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CNC Machine Based on Embedded Wireless and Internet of Things for Workshop Development

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Abstract: This paper focus on the integration of wireless technology and CAD/CAM system for CNC workshop development. A specific case study is described a system based on embedded wireless device and Internet of Things (IoT) concept with Bezier techniques for the proposed model. The focus of the case study is to show a complete stage of manufacturing process starting from modeling in CAD system passing through CAM system, transferring NC code, gathering machine data, monitoring whole process and finally manufacturing product. Using MATLAB and UG-NX software for modeling, Monitoring machining process using temperature, accelerometers and gyroscope sensors based on IoT concept. Transferring NC codes to CNC machines using FTP protocol and DNC software, real-time report demonstrate information about machine name, parts progress, time, operation condition and Machine Cycle Time depending on DNC network.

Keywords: CAD/CAM; Bezier technique; Wireless Controller system; IoT; DNC; NC code; CNC workshop.

1. Introduction

There are various types of controller system which are controlling different machines in any kind of manufacturing industries. Considering a small industry to a large industry everywhere in production scenario, it is required to keep a track of production process and the machine time consuming [1]. In workshops which employ mass production daily, the registering of daily production is done manually by using a production line counter. And about the monitoring of CNC machines, most registering of machine performance, the operation, the number of jobs produced/worked upon are entirely drafted on paper. Produced reports are also manual which are either printed on paper or generated on computer by manually entering the data. The data can be like machine running time, machining time, number of work pieces. Likewise, the report generation if done manually is a time taking job and highly erroneous. This also leads sometimes to data manipulation as well as misunderstanding. The other feature is to make a remote control of CNC machine using a local wireless network [2].

DNC is referred to as the Direct or distributive Numerical Control, Heading for direct digital control. The definition depends on if it means a number of numerical control equipment directly connected to a computer or multiple network connected with each other, and the central computer in charge of the NC program's management and transfer. At present, DNC system includes not only the NC program, but also the manufacturing data of the specific tasks required for the production, such as cutting tools data, scheduling, configuration information of machine tools, and so on, and part of the DNC system also has the functions of machine tool state acquisition and remote control. This automation should include as many parameters of machine as possible to be continuously recorded mostly on some sort of local storage as well as a remote storage. This remote storage can act as an effective monitoring tool for the supervisory persons. If the remote storage is on internet, the data monitoring can even be done sitting almost anywhere in the world also achieved CAD / CAM and numerical control system integration, so as to realize Group Control Processing by machine network and centralized control [3].

Based on HLK-RM04, an embedded Wi-Fi communication module is constructed to facilitate the communication between the upper industrial control computer, the field monitoring host and the various CNC machine Tools. It can be applied to many traditional NC systems to realize remote monitor and management [4].

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The new age of CNC machines is how to integrate the communication system and the advancement in the information technology (IT) with CNC machines. Wireless technology had been developed and becomes the major connection for computer network or devices [5]. With the improvement of the performance and reliability of Wi-Fi technology, industries are stirring Ethernet connections aside. As Wi-Fi gains favor and usurps wired access, Wi-Fi capabilities are varied rapidly, producing an important difference in WLAN architectures and implementation models [6,7]. Xinghong Kuang and Haibo Huo [8], had designed a Wi-Fi wireless transmission module based on the control of the machine control unit (MCU). The design explain hardware schematics and wireless transmission process, describes the principle of Wi-Fi wireless transmission based on the MCU.

