https://doi.org/10.31436/iiumecp.v1i1.2995

ENHANCING AND ENRICHING AN EXISTING 3-AXIS CNC MACHINE FOR TEACHING AND LEARNING: A CASE STUDY AT IIUM

DAKHEL ABDULRAHMAN, TANVEER SALEH*

Department of Mechatronics Engineering, International Islamic University Malaysia, Jalan Gombak, 53100, Kuala Lumpur, Malaysia

**Corresponding author: tanveers@iium.edu.my*

ABSTRACT: CNC machines are widely used in manufacturing, but their controllers are vulnerable to damage, which can render the entire machine inoperable. Repairing or replacing a damaged controller can be expensive and time-consuming, leading to significant downtime and lost productivity. This project aims to address these issues by developing a replacement controller for stepper motor-based CNC machines. The objective is to create a controller that can be easily installed and used to quickly restore machine operation in the event of controller damage, minimizing waste and lost productivity. The project utilizes a systematic approach, incorporating various key elements. An Arduino-based GRBL controller, known for its open-source firmware, is chosen for seamless integration with the CNC machine's stepper motor drivers, enabling precise control over axis movement. To provide users with a user-friendly interface for machine control, g-code file loading, and status monitoring, a graphical user interface (GUI) is developed using C# Windows Forms. A Raspberry Pi serves as the machine's computer due to its affordability and powerful capabilities. Running the GUI and necessary software, the Raspberry Pi enhances user interaction through a connected touch screen. Additionally, a protective case is constructed to house all components, ensuring their safety and facilitating device transportation and setup. To enable remote monitoring and receive alerts, the device incorporates IoT monitoring using AWS. This feature adds convenience and functionality for users. Rigorous testing is conducted to ensure the replacement controller performs reliably as expected. The developed replacement controller achieves a high level of precision for most CNC machines, with repeatability within +/- 0.01 mm for the X and Y axes and +/- 0.02 mm for the Z axis.

KEYWORDS: *CNC machine, Value addition, Retrofitting*

1. INTRODUCTION

In recent years, there has been a growing recognition of the environmental impact of our lifestyle, leading to an increased awareness of the need to shift from consumerism to minimalism. In light of these considerations, it is worth exploring the retrofitting of existing machines using off-the-shelf components and simple control strategies. This project focuses on developing a controller implemented on the Arduino platform to repurpose an existing CNC machine for milling operations. By utilizing available hardware components and open-source GRBL software, non-functional machines can be revitalized. Numerous CNC machines are left idle due to major component failures like the controller or motors. As a result, these machines occupy valuable space and become wasted resources. However, the structural integrity of these machines remains intact. This project aims to offer a sustainable solution by reducing electronic and industrial waste through straightforward retrofitting operations.

The discussion in [1] revolves around the use of GRBL (pronounced as gerbil), an open-source high-performance software designed for controlling CNC machine motion. The software runs on ATmega328-based microcontrollers, and it effectively converts G-code instructions into corresponding motions. GRBL has been successfully employed in various CNC machines, allowing researchers to build advanced axis motion-based machines with motor control in a practical and seamless manner, resulting in high-performance CNC motions.

Recent developments, such as an Arduino-based GRBL-powered CNC laser cutting machine [2] and low-cost CNC routers [3], further demonstrate the potential of GRBL in creating CNC machines. Several other researchers have also utilized GRBL in the development of CNC machines [4]–[7] . Kolla et al. [8] proposed a methodology for retrofitting legacy machines by incorporating Industrial Internet of Things (IIoT) capabilities. Aebersold et al. [9] integrated IIoT systems into an existing industrial CNC machine, enabling control via mobile devices. Also GRBL based CNC system has also been utilized for mechanized rehabilitation system as well [10].

Building upon the current research trends, this study aims to provide a cost-effective solution for CNC machines with damaged controllers. To the best of the authors' knowledge no research has been carried out on the upgradation of the broken CNC system with the capability of IIoT based monitoring system. The objective is to develop a replacement controller that can be easily installed, thereby restoring the machine's functionality and promoting the reuse of otherwise discarded systems. Additionally, IIoT monitoring has been incorporated to enable remote monitoring of the machine's performance, enhancing overall efficiency.

2. MATERIALS AND METHODS

In this project, a replacement controller for stepper motor-based CNC machines was developed. The methodology employed several key elements to ensure the device's ease of installation, use, and upgrade. The first step involved utilizing an Arduino-based Grbl controller as the machine's control system. Subsequently, a Graphical User Interface (GUI) was developed using C# Windows Forms, simplifying machine control, g-code file loading, and status monitoring for users. A Raspberry Pi was employed as the machine's computer, providing a cost-effective and powerful platform for running the GUI and other software. To enhance user interaction and usability, a touch screen was connected to the Raspberry Pi, making the GUI more user-friendly. Additionally, a protective case was constructed to house all components, offering protection and facilitating device transportation and setup. The device was equipped with IoT monitoring using Amazon Web Service (AWS), enabling remote monitoring and receiving alerts in case of issues. Finally, comprehensive testing was conducted to ensure the device's expected functionality and reliability before its market release.

