PERFORMANCE ANALYSIS OF A CAD/CAM-MATLAB/ SIMULINK INTERPRETER IN MILLING MACHINE APPLICATION

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Article History: Received 7 July 2023; Revised 30 August 2023; Accepted 1 November 2023

ABSTRACT: Geometrical accuracy and precision in machining process requires an efficient and accurate data conversion from the CAD of the part into the CAM machining details and subsequently the tracking control of the trajectories. For this purpose, a data exchange system via an interpreter design that integrates the CAD/CAM software and a milling machine position controller in MATLAB/Simulink platform was developed using the MATLAB graphical user interface module. The flexibility of the position control system of the milling table to accept alternative graphical input reference types was then enhanced. The G-codes of the standard three-dimensional geometrical CATIA-based CAD/CAM part production serve as input to the interpreter while the outputs were the respective x and y position data. These position data became the inputs to the cascade P/PI position controller of the milling machine. The experimental evaluations performed on the milling machine have proved the consistency in performance of the interpreter in tracking three different geometrical objects; a circular-shape, an oval-shape, and a random-curvy-shape. The root mean square of error (RMSE) values of 0.0057mm and 0.0064mm, 0.0063mm and 0.0064mm, and 0.0203mm and 0.0068mm for the x and y axes were measured respectively. The small position errors recorded testified the effectiveness of the interpreter design.

KEYWORDS: *CAD/CAM; MATLAB/Simulink; Interpreter; Position Controller*

1.0 INTRODUCTION

Material removal processes via CNC machining technologies are commonly found in most manufacturing activities. CNC technologies are preferred for its (i) high productivity, (ii) consistency of product quality, (iii) flexibility, (iv) minimized component rejection, (v) less human intervention and (vi) ease in machining of complex shapes [1]. The ability to produce parts with great precision and accuracy are highly desired giving rise to demands for efficient manufacturing processes and activities. Modern machine motion control systems especially those embedded in CNC machines need to utilise the various advantages of modern and robust position controllers to constantly meet the more than ever stringent requirements on parts precision and accuracy in manufacturing process. Over the years, various advanced position controllers have been developed such as in [2-5]. These advanced control algorithms are known for its robustness against external disturbance forces thus producing minimal tracking errors and excellent performance in reference tracking.

Efficiency and accuracy of the CAD/CAM data transfer and conversion governs the final quality of the parts produced [6]. For a complete control system integration in CNC machining, a seamless and efficient translation of the CAD drawing specifications and machining characteristics with the motion controller are necessary and highly desired. To-date, most advanced position controllers related to machine tool applications remained as successful research outputs whereby the realization of an efficient and accurate application of CAD/CAM geometrical data as a direct reference input to these advanced position controllers would bring flexibility and greater quality of the end-product. It is therefore the objective of this work to uplift the current capability of a machine control system to perform according to the potential performance values of the advanced controllers producing accurate trajectories for highly precise and parts and products. The introduction of an interpreter will enable and removes limitation currently existed as the G-codes generated automatically from the post-processor software have limited flexibility to directly become the reference input to the position controller. Several technologies become enabler and aid in the transfer of data between one location to another for effective data communication. With many robust and advanced controllers being designed in MATLAB environment, there exist a need to develop an interpreter using MATLAB platform so as to capitalize the strengths of these controllers in actual applications. As per definition [7], interpreter is a technology that compiles programming languages into forms easily understood by a computer.

Previous works have seen integration between CAD/CAM software and position controller through interpreters designed using interactive software [8-11] such as Java IDE, Python, NI LabVIEW, Visual C++, and Visual Basic. [12] had designed an interpreter using concepts in software engineering and had proposed a graphical user interface (GUI) as the tool to create a more interactive interpreter. Also, an interpreter that links CAD/CAM software and LabVIEW was designed by [13] utilising the Java NetBeans software as the platform of design. However, developments of interpreter in MATLAB environment were seen to be very limited. The novelty of this work lies on the design and application of an interpreter that links geometrical part design and machinability in CATIA with a position controller in MATLAB/Simulink environment using a MATLAB Graphical User Interface module.