The Internet has changed industry and personal life in last years and continues to do so. Internet of Things (IoT) gives the ability to make integration between sensors and things by using the internet as a communication medium, which gives developers a wide area to take benefit of it. Claiton de Oliveira et al [9], made an analysis of using wireless technology to create automatic shop-floor data collection by monitoring and supervision systems, adds precision and control improvements into the decision-making process. Li Boquan et al [10], improved the level of automation in CNC equipment by using CNC machine with RS232 interface to connect it with WLAN and create a DNC network. Y. L. Zheng et al [11], design an IoT protocol to achieve the real-time communication between the CNC operating platform and the wireless sensor nodes and show that the CNC monitoring system based on (IoT) technology can provide the temperature and vibration information for the CNC operating platform in time with the advantages of simple layout and reliable communication. Kong Dexin et al [12], applied Ethernet hardware connection (ZNE-100TL module) as a solution to implement information management, which provides a convenient for production management and data transmission in numerical controlled workshop. Jaromir Skuta [13], used standard personal computer (PC) as a higher level of control and running the CAD/CAM application with a user interface for generating G-code. The commands between the PC and the controller are sent using modules that provide wireless transmission of information. L. Gui et al [14], has been developed a CNC online monitoring system based on IoT use the machine tool as an example, by the way of internet communication, monitor the parameters of machine equipment effectively and uniformly at Web server. Then achieve the ultimate goal of connection between two objects.

The main objective of this research is to create a system that's having the ability to gather and transfer data, processing and reporting for workshop's machines. Any workshop has various types of machines which have different type of operation system platform and output device ports (RS-232 and RJ-45). Some of the workshop's machines have a DNC option in its platform that's made it easy to connect to DNC network, in other hand, some doesn't have only RS-232 port used to transfer NC program to the machine. In this paper had implemented a complete system with all types of interface ports (WLAN, Ethernet and RS-232), starting from modelling, monitoring, management, processing to manufacturing.

2. SYSTEM DESECRUPTION

According to the aim of research, a developed system had been used consist of:

A. Wireless Controller System

This system consists from Central Computer and the wireless devices that's connected to Machine Control Unit (MCU) of the machine to make wireless network. Due to the variety machine types that exist in the workshop and commonly workshop machines had been limited with two types of connection (Ethernet RJ-45 or RS-232). In this case, to achieve our aims have to use a low-cost embedded UART-ETH-Wi-Fi module (Serial port, Ethernet and Wireless network) which offer Wi-Fi possibility to transfer data to different types of machines. The embedded UART-Wi-Fi modules (HLK-RM04) based on the universal serial interface network standard, built-in Transmission Control Protocol (TCP) / Internet protocol (IP) protocol stack, enabling the user serial port, Ethernet, wireless network (Wi-Fi) interface between the conversions. This module work with network standard: IEEE 802.11n, IEEE 802.11g, IEEE 802.11b., IEEE 802.3, IEEE 802.3u, as shown in figure (1). Any computer with wireless capability like (personal computer, laptop, Pad and Pendent) can connect to the CNC machine and become the device under Wi-Fi LAN and more of that was having the capability to become a part with other network connected to internet through WAN.WAN default IP is dynamic IP address. LAN, Wi-Fi for the same local area network, enabled by default DHCP server.

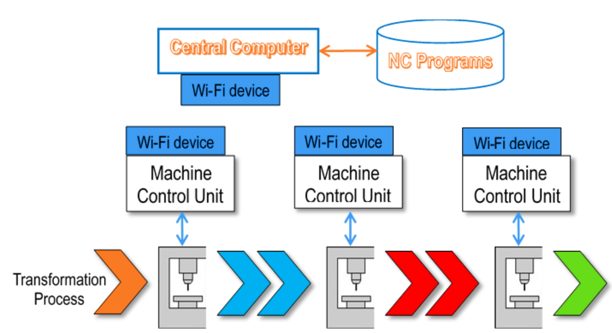


Figure 1. Wireless Controller System.

B. Internet of Things for CNC Machine Monitoring

In the process of machining workpiece, the simulation and automation center needs a real time data information about vibration, temperature, humidity, noise level, accelerometers, rotation and object detection to make the right decision if any problem happen, The IoT for CNC monitoring is consist from: sensors, middleware and application or user interface.

1) Sensing Unit: Each sensing unit consisting from Bluetooth Low Energy chip, printed circuit board (PCB) and Li/ion coin cell battery. This unit consists of multiple sensors like:

a) Temperature/Humidity: HTU21D (F) RH/T Sensor IC, a low power digital sensor of relative humidity and temperature, Low power consumption, Fast response time.

b) Accelerometers/Gyroscope: MPU-6500 Sensor IC, six-axis (gyroscope+ accelerometer).