The CNC machine in this project offers two distinct operating modes. The first mode, known as "Computer Connection Mode" (shown in Fig. 1), involves directly connecting the device to a computer. By establishing this connection, the computer becomes the primary control interface for the CNC machine. It enables the user to send G-code commands to the machine, controlling its movements with precision. Additionally, the computer provides the ability to make adjustments to the machine's settings and parameters, granting greater flexibility in customization. Operating the CNC machine in Computer Connection Mode offers several advantages. Firstly, the computer's processing power allows for the execution of

https://doi.org/10.31436/iiumecp.v1i1.2995

complex programs and the performance of advanced operations. This means that intricate designs and intricate machining tasks can be achieved with ease. Furthermore, the user can benefit from the comprehensive control and monitoring capabilities offered by the computer, enabling real-time adjustments and ensuring optimal performance. In summary, Computer Connection Mode provides a versatile and powerful approach to operating the CNC machine. By connecting the device to a computer, users gain enhanced control, flexibility, and the ability to perform intricate machining tasks and advanced operations.

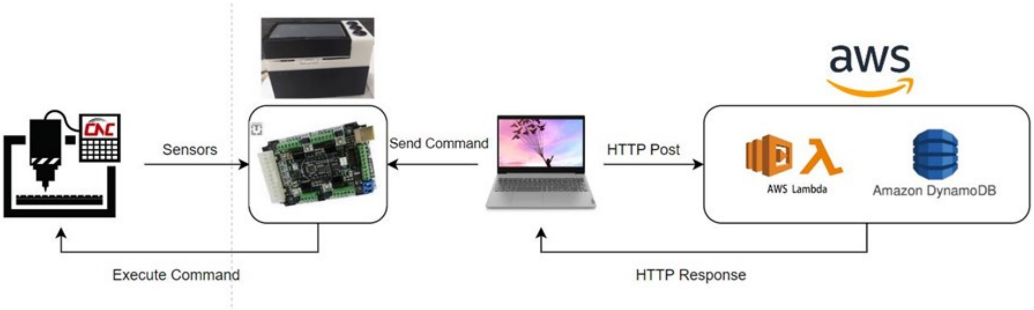


Fig. 1. Computer Connection Mode

The CNC machine in this project offers an alternative operating mode called "Onboard Interface Mode" (shown in Fig. 2). This mode allows users to operate the machine directly using the onboard computer and touch screen, eliminating the requirement for an external computer. Fig. 3 shows the developed onboard Raspberry PI based CNC controller. In Onboard Interface Mode, the machine's onboard computer and touch screen serve as a user-friendly interface for controlling the CNC machine and performing basic operations. This mode caters to users who prefer a streamlined and simplified approach to machine control. By utilizing the onboard computer and touch screen, users can conveniently navigate through menus, input commands, and adjust machine settings with ease. This approach offers several advantages. Firstly, it eliminates the need for an additional computer, reducing complexity and setup requirements. Users can simply power on the machine, access the onboard interface, and begin operating the CNC machine without any external dependencies. The touch screen provides an intuitive and user-friendly interaction, making it easy for both experienced and novice users to control the machine. Onboard Interface Mode is particularly well-suited for users who prioritize simplicity and efficiency. It offers a straightforward and accessible method of machine operation, allowing users to quickly perform basic operations and achieve their desired results without the need for advanced programming or complex setups. In summary, the Onboard Interface Mode provides a convenient and user-friendly alternative for operating the CNC machine. By utilizing the onboard computer and touch screen, users can enjoy a streamlined and intuitive experience, eliminating the need for an external computer and simplifying the control process.