This paper presents the performance analysis on the application of the CAD/CAM-MATLAB/Simulink interpreter on an XY positioning table of a milling machine. The performances were analysed on the basis of the magnitude of the tracking error of the milling table for three different types of part geometries; namely a circular-shape, an oval-shape, and a random-curvy-shape. The organization of this paper follows the following sequences; the interpreter design and structure are described in section II, followed by results and discussion in section III. The conclusion of main findings and future works are then presented in the final section IV.

2.0 METHODOLOGY

2.1 System Architecture of Interpreter

This paper proposed an interpreter for the CAD/CAM to MATLAB/Simulink data exchange via a MATLAB GUIDE-based [14] user interactive development platform. It enables data communication between the ACD/CAM part design software and the position controller of the CNC positioning system. The followings are the capabilities of the interpreter: (i) loading file, (ii) extraction of data, (iii) conversion of data, (iv) execution of data, and (v) data simulation. Execution of interactive tasks is possible bypassing the requirements of script writing in MATLAB Editor or even the manual tasks of inserting commands in MATLAB Command Windows. The positions of both the x and y axes of the milling table became the outputs of the interpreter. The interpreter serves as the interface to the receiver which is the position controller architecture in Simulink. Figure 1 shows the overall architectural design framework of the interpreter which integrates multiple software such as CATIA, MATLAB, Simulink, and ControlDesk into a complete system.

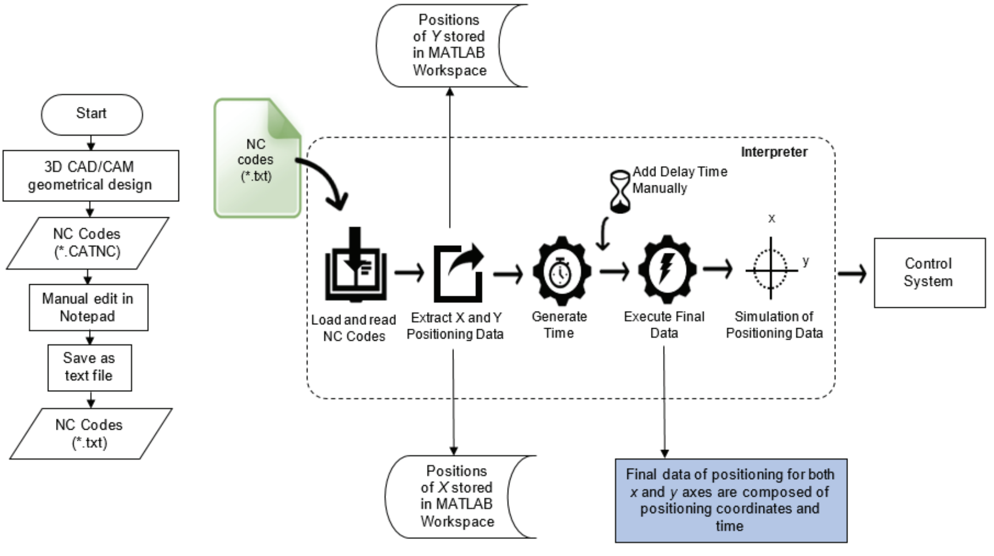


Figure 1: Architecture design of the interpreter

2.2 Interpreter Design and Interface

The CAD/CAM geometrical inputs were prepared using CATIA software. This was then followed by the conversion to *. ASCII text file with *.txt format from the initial *.CATNC forms of the NC codes using the Notepad software. In the subsequent step, these text files are read and presented as *Full Path Name* in a string text box and as NC Manufacturing Codes in full lines of a multi-line string edit box. MATLAB GUIDE permits the act of scrolling of the vertical scrollbar to enable multi-line edit boxes in the property inspector. The position coordinates of both the *x* and *y* axes were extracted from the NC manufacturing codes via the *Extract* pushbutton.

