DESIGN OF A CAD/CAM-SIMULINK DATA EXCHANGE SYSTEM FOR MACHINE TOOL APPLICATION

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ABSTRACT: This paper presents design of a CAD/CAM-Simulink Data Exchange System (CS-DES) that integrates CAD/CAM software and control system architecture with the aim to further enhances capability and flexibility of a prototype milling machine. In its current state, the XY milling table positioning system is controlled using in-house designed position controller that is able to effectively control positions of the milling table using predefined reference trajectory. The application of this position controller is restricted by the signal input forms that are only available via the Simulink reference input signal library. The proposed system design allows integration of the CAD/CAM technology with the MATLAB/Simulink platform of the control system architecture, enabling variations of input signal types. The designed integrated system allows data input in the forms of Computer Aided Design and Computer Aided Machining. The main design component of the interface system was developed using MATLAB Graphical User Interactive Development Environment. This paper presents an overview of the system architecture for the CAD/CAM-Simulink data exchange system. A successful implementation of this novel data exchange system would simplify current control system development process thus providing greater flexibility and capability that could be translated into improved performance of the machine tools drives system.

KEYWORDS: *CAD/CAM; User-Interface Design; Integrated System; MATLAB/Simulink; Control Systems*

1.0   INTRODUCTION

System engineering has seen rapid developments and improvements in technology with the rise in applications of complex systems in manufacturing industry. Recent trends showed aggressive demands for isolated systems to be integrated into smart and effective system engineering for the purpose of achieving better production efficiency, safety and flexibility [1]. Integrated system reduces production time as manufacturing activities between the different work processes are simultaneously monitored and updated, resulting in seamless flow of information between the different components of manufacturing. In manufacturing of discreet products, the ability to utilize the CAD/CAM systems effectively is very important during the design and modeling stage and during manufacturing of the products. Model that is developed must describes as accurately as possible the desired product functional structures such as geometric information and non-geometric data, like technological, physical and management data. An integrated CAD/CAM system involving product modeling has been proposed in [2]. Also, CAD/CAM systems have been made to interconnect optimization and trajectory planning of robotics system [3] with Product Data Management [4]. It was also evidence in [5] that in the future, CAD/CAM data could replace the G and M codes of CNC machining language with STEP-NC technology. Appropriate interfaces were designed using LabVIEW [6-7] and function blocks that later formed the IEC 61499 standard for control system design applications [8-9]. Motion simulations in CAD/CAM system was introduced by [10-11] using SolidWorks software that is integrated with SimMechanics from MathWorks for human-machine interface in an industrial robot application.

Besides SimMechanics [12], MathWorks has also introduced MATLAB GUIDE (Graphical User Interactive Development Environment). The benefits of MATLAB GUIDE include: (i) high-level script based development, (ii) seamless integration with current MATLAB computational power, (iii) possess operating system that is independent from the GUI applications, and (iv) that it has user interactivity and real-time measurements. The design and development of MATLAB GUI had been widely applied in control system. For example, [13] had showed that the proposed MATLAB

GUI design allowed for the design of the fuzzy logic controller and for the integrated fuzzy logic controller to be accessed and tuned easily. This was applied for liquid level control in a cylindrical tank. In addition, [14] had applied a MATLAB GUI to perform simulations and experimental work in the presence of a control algorithm such as predictive disturbance observer based filtered PI (PDO-FPI) control. The control system performances were analyzed using measures such as settling time, overshoot, integral of absolute error (IAE), integral of square error (ISE), the time integral of absolute error (ITAE) and time integral of square error (ITS). It was reported that MATLAB GUI development provided a simple and easy evaluation of the design parameters.

Furthermore a nonlinear disturbance observer that is based on a PID controller was designed in [15] for a three-tank hydraulic system. The controller was built using MATLAB/Simulink software with a developed GUI. The GUI that was developed consisted of system choice, controller parameters, observer parameters, experimental choice panel with and without internet and several other panels. Results presented showed that the GUI tool has provided easy evaluations of the control system's performances and robustness to uncertainties. In a subsequent study, [16] had designed a trajectory tracking and a PI controller for a coupled tank using a MATLAB/Simulink graphical user interface via internet as a virtual or remote laboratory.