2) Middleware: All sensors will have connected to master unit and by using BLE to crate Node, this node has to be connected to the internet by Wi-Fi via gateway like a wireless router.

3) Application and User Interface: After connecting sensors with master unit and connected master unit with the internet, sensor units must be defined to the cloud server, Create account in Relayr cloud server with an email, this account will be pairing the specific master unit with its relevant sensing unit, so that when they start publishing data, only master unit will be able to collect that data and transmit it to the cloud platform, making it available for user interface application. The dashboard app posts a request to the cloud server application programming interface (API) to register a new device. The API processes the request and returns a set of IDs to be written to the Master unit and the six Sensor unit. The IDs ensure that only the specific Master unit is then able to receive data from the specific sensors and relays it to the cloud. Once all the sensing unit's setup with master unit and connected to internet, now can view the real-time sensor data on webpage (Device Dashboard). This will let know if and how the devices are communicating and can act as a way to troubleshoot. Can also view sensor data through the phone by using Dashboard downloaded from google play as shown in figure (2).

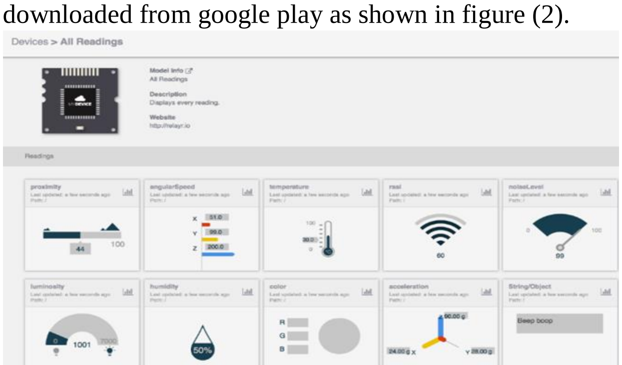


Figure 2. IoT software user interface.

B. CNC Milling Machine

The CNC milling machine C-TEK model KM80D as shown in figure (3) was used. This machine has RS-232 port and Ethernet for FTP file transfer.

Figure 3. CNC Milling Machine.

3. Proposed Surface and G-code Generation

Modeling process depend on CAD/CAM software, as a case study of the proposed surface shown in figure (4) was designed based on Bezier method with 7 control points.

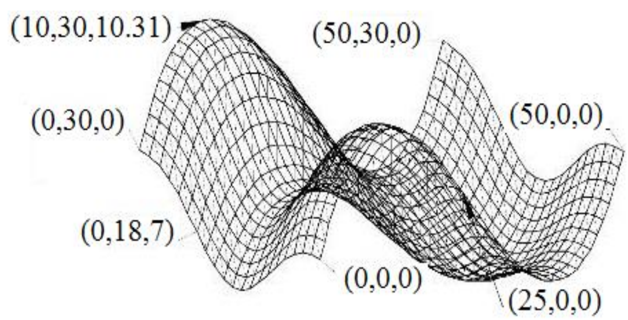


Figure 4. Proposed surface with control point.

The proposed surface and G- code generation were presented by using MATLAB as a laboratory software and UG-NX10 as workshop software:

1) *MATLAB software*: To design the proposed surface use the Bezier matrix control points as input data to MATLAB software. Figure (5.a), represents the flow chart of it. While figure (6) represent the program output. The G- code generation here will depend on G-code that generated from the proposed flow chart of tool path shown in figure (5.b), the G-code generated with linear interpolation (G01), and according to the written program in MATLAB a text file contain G-codes will save. This file opened in CIMCO edit V5 program for making a simulation of tool path.

2) *UG-NX10 software:* To create the proposed surface will be extracting the results of surface's points from AutoCAD software and save it as data file has extension (.dat) and open the data file in UG-NX10 software at multi stages as shown in figure (6). UG-NX10 software provides machining environment and there are many steps must be taken before creating an actual tool path. There are two phases of the operation that rough and finish machining. Therefore, the first is to creating tool path for rough machining. The tool path generation for model in UG-NX can be shown in figure (7 a, b) and it illustrates the status of the part after rough machining is to using flat-end tool. After identifying machining parameters and selecting the required type of tool path for rough machining, the software provides a simulation process to clarify the operation. The second phase is finishing process using ball- end tool (10 mm) in diameter. Cutting area has been performed according to machining method and found that the side-step will be very small values as compared to rough machining to achieve a smooth surface. Figure (7 c, d) shows the finishing process with a ball-end tool.