Subsequently, the *str2double* command then initiated the float number value conversion from string texts which were later saved as *.mat file. The terms *final_x* and *final_y* refer to the *x* and *y* data positions in the MATLAB workspace. Total sampling time was calculated and displayed based on the user input of the sampling data. Simulations of the saved position data can then be performed to analyse the accuracy of the reference trajectory. Figure 2 illustrates the graphical user interface of the interpreter. It identifies the different major functions of the interpreter module.

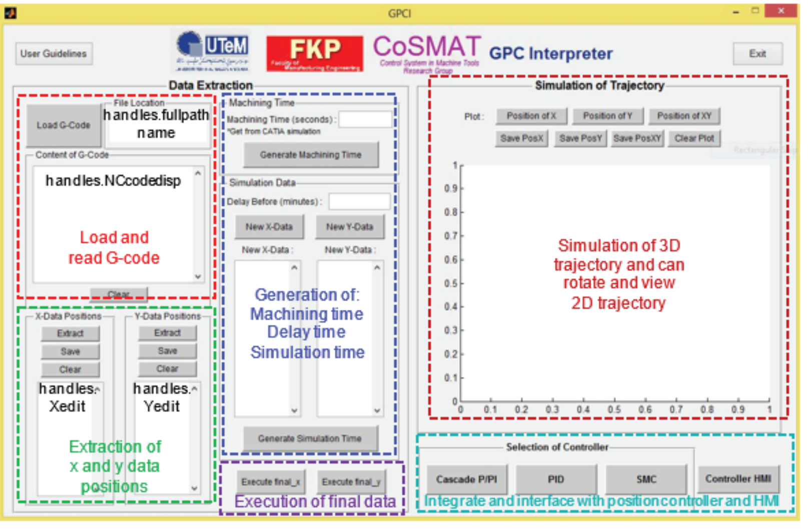


Figure 2: Graphical user interface of the interpreter

Finally, the position data obtained from the interpreter and stored in MATLAB Workspace were ready to be automatically link as input reference signal to the control algorithm in Simulink. For this, the interpreter needs to be interfaced with the controller in Simulink and the actual machine via the human-machine interface of dSPACE Control Desk software. At present, user has the flexibility to select either classical position controller such as PID and cascade P/PI with disturbance observer, or a robust controller such as Sliding Mode Control (SMC) and Super Twisting Sliding Mode Control (ST-SMC). Figure 3 illustrates the schematic diagram of the system that integrates the interpreter, Simulink, and the Control Desk.

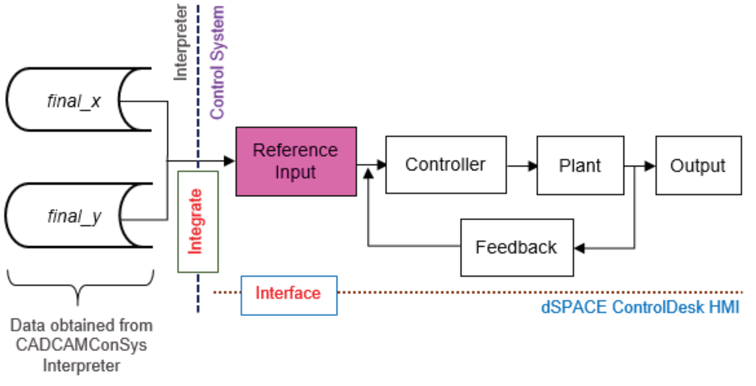


Figure 3: Integration between elements of the CAD/CAM-MATLAB/Simulink interpreter and the control system

3.0 RESULTS AND DISCUSSION

The CAD/CAM-MATLAB/Simulink interpreter was designed to compile and convert the geometrical data of a part in CAD/CAM into a text file. The output of this becomes the reference signal to the position controller in Simulink. The implementation of this interpreter on an XY positioning table of a prototype milling machine is visualised in Figure 4 illustrating components such as CATIA, interpreter module, MATLAB/Simulink, and the ControlDesk software. Aluminium block with dimension of 100mm x 100mm x 24mm was prepared for three different part geometries with the followings dimensions and shapes: (i) circular island with diameter of 60mm x 1mm, (ii) oval island with diameter of 60mm x 1mm, and (iii) random-curvy-shaped island with 1mm height padded. These contours are illustrated in Figure 5.