Aside from the CAD/CAM perspective, the precision and accuracy of parts and products that produced during machining activities are also dictated by the effectiveness of the position controller applied by the machine tools. Various independent research have been conducted to develop effective controllers for machine tools applications [17]. Various control architectures and configurations have been designed with aim to produce machine tools that are accurate in tracking and robust against input disturbance. Author [18] had designed a cascade and sliding mode controller for an XY milling table with excellent performance in reference tracking whereby a reference input signal was used to observe the tracking errors.

An effective integration of controllers designed in literature with a CAD/CAM system would benefits practitioners of machine tools. A system that effectively combined both the controller and the CAD software would add flexibility to the overall control system thus expanding the quality of parts and products that are produced. Therefore, the primary objective of this study is to design a user-interface system that integrates a CAD/CAM geometrical data software with advanced controller built on the platform of MATLAB / Simulink for effective and flexible control system of an XY ball-screw driven milling table. The system interfaced the CAD/CAM component of the part manufacturing with the drives system controller for both x-axis and y-axis of the positioning table. The controller that was applied in this study consisted of the cascade P/PI and a robust nonlinear sliding mode controller.

This paper presents a novel system architecture design for a CAD/CAM - Simulink Data Exchange System of a machine tool. The paper is organized as follows. Section 2.0 explains the architectural design and experimental setup used for this study. Section 3.0 then presents design of the user-interface system with discussions on the system workflow. Finally, Section 4.0 concludes the findings of this study.

2.0   METHODOLOGY

A graphical user interface (GUI) is a pre-requisite for this software development as it integrates the CAD/CAM data with control system architecture of a machine tool application. The user-interface was designed using MATLAB GUIDE (Graphical User Interactive Development Environment). The methodology applied for this work can be generalized into three distinct phases: (i) Input: CAD/CAM generation, (ii) User-interface system: CAD/CAM-Simulink data exchange system (CS-DES), and (iii) Experimental work: XY table ball-screw driven system. Figure 1 illustrates the architectural design of this study.

Firstly, a geometrical drawing was designed in Computer Aided Design (CAD) platform and machining properties such as selections of cutting tools, spindle speed, and feed rate were added in Computer Aided Machining (CAM). CATIA software is applied for this purpose. It combined the two functions of CAD and CAM. Next, the numerical control (NC) manufacturing codes were auto-generated from CATIA and saved in a *.txt file.
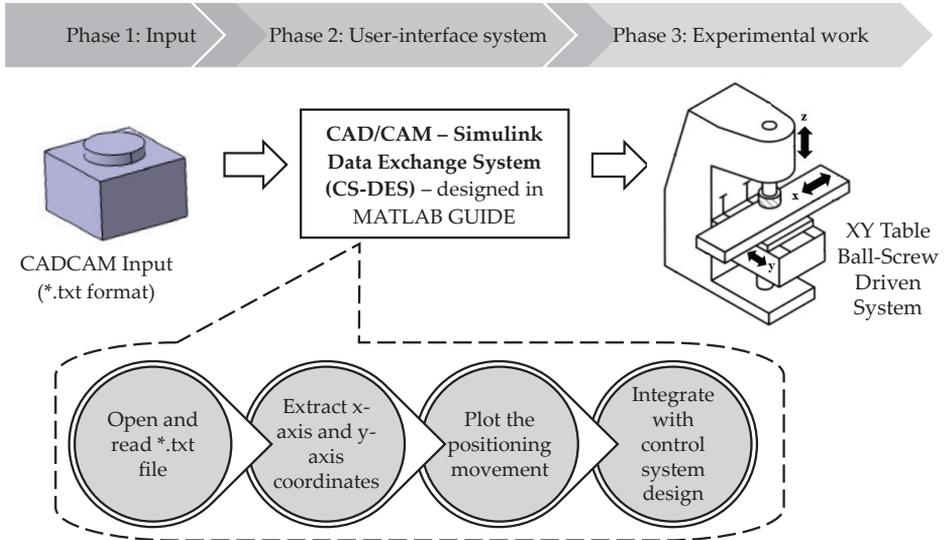