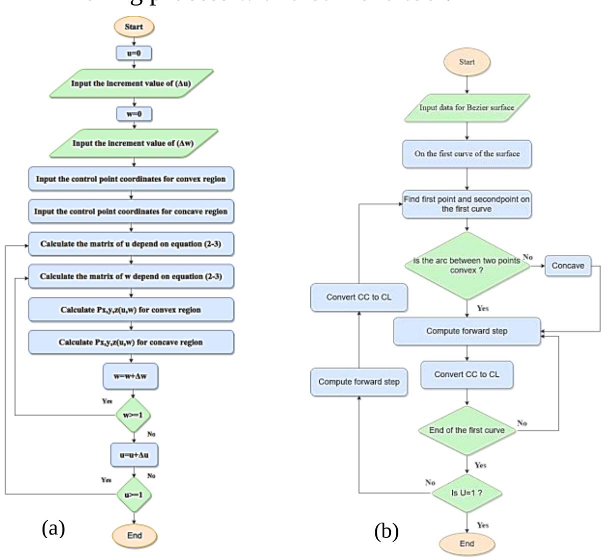
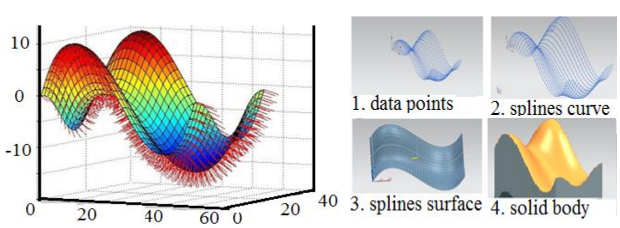
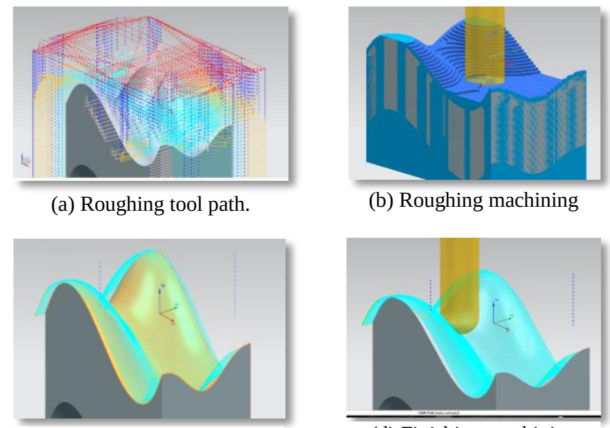


Figure 5. (a) Flowchart of Bezier surface design. (b) Flow chart of tool path in MATLAB.



(a) Using MATLAB. (b) Using UG-NX10.

Figure 6. The proposed surface.



(a) Roughing tool path. (b) Roughing machining

(c) Finishing tool path. (d) Finishing machining process.

Figure 7. Tool path simulation by UG-NX software.

4. Internet of Things System Implementation

To implement this system, need some steps starting from connecting sensors with master unit to build a node in the machine. This node connected to the cloud server via wireless local area network. The data collected from the machine will be stored in cloud server and this gives the capability to reach and analyses data from different devices or location. The present work has created a CNC monitoring system that's allowed implementation rules and identify patterns.

A. Sensor Unit Configuration

The most important step in IoT system is to make unique identity for device, to do that there are two main parameters in sensor unit need to be configured before can connecting it to cloud server as shown in figure (8). At beginning configured the Readings, will need to set the following properties:

- Meaning: Description of device reading.
- Name: The name of the command or configuration.
- Path: An optional filter that lets to differentiate between multiple readings / commands / configurations with similar meanings / names.

- Value type: Tells the cloud, what type of value is being sent from this reading / command / configuration.