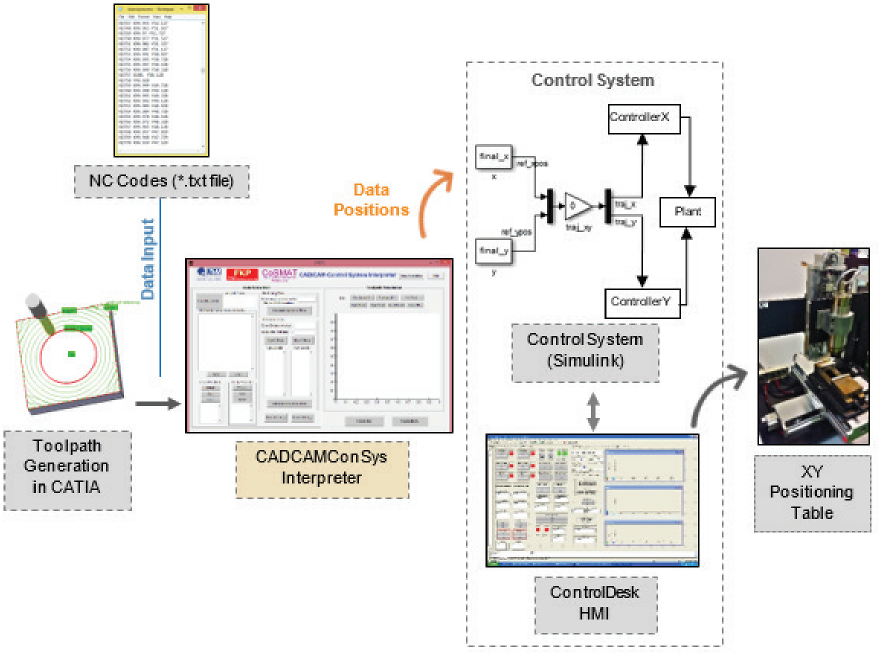


Figure 4: Implementation of CAD/CAM-MATLAB/Simulink interpreter with a milling machine positioning table.

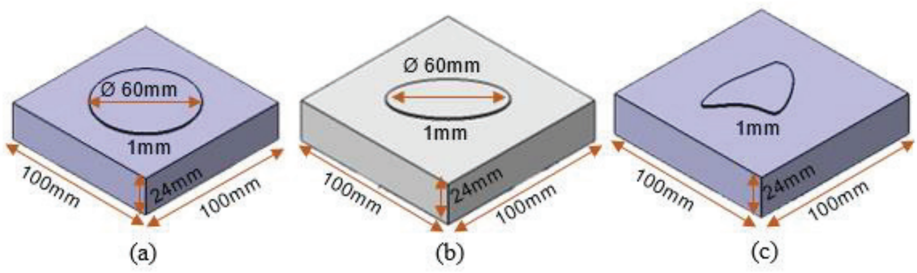


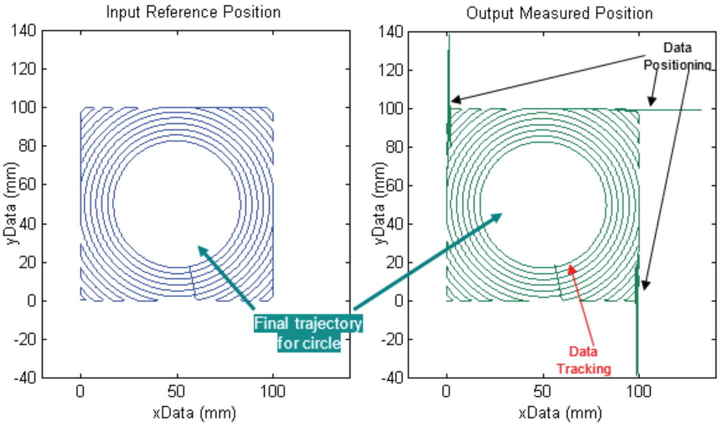
Figure 5: CATIA Drawing of a Cube with Top of (a) Circular Island, (b) Oval Island, and (c) Random-Curvy-Shaped Island