Figure 1: Architectural design approach

A CAD/CAM-Simulink data exchange system (CS-DES), that is the main objective of this research, was then developed. CS-DES enhances the capability of current machine tools control system with additional flexibility in term of the types of reference input forms that the system can respond. Indirectly, CS-DES improves data communication efficiency resulting in a machining process that is precise and reliable.

An interface system was designed to integrate the CAD/CAM data with the control system architecture that was designed using the Simulink platform. CS-DES interface system was designed with several functions: (i) open and read the CAD/CAM input in *.txt format, (ii) extract x and y-axis coordinates, (iii) plot the positioning movement, and (iv) integrate the interface system with in-house built Simulink control system design. This interface system was then applied in experimental work for validation purposes.

For experimental validation, a prototype of a CNC milling machine with an XY positioning table controlled using advanced position controller was utilized. The system consisted of four components: (i) a personal computer, (ii) a digital signal processing unit (DSP), (iii) a servo drive amplifier, and (iv) an XYZ milling machine. The XY positioning table is ball-screw driven and produced by Googol Tech. The CNC prototype milling machine comes with three positioning axes, each driven by a Panasonic MSMD 022G1U AC servo motors [19]. Figure 2 shows the main components of the XYZ prototype of CNC milling machine.
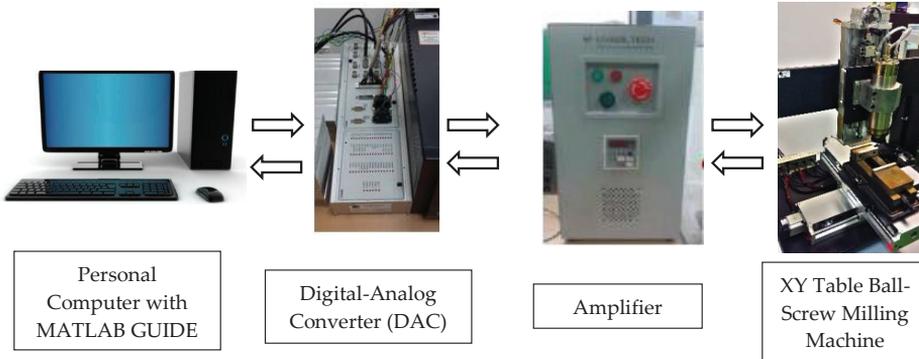

| Personal Computer with MATLAB GUIDE | Digital-Analog Converter (DAC) | Amplifier | XY Table Ball-Screw Milling Machine |

