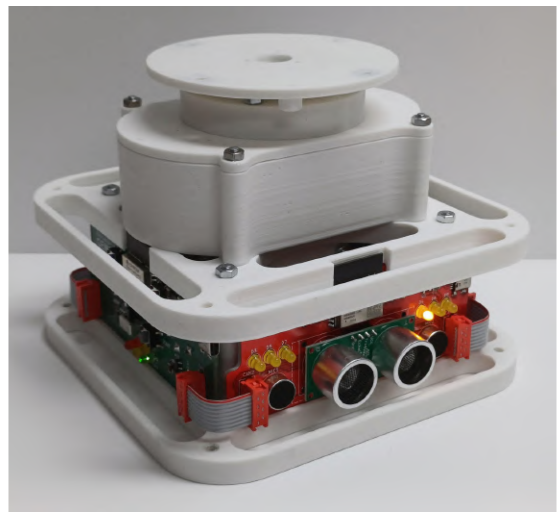

Fig. 1. The GEMS hardware platform.

One of the challenges in the mechatronics teaching process is the lack of suitable platforms and tutorials. It is important to keep the balance between theoretical knowledge and application skills. The related resource should be attractive, engaging and inclusive. Students should be able to get the learning resources equally without spending a lot of energy. These are the priorities and targets of the GEMS (Graceful Equalizing of Mechatronics Students) project which includes a modular platform, teaching tutorials and online courses. The project focuses on accessibility and aims to promote mechatronics. The project can also equalize students' learning opportunities. The platform shown in Fig.1 has four electronic modules and each module can work independently or in combination. Additionally, a gearbox is designed to adjust the speed and torque of the DC motor. Mechanical components in the gearbox are 3D-printed parts which are low-cost and DIY friendly. Students can build their own prototypes according to their interests and needs with minimal modules. All the design software used in the project and design files are open source. Students can download all the resources on the website and modify the files freely for further use.

In the GEMS project, the TU Delft team is responsible for one of the four modules—the Diamond module, from the initial idea to the final design. Many students were involved in assembling and testing the module. This paper introduces the GEMS project and the design of the Diamond module—the DC motor drive and control module in detail. The rest of the paper is organized as follows. Section II presents how the DC motor drive and control module is designed. Section III discusses the feedback from university students and high school educators. The conclusions and future work are included in Section IV.

II. The Diamond Module

As mentioned in the Introduction, the GEMS platform has four electronic modules. Each module is named after a gemstone. Four universities and institutions are involved in this project. Table I shows the details of their work. Each module contains platform design, tutorial and online course development. This section describes the Diamond module in detail, shown in Fig.2.

TABLE I
Modules In The GEMS Platform

Module Name	Team	Design
Emerald Module	University of Ljubljana	Power supply and drive train
Diamond Module	Delft University of Technology	DC motor drive and control
Ruby Module	University of Alcala	Sensor module
Sapphire Module	Teaching Factory Competence Center	Communication module

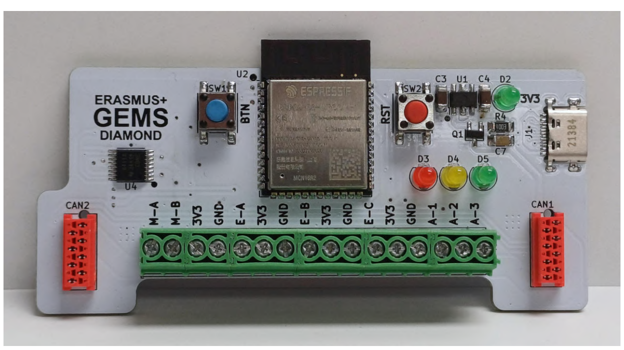

Fig. 2. The Diamond module.

A. Overview

The Diamond module is a DC motor drive and control module. It takes the 5V DC voltage as input and generates a stable 3.3V DC voltage. The power supply can be a battery or the DC voltage from USB-C. There are four LEDs (one red, one yellow and two green) which can indicate the debug, overcurrent fault and 3.3V DC voltage. The module contains an H-bridge converter to drive the DC motor. There is also a current sensor to measure the motor coil current to realize the overcurrent protection. The position sensor signal can be input into the MCU for speed control. Two buttons are used to boot and reset the MCU. Two connectors are implemented for CAN communication among different modules. The architecture of the motor drive system is shown in Fig.3. With this architecture, the students can expand the DC motor drive design to a three-phase motor drive design.