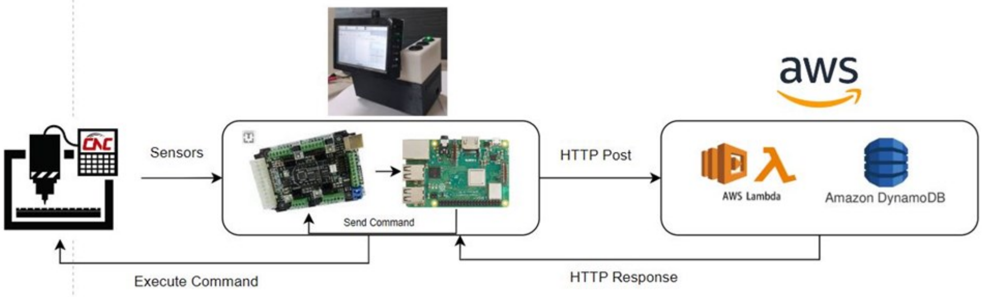


Fig. 2. Onboard Interface Mode

https://doi.org/10.31436/iiumecp.v1i1.2995

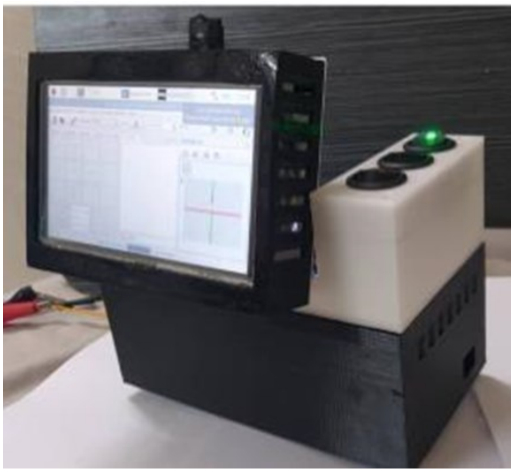


Fig. 3. Raspberry PI based onboard controller for the CNC system

Both of the aforementioned modes involved integrating the CNC system with the AWS system through the HTTP protocol, enabling remote monitoring of the machine's status via the Industrial Internet of Things (IIoT).

3. RESULTS AND DISCUSSIONS

The primary goal of this project was to create a replacement controller with a user-friendly graphical user interface (GUI) specifically designed for stepper motor-based CNC machines. The intended purpose of the controller is to effectively replace any malfunctioning controllers and restore the functionality of the machines. By offering a cost-effective solution, the project aims to cater to numerous users who possess older machines and wish to sustain their operations without the need to purchase new ones.

3.1. Functionality test of the machine using onboard controller

In order to evaluate the functionality of the modular controller, the CNC machine was connected to it, and all the necessary wiring was meticulously inspected to ensure proper connections, as illustrated in Fig.4.

Fig. 4. Modular controller hosting the GUI to operate the CNC machine

https://doi.org/10.31436/iiumecp.v1i1.2995

The modular controller was found to be fully operational, effectively executing commands specified by the G-Code program. Additionally, the performance of the modular controller was assessed while integrating it with IoT monitoring through AWS. Data including machine status, run time, estimated time, percentage of completion, as well as machine and work positions, were diligently recorded and transmitted via the internet to the AWS DynamoDB database for real-time monitoring. The IIoT monitoring system utilizing AWS performed as expected and was also tested with a mobile phone, as depicted in Fig.5, allowing for remote monitoring and prompt alerts in case of any machine-related issues. During the testing phase, the controller exhibited overall performance that aligned with the anticipated outcomes, without any encountered issues or errors. These findings affirm the controller's ability to function as intended and fulfill the requirements of the CNC machine.

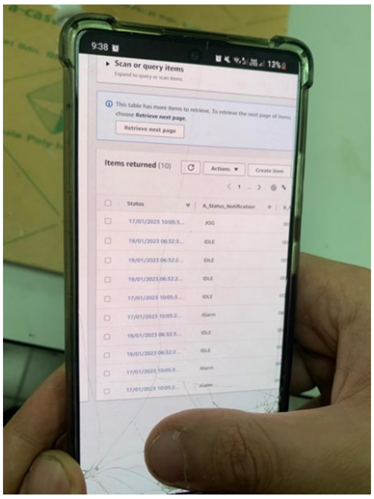


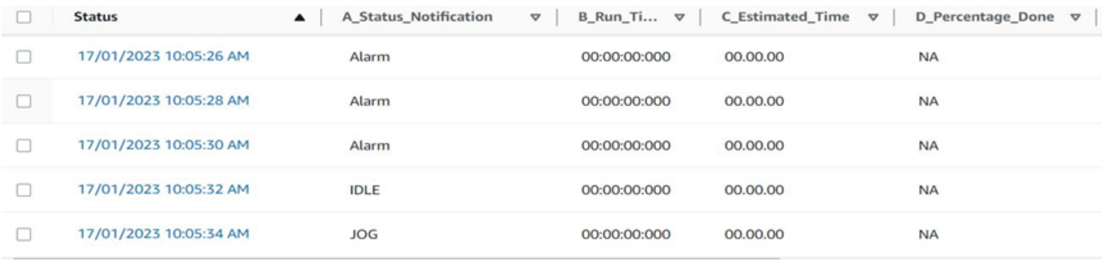
Fig. 5. AWS IIOT Monitoring of the machine status via mobile device.

3.2. Functionality test of the machine using windows based graphical user interface (GUI)

The CNC machine established a connection with the laptop's hosted GUI using a USB interface. The machine exhibited complete functionality comparable to that of the onboard controller. Furthermore, the IIoT system based on AWS performed according to expectations. Fig. 6 illustrates the laptop hosting the GUI responsible for controlling the machine, while Fig. 7 presents a snapshot of the AWS database capturing real-time machine status through the utilization of standard IIoT protocols.