Figure 2: Experimental setup of XY table ball-screw driven system

3.0　　RESULTS AND DISCUSSIONS

CS-DES program was developed to allow seamless communication between CAD/CAM data with the control architecture built using the Simulink platform. Figure 3 shows the graphical user interface of CS-DES program consisting of the CAD/CAM-Simulink data exchange, position data, and the Simulink controller scheme. The CAD/CAM-Simulink data exchange section functions to extract x-axis and y-axis position data from the CAD/CAM data provided by the CATIA CADCAM software. The saved x and y axes coordinates are then viewed in section regarding positioning movement in order to simulate or preview the reference trajectory before being uploaded to the control scheme in Simulink platform for machining purposes. The CADCAM data is now integrated with the positioning controller of the drive system. Figure 4 shows the overall flowchart of research methodology applied for design of the CADCAM-Simulink data exchange system (CS-DES).
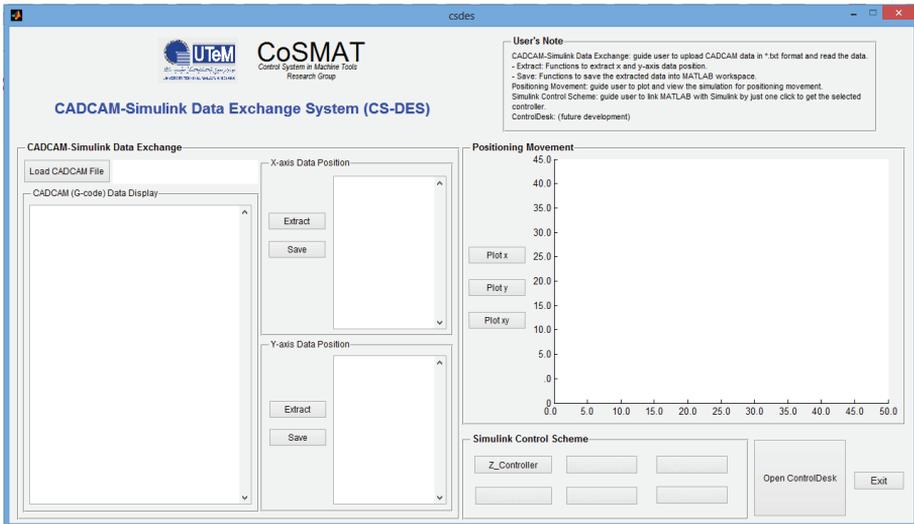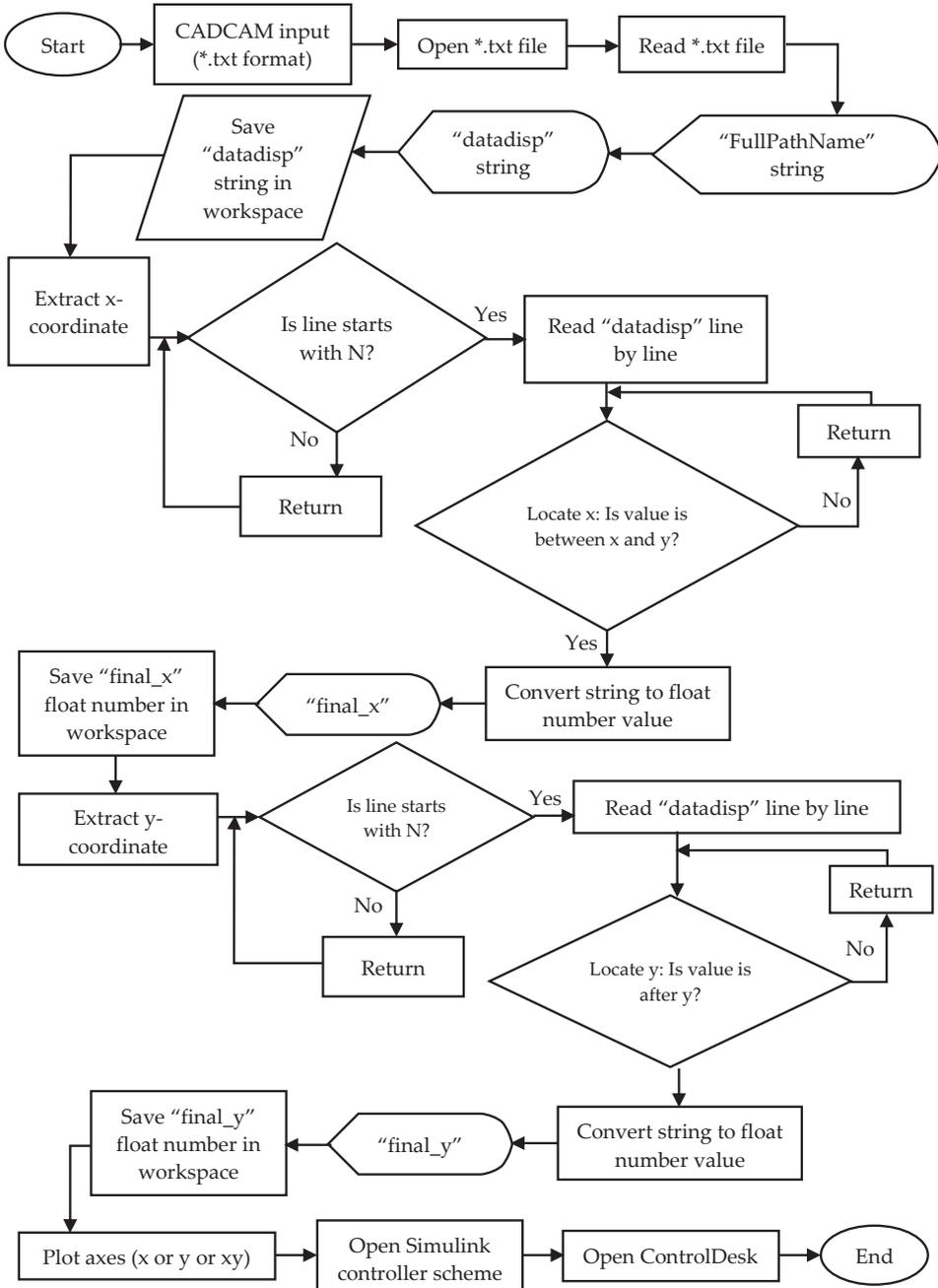
Figure 3: The developed CS-DES interface system