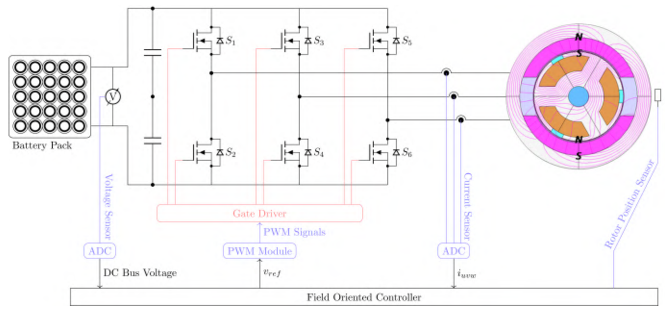

Fig. 3. Three-phase motor drive system.

B. Hardware design process

The size of the Diamond module PCB is approximately 90mm×40mm. It is a two-layer PCB. The footprints of components are through-hole and surface mounted devices (SMD), which are the most common footprints. The same footprint has multiple products so that the students can choose the manufacturer freely. All PCB design-related files are generated by KiCad, which is free and open source.

The first section is the voltage regulator circuit. It can generate a stable 3.3V DC voltage to power other ICs and the DC motor. An R1170H331B positive voltage regulator is implemented. Its maximum input voltage is 6V and minimum output current is 800mA. It also contains the built-in current limit circuit and the built-in thermal shutdown circuit. To indicate the status of 3.3V DC voltage, a green LED is used. When the green LED is on, the 3.3V DC voltage is generated successfully by the R1170H331B.

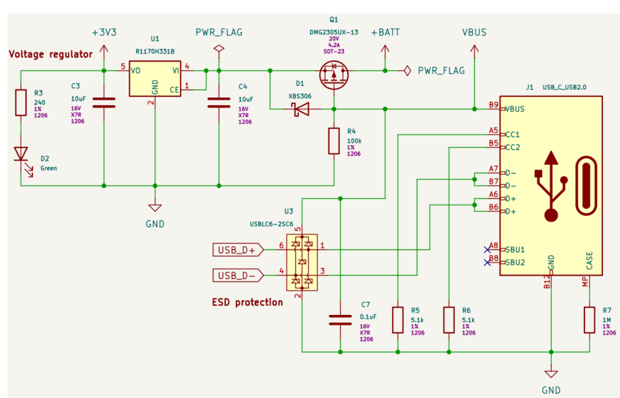

Fig. 4. Voltage regulator and USB-C circuit.

The second section is the H-bridge converter. A DRV8411 dual H-bridge motor driver is used. It can drive two brushed DC motors with 4A output current. In the Diamond module, only one output is used. Students can redesign the PCB with the same components for further application. The gate drive is integrated into the IC and no other gate drive circuits are needed. With the PWM signal from the MCU, it can modulate the output voltage and drive the DC motor. A fault signal is input from the MCU to realize the protection.

The third section is the current sensor circuit. An ACS71240 is selected for this function. It is a galvanically isolated current sensor IC with overcurrent detection. One output of the H-bridge is connected to ACS71240 to measure the current of the DC motor coil. The output of ACS71240 will be sent to the MCU. If the overcurrent fault happens, ACS71240 will send the fault signal to the MCU and the overcurrent protection will be applied. A low-pass filter is designed for the output and the cutoff frequency is 160Hz.

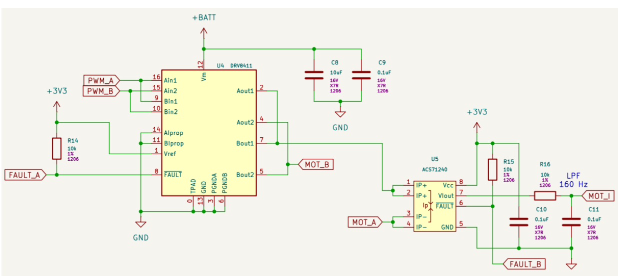

Fig. 5. H-bridge and current sensor circuit.

Another section of the Diamond module, which is the most important part, is the MCU. The MCU used on the Diamond module, and also the Sapphire module, is ESP32-S3 with an on-board PCB antenna. The chip has 2.4GHz Wi-Fi and Bluetooth module, which makes it possible for wireless communication. The rich set of peripherals can satisfy the requirements of the motor drive and even for further use. ESP32-S3 generates the PWM signal for the H-bridge converter and processes different input signals. The code for the MCU can be written in C.

There are still two sections in the Diamond module: the CAN communication part and the USB-C communication part. A TCAN332DR CAN transceiver is used for CAN communication. Some data, such as speed and current, can be transferred to other modules for further use through two connectors. The USB-C allows students to download programs from PCs. It can also be used as the DC power supply. A USBLC6-2SC6 is implemented to connect the MCU and PC.

The DC motor can be connected to the connector with cables, as well as the Hall effect sensors. Three Hall effect sensors are used. Two for the DC motor position detection and one for the output of the gearbox. There are some additional signals on the connector, including 3.3V, ground and analogue input. Different sensor signals can be input to the MCU from other modules. These signals can be used for status monitoring or DC motor control. More functions can be realized for further application.