The cascade P/PI position controller in the MATLAB Workspace was first compiled before receiving output position data labelled *final_x* and *final_y* extracted from the CAD/CAM file. The sampling period was 0.005 seconds at sampling frequency of 2000Hz. A HSS milling cutter with diameter Ø6mm and 3 flutes was selected as the cutting tool. The table position, reference position, and tracking errors were measured in the experiments. Motors for the XY positioning table are included with encoders which provide position and velocity feedback. Tracking errors refers to the difference between measured position and input position.

Basically, the G-code data consisted of coordinates for rapid positioning (G0), linear interpolation (G1), and circular interpolation (G2). Here, the GPC interpreter executed the overall coordinates of position for implementation as alternative input reference for the position controller, including the rapid positioning of data. However, a position controller can only control the tracking of position and not the rapid positioning. Figure 6-8 show the experimental results of reference positions and the corresponding measured positions for the three selected contours namely, oval, and random-curvy-shape.

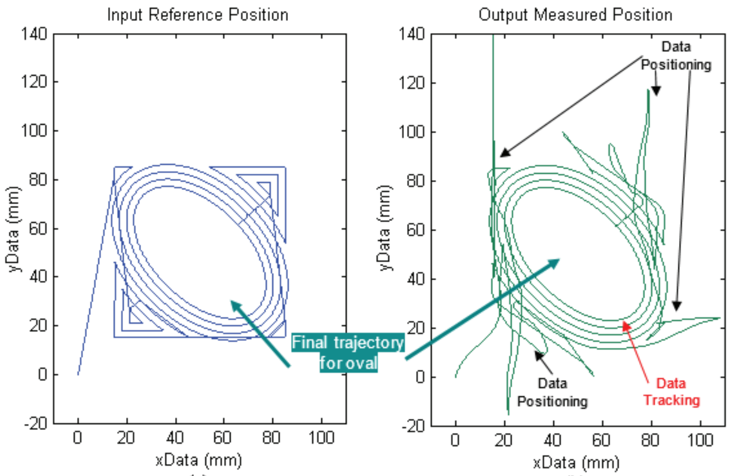
Results showed that cascade P/PI position controller was able to successfully follow the desired interpreted CAD/CAM geometrical-based- trajectories as proven by the measurements of the output trajectories of each contour which recorded near perfect similarities with the reference trajectories. The tracking performances were analysed by comparing the root mean square of the tracking errors (RMSE) and the percentages of the errors of both the x and y axes of the positioning table.

Table 1 summarizes the RMSE values and the corresponding percentages of errors for both the x-axis and y-axis based on the final tracking positions of the three trajectories. The RMSE values of the x and y axes for the circular trajectory were 0.0057mm and 0.0064mm, 0.0063mm and 0.0064mm for the oval contour, and finally 0.0203mm and 0.0068mm for the random-curvy-shaped trajectory. On the other hand, the percentages of errors for the circular trajectory were 0.597% and 0.001% for the x-axis and y-axis respectively while the percentages of errors for the oval trajectory were 0.733% for the x-axis and 0.023% for the y-axis. Finally, the percentages of error for the random-curvy-shaped trajectory were 0.027% and 0.020% for the x and y axes respectively. Results showed that the complexity of the trajectory has proportional impact on the magnitude of the error produced.