Start → CADCAM input (*.txt format) → Open *.txt file → Read *.txt file

Save "datadisp" string in workspace ← "datadisp" string ← "FullPathName" string

Extract x-coordinate ← Is line starts with N? —Yes→ Read "datadisp" line by line

Is line starts with N? —No→ Return

Locate x: Is value is between x and y? —No→ Return

Locate x: Is value is between x and y? —Yes→ Convert string to float number value → "final_x" → Save "final_x" float number in workspace

Save "final_x" float number in workspace → Extract y-coordinate ← Is line starts with N? —Yes→ Read "datadisp" line by line

Is line starts with N? —No→ Return

Locate y: Is value is after y? —No→ Return

Locate y: Is value is after y? —Yes→ Convert string to float number value → "final_y" → Save "final_y" float number in workspace

Save "final_y" float number in workspace → Plot axes (x or y or xy) → Open Simulink controller scheme → Open ControlDesk → End

Figure 4: Workflow of CS-DES interface system

Firstly, the system was initiated by opening and reading the *.txt file. The system then displayed the "FullPathName" of the data file path located in the computer. In addition, the "datadisp" string was also displayed in a multi-line edit box. Next, the "datadisp" was saved in the MATLAB workspace. The x-axis and y-axis position values were then extracted from "datadisp". In order to extract the x-axis coordinates, if the data line starts with N, then proceed with reading "datadisp" line by line, and locate the position x. However, if there is a value between x and y, the the value is converted from the string format to a float number value. Else, the program will return to the previous command. The float number values are saved in MATLAB workspace as "final_x". The same command procedures are applied for y-axis coordinates. However, in locating the y-axis coordinates, if there is a value after y, the value is converted from string to float number value. Else, return the programming to the previous instruction.

Upon extracting the geometry positions that are labelled "final_x" and "final_y" in the MATLAB workspace, the values are then used to plot the position trajectory for motion control purposes. There are three available options, namely; (i) plot the x-axis only, (ii) plot y-axis only, and (iii) plot both x-axis and y-axis. The plot function was designed to simulate position of the table as confirmation before any experimental work is performed. This would ensure safety and efficiency of the machining process.

Finally, a pushbutton was designed to integrate the interface with the controller Simulink platform and a program was created for this purpose. User has the freedom to apply any controller scheme that was designed in MATLAB/Simulink environment. Examples of such motion controller schemes are cascade P/PI controller and the classical proportional-integral-derivative (PID) controller. In the future, the system is to be linked to a digital signal processing unit user interface panel named Control Desk for better management of the control system.