After that will configure the model details and enter the following information for device model:

- Device model name: The name of the model.
- Description: A description for the model.
- Website: URL of the website for the model.
- Manufacturer details: Information about the manufacturer of this model.

At this point the device settings are completed and ready to connect to cloud server.

Figure 8. Device configurations interface.

B. Create Monitoring Rule

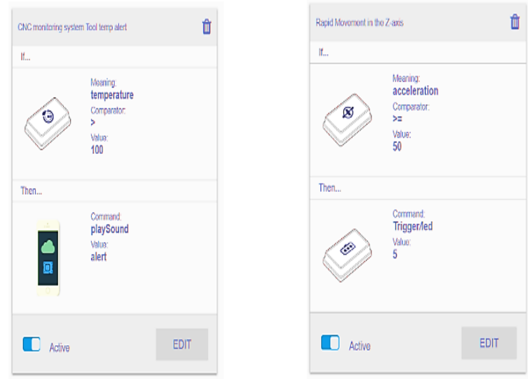
Creating rule for devices to facilitate interaction between devices by sending a command or a configuration to the device when reading from another device matches a certain condition. In this work two rules have been used.

1) *Machine tool temperature rule:* One of the important monitoring parameter in CNC machine is machine tool temperature. A machine tool temperature alert has been created to accomplish this role must make some coding in JSON Schema. JSON Schema describes existing data format, clear for human and machine readable documentation. After device created will now setup the control step "Role" this role gives an alert when the temperature gets higher than 100°, the alert can be sound or signal send to device to do an action as shown in figure (9.a).

2) *Rapid movement in the Z-axis rule:* This rule created for monitoring the movement of an axis or its location. In present work this role named rapid movement in the Z-axis depended on acceleration sensor as shown in figure (9.b).

C. Visualizing Device Data

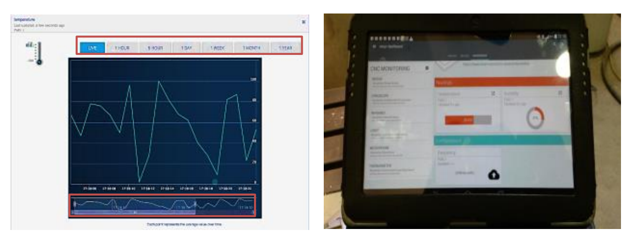
All data of the CNC monitoring system can be visualized from control panel. The data visualization interface displays data in a format based on the type of value being read by the sensor. Some charts can display live data being read from the sensor, and some charts can only display data that have already been read at the time when it was generated. All readings, regardless of type, can be visualized over a specific time interval, which can be chosen at the top of the chart area as shown in figure (10.a).



(a) Machine tool temperature rule. (b) Rapid movement in the Z-axis rule.

Figure 9. Create Monitoring Rule.

D. DNC Network



(a) Temperature chart for specific time. (b) Thermometer reading displayed in Android Tablet.

Figure 10. Visualizing Device Data.

Creating a DNC communication system by using designed method and a DNC software. This method can connect different machine types to a Central Computer. To implement this method, need to connect every machine with a wireless system and setup it to connect with computer like laptop via Wi-Fi connection by using HLK-RM04 module and setup it on CNC machine with wireless serial device then setup CNC machine IP setting for DNC network. Install CIMCO DNC software on laptop to create and setup DNC-Max Server V7 that made the laptop as local server and addressed it with a local host Internet Protocol (IP). Using DNC-Max Client V7 to create a connection with machines as shown in figure (11).

Figure 11. CIMCO DNC Network.

5. Implementations and Discussions

Result and discussion have divided to:

A. *Comparison between Methods of G-code Generation*

The G-code files are obtained from both operations (rough and finishing) using the post processing of the program after specifying the number of the axis of the required machine. The tool path statistical for both methods be shown in table (I), MATLAB method use linear interpolation (G01), so arc distance in MATLAB method is zero but in UG-NX method can see in roughing phase the arc distance appeared because UG-NX use a circular interpolation (G02 and G03) for this phase. Cutting time in MATLAB method is less than UG-NX10 because the cutter path is connecting adjacent cutter location points by straight line segment due to linear segmentation of the curved path in forward direction. G-code steps in MATLAB method for roughing phase are greater than in UG-NX method for same phase because the linear interpolation takes more steps to simulate arc shape. Cutting time and Number of steps of G-code in MATLAB method for finishing phase are equal to UG-NX method for same phase because there is no arc distance and both used linear interpolation.