C. Software design process

As mentioned in the last section, the programme of the Diamond module is implemented in C. Students can use VS Code to modify and download the program. With the ESP-IDF extension in VS Code, students can use the code easily and freely.

Before discussing the software of the Diamond module, the theory of the control algorithm should be introduced. As mentioned in the last section, the current signal and the position signal can be used as feedback to control the DC motor. Students can implement speed control first and finally achieve the double closed-loop control. The final control block diagram of the double closed-loop control is shown in Fig. 6.

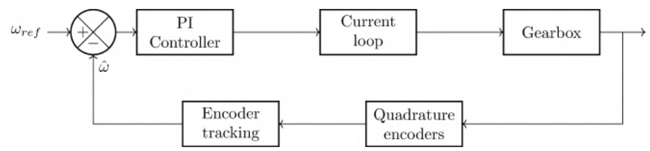

Fig. 6. Current and speed close loop block diagram.

The settings and usage of different peripherals are encapsulated into different functions. Students can call different functions in the main function. Meanwhile, new functions can be defined for further applications. The application of the macro definition makes it clear for students to understand the code.

D. Tutorials and online course

The tutorial and online course of the Diamond module contain 6 chapters which help students build their own prototypes. The first chapter is the introduction of the GEMS project and platform to help students have an overview of the project. The second chapter discusses the relationship between electricity and magnetism and how the DC motor works. The H-bridge converter and its modulation are presented in the third chapter. The fourth chapter is about the architecture of the DC motor drive and the control of the DC motor drive is in the fifth chapter. For the last chapter, the hardware and software are discussed. TU Delft has a lot of experience in online courses and the course video production is done by the LfL team in TU Delft.

III. Result and discussion

A. Analysis of the students' report.

During the whole project process, more than 20 TU Delft students participated in assembling different versions of the platform, including undergraduate students, postgraduate students and PhD students. They provided valuable feedback on both mechanical parts and PCB design.

According to their reports, the mechanical parts were replaced or redesigned for to achieve a more robust connection. New PCB design and component package were selected to provide learners with a better soldering experience. Although tutorials were provided, participants who have no experience in

PCB assembling and soldering indicated that the process was quite challenging, especially for the components with small footprints. They expressed their doubts about the soldering sequence, the IC datasheet and so on. Many undergraduate and postgraduate students practiced their skills during the process. It should be highlighted that some students further developed the platform. They used it as their graduate projects and got positive feedback.

B. Feedback from promotion presentation.

As of the writing of this paper, two promotional presentations have been processed in the Netherlands. The two promotional presentations happened at Oranje Nassau College, Zotermeer and Melanchthon Bergschenhoek, Bergschenhoek, both are high schools. The participants were high school teachers of science. They all showed great interest in the GEMS platform. Based on their feedback, the GEMS platform can arouse the interest of last-year students in high school. It can help them to have a general understanding of the mechantronics engineering and explore what they want to study during the university period. Those who are interested in this platform can also further develop this platform during undergraduate and postgraduate periods.

These participants also raised some concerns about future applications in high schools. The first is the assembly of the platform. Although many high schools are equipped with 3D printers and can manufacture mechanical parts, it is difficult for them to work on PCBs. Some teachers in high schools are not familiar with PCBs and most high school students never solder SMD and TSOP components. The second is that the present tutorial is not suitable for high school students. It contains enough theoretical knowledge but some knowledge is difficult for high school students. High school teachers need to judge what is acceptable for students. It will take some time for them to establish their prototypes and generate proper tutorials for students.

In conclusion, there is a high possibility that the GEMS platform can be used in high school to promote students' interest in mechatronic engineering. However, it will also be a big challenge for both teachers and students. During this process, the cooperation between high schools and the GEMS project team will be promoted.

IV. Conclusions and Future Work

As of the writing of this paper, the online course of the GEMS project is still in process. The online course will contain videos, powerpoints and tutorials. It will be published in September on the EdX platform. Everyone can take the course without any cost. At the end of each chapter, there will be questions related to the theoretical knowledge. Meanwhile, the summer school of the GEMS project is being prepared in TU Delft. It will start on 15th, July. In the summer school, the participants will learn how 3D printing works as well as the knowledge about converter and motor drive architecture. They work on the GEMS platform and try to complete different tasks. Students in TU Delft and high school teachers and students will be invited to take part. There will also be more promotional presentations in the coming months. Improvements to the online course will be applied according to the feedback.

Acknowledgment

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A. Disclaimer

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CMEPIUS. Neither the European Union nor the granting authority can be held responsible for them.

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