For preliminary validation and analysis, a case study was conducted using a geometrical drawing designed in CATIA. The geometry took the shape of a cubic with dimensions of 60mm x 60mm x 60mm. In

order to get the NC manufacturing codes, machining properties such as feed rate, spindle speed and cutting tool were identified in CATIA Process. However, for current study, these properties were not specifically considered since no actual cutting is performed; only positioning of the XY table is considered. Figure 5 shows the NC manufacturing codes obtained from CATIA. CS-DES has enabled data exchanging of the NC manufacturing codes. The codes were then saved as text file in *.txt format. The x-axis and y-axis positions were extracted as reference input position for the controller. Figure 6 then shows the example of extracted x-axis and y-axis positions data. The next step would be for the machine position controller to utilize the position data as reference trajectory of the corresponding geometry.

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N10 G20 G90 G40 G17 G94 G00 G49 G80 G98 G64 G54
N20 T1 M6
N30 G0 X29.539 Y25.021 S70 M3
N40 G43 Z1. H1
N50 G1 G95 X27.669 Y25.577 F1.
N60 X26.153 Y26.806
N70 X25.224 Y28.521
N80 X25.021 Y30.461
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N1080 X32.075 Y10.108
N1090 X28.155 Y10.085
N1100 M5
N1110 M30
N1120 M2
N1130 M30
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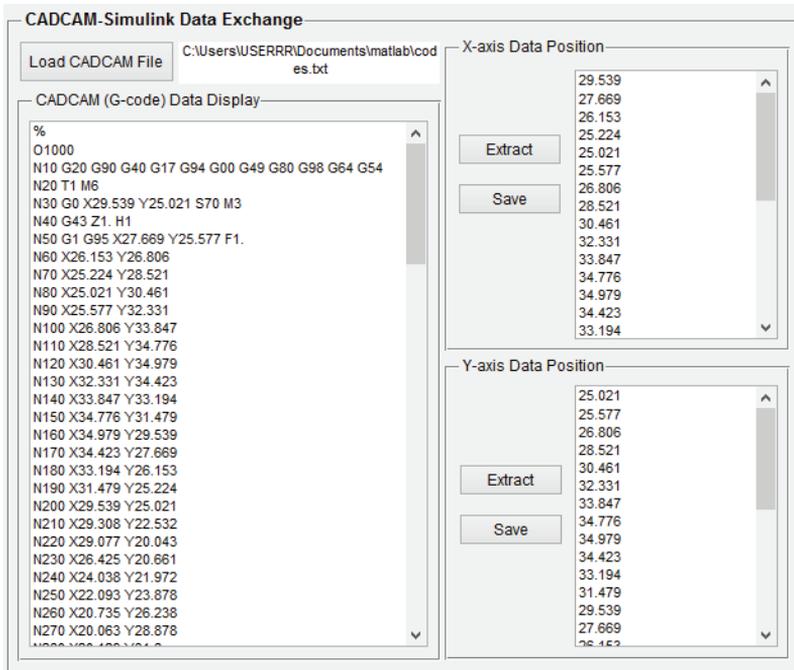
Figure 5: NC manufacturing codes obtained from CATIA

Figure 6: Example of extracted *x*-axis and *y*-axis positions data

4.0   CONCLUSION

In conclusion, this paper introduces a novel CAD/CAM-Simulink Data Exchange System (CS-DES) that creates additional flexibility in term of variety in types of input reference signal for development of machine tools control system utilizing advanced controllers developed in literature. The system interface was designed using MATLAB GUIDE environment. The interface enhances the ability of the control system to read input reference position data in graphical form resulting in a more efficient system. A detailed workflow of this interface system design was presented and elaborated. A case study that was presented showed the ability and success of CS-DES to extract and integrates the x and y axes position data with the position controllers. The system is to be further enhanced with additional integration that links the control system architecture with machine process interface via the Digital Signal Processing unit of the servo drive system.

ACKNOWLEDGMENTS

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