Fig. 6. Laptop hosting the GUI to operate the CNC machine

https://doi.org/10.31436/iiumecp.v1i1.2995



☐	Status	A_Status_Notification	B_Run_Ti...	C_Estimated_Time	D_Percentage_Done
☐	17/01/2023 10:05:26 AM	Alarm	00:00:00:000	00.00.00	NA
☐	17/01/2023 10:05:28 AM	Alarm	00:00:00:000	00.00.00	NA
☐	17/01/2023 10:05:30 AM	Alarm	00:00:00:000	00.00.00	NA
☐	17/01/2023 10:05:32 AM	IDLE	00:00:00:000	00.00.00	NA
☐	17/01/2023 10:05:34 AM	JOG	00:00:00:000	00.00.00	NA

Fig. 7. Snapshot of the AWS database storing various machine related information in realtime

4. CONCLUSIONS

In summary, this project has successfully achieved the development of a user-friendly replacement controller that efficiently restores the functionality of old CNC machines. The integration of a dual approach to operating the CNC machine enhances flexibility and convenience for operators, enabling them to select the method that aligns with their needs and skill level. Additionally, the device incorporates an innovative IoT monitoring feature utilizing AWS, enabling remote monitoring and real-time alerts in the event of any issues, thus enhancing safety and security. Thorough functionality tests were conducted for both the GUI from the laptop and the modular controller, yielding positive results as everything performed according to expectations.

ACKNOWLEDGEMENT

Authors' express their gratitude to IIUM for the facilities provided to conduct the research. The corresponding author also acknowledges the use of CHAT GPT to improve the writing style of the manuscript.

REFERENCES

[1] S. S. Sarguroh and A. B. Rane, "Using GRBL-Arduino-based controller to run a two-axis computerized numerical control machine," in 2018 International Conference on Smart City and Emerging Technology (ICSCET), IEEE, Jan. 2018, pp. 1–6. doi: 10.1109/ICSCET.2018.8537315.

[2] M. Nasir Khan, A. Maheshwari, and H. Verma, "Study and Design of Arduino Based CNC Laser Cutting Machine," IOP Conf Ser Mater Sci Eng, vol. 1224, no. 1, p. 012008, Jan. 2022, doi: 10.1088/1757-899X/1224/1/012008.

[3] A.T. Suryawanshi, D. S. S. Sudhakar, and B. T. Patil, "Low cost and open source software-based CNC router for machining contours," IOP Conf Ser Mater Sci Eng, vol. 872, no. 1, p. 012084, Jun. 2020, doi: 10.1088/1757-899X/872/1/012084.

[4] M. Marsono, Y. Yoto, A. Suyetno, and R. Nurmalasari, "Design and Programming of 5 Axis Manipulator Robot with GrblGru Open Source Software on Preparing Vocational Students' Robotic Skills," Journal of Robotics and Control (JRC), vol. 2, no. 6, 2021, doi: 10.18196/jrc.26134.

[5] J. Veeramony and M. N. Osman Zahid, "A Customizable Controller for 3 Axis Modular CNC Machine," Journal of Modern Manufacturing Systems and Technology, vol. 6, no. 2, pp. 55–62, Sep. 2022, doi: 10.15282/jmmst.v6i2.8567.

[6] V. Lawson, M. Phister, and C. Rogers, "Automated Rotor Assembly CNC Machine," in 2020 Systems and Information Engineering Design Symposium (SIEDS), IEEE, Apr. 2020, pp. 1–5. doi: 10.1109/SIEDS49339.2020.9106641.

[7] Marsono, Yoto, A. Nafiah, and R. Nurmalasari, “Calibration the travel resolution stepper motor machines of CNC-based batik robot running GRBL firmware,” 2023, p. 020011. doi: 10.1063/5.0106246.

[8] S. S. V. Keshav Kolla, D. M. Lourenço, A. A. Kumar, and P. Plapper, “Retrofitting of legacy machines in the context of Industrial Internet of Things (IIoT),” Procedia Comput Sci, vol. 200, pp. 62–70, 2022, doi: 10.1016/j.procs.2022.01.205.

[9] S. A. Aebersold, M. O. Akinsolu, S. Monir, and M. L. Jones, “Ubiquitous Control of a CNC Machine: Proof of Concept for Industrial IoT Applications,” Information, vol. 12, no. 12, p. 529, Dec. 2021, doi: 10.3390/info12120529.

[10] A. Blanco Ortega et al., “CNC Machines for Rehabilitation: Ankle and Shoulder,” Machines, vol. 10, no. 11, p. 1055, Nov. 2022, doi: 10.3390/machines10111055.