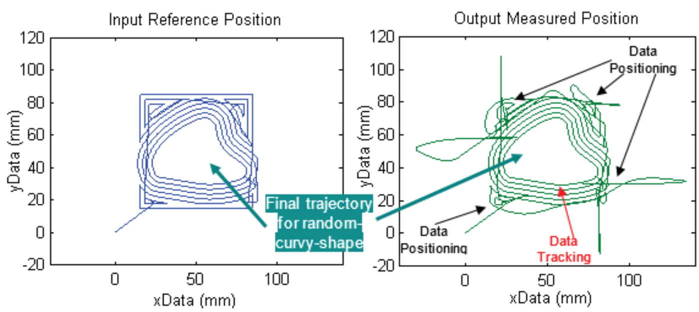
(a) (b)

Figure 6: (a) reference tracking and (b) measured tracking data for circular contour



(a) (b)

Figure 7: (a) reference tracking and (b) measured tracking data for oval shape contour



(a) (b)

Figure 8: (a) reference tracking and (b) measured tracking data for random-curvy-shape contour

Table 1: RMSE and percentage error for the final tracking of the random-curvy-shape, oval, and circular trajectories for x-axis and y-axis

Types of Trajectory	RMSE (mm)		Percentage Error (%) (RMSE / amplitude) x 100%	
	x-axis	y-axis	x-axis	y-axis
Circular	0.0057	0.0064	0.57%	0.64%
Oval	0.0063	0.0064	0.63%	0.64%
Random-curvy-shape	0.0203	0.0068	2.03%	0.68%

The RMSE value for the case of random-curvy shape contour was almost four times higher compared to the circular-type contour. The RMSE value for the x-axis increased from 0.0057mm to 0.0203mm. Similar observation was not recorded for the y-axis. This was due to the higher stiffness value of the y-axis controller compared to the x-axis. Increases in the number of points with increases in degree of complexity have also impacted the overall errors measured. With more complex trajectory design, the frequencies component of the motion also increases as velocity and acceleration requirement increases to cater for the complex motions. Controller performances are limited by the bandwidth of the controller. A controller with higher bandwidth permits input reference of higher frequencies before the system performances deteriorate beyond acceptable value. However, controller bandwidth value is often limited by the system stability that reduces with every increase in the controller gain values.

The interpreter has extended the flexibility of existing control system of a CNC milling machine positioning table applied in MATLAB/Simulink environment with direct data communication between the geometrical data of the part and machining details, and the advanced position controllers of the drives systems. Furthermore, the user-friendly interpreter provides users with easy access to the G-code data. In addition, the interpreter brings the benefits of CAD/CAM geometrical products into a customized controller in a machine tool control structure. Ultimately. this outcome provides alternative to previous work that utilises other simulation tool and software such as LabVIEW and the Java NetBeans [13].

4.0 CONCLUSION

This paper has positively demonstrated the successful design and application of an interpreter for data exchange between CAD/CAM software and MATLAB/Simulink validated on an XY positioning table of a milling machine. Results acquired have shown the ability of the system to efficiently received trajectories data of three different types of geometrical shapes; circular, oval and random-curvy shape, as input references for the position controllers of the servo drives system. As a result, the machine tool position controller within the Simulink platform was able to receive the x and y axes data positions based on the ASCII text data of the CATIA design software. Realization of this system has extended the capability of the machine tool control system to receive alternate geometrical input reference signal types directly from the CAD/CAM design software. Successful implementations were validated based on the magnitude of the position tracking errors and the percentage of the tracking errors which were less than 1%. However, further study in case of parts with more complex features is necessary especially with regard to the implementation of the system with other advanced position controllers; aside from the current cascade P/PI.

ACKNOWLEDGEMENT

The authors would like to express our gratitude and appreciation to the Faculty of Industrial and Manufacturing Technology and Engineering, Universiti Teknikal Malaysia Melaka for the support extended in realising the success and smooth implementation of this project.

AUTHOR CONTRIBUTIONS

A. Sudianto: Conceptualization, Methodology, Software, Writing-Original Draft Preparation; Z. Jamaludin; N. Mat Seman; A. Othman: Data Curation, Validation, Supervision; M. Maharof; S.H. Yahaya; A.U. Patwari: Software, Validation, Writing-Reviewing and Editing.

CONFLICTS OF INTEREST

The article has not been published elsewhere and is not under consideration by other journals. All authors have approved the review, agree with its submission and declare no conflict of interest on the article.

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