B. *Analysis of Transferring NC Program*

The DNC software with help of wireless system gives an information about machine working time (online, offline), part machining time, the advantages of transfer G-code data via WLAN to CNC machine because it can connect directly via Wi-Fi, there is no need to direct handle it, provides long distance control to machine, as long as it connects to Wi-Fi, reduce machine downtime for program transfer. Call programs from machines, without going to PC can perform tasks such as running the file, copy, delete, create folder. Send a message via the network: can send a message to DNC device from software, the staff can receive and follow. It locks USB port or other ports and not allow retrieving data out, so when the operator control software used to run the file that transfer to the CNC machine, staff will not know which is unable to copy files, so information will be secured. No wires, easy to connect, scalable network. With the built-in report functions, can easily display and visualize data, in order to explore productivity information to evaluate the work. Table (I) show time spent for transfer file for MATLAB and UG-NX.

TABLE I. Tool path statistical

	MATLAB		UG-NX	
	Roughing	*Finishing*	*Roughing*	*Finishing*
Linear distance (mm)	3588.9114	424.2542	2548.7558	424.4508
Arc distance (mm)	0.0	0.0	1065.1044	0.0
Machining time (min)	51.26	17.36	51.49	17.36
Cutting time (min)	48.47	4.55	49.10	4.55
Tool path length (mm)	3588.9114	424.2542	3613.8608	424.4508
Cutting length (mm)	1726.8632	173.8822	1740.2664	173.8821
Rapid length (mm)	1862.0482	250.3720	1873.5943	250.5687
No. of steps	22492	3154	12736	3154
Size of file (KB)	473	89	327	90

TABLE II. Transfer time

Type of Connection	Speed Rate (Mb/s)	Transfer time (ms) MATLAB File size 562 KB	Transfer time (ms) UG-NX File size 417 KB
RS-232	0.1098	39027	29
Ethernet	100	43	32
Wi-Fi 802.11b	54	79	59
Wi-Fi 802.11n	150	28	21

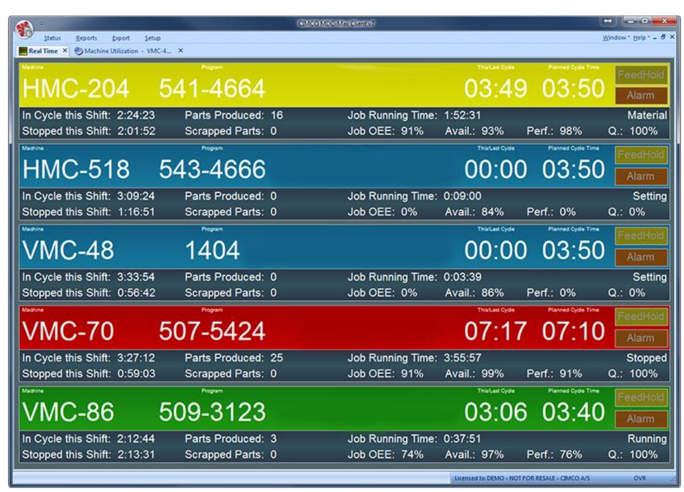


Figure 12. Machining process information.

Figure (12) show real-time report displays information about machine name, parts progress, time, operation condition and Machine Cycle Time.

C. Machining Workpiece

Workpiece machined according to MATLAB NC program with long line tool path extended from starting to the end of workpiece based on the propose algorithm using linear interpolation as shown in figure (13.a). Workpiece machined using UG-NX10 NC program with zig zag cut pattern of workpiece as shown in figure (13.b).

(a): Workpiece using UG-NX10 software.

(b): Workpiece using MATLAB software.

Figure 13. Machining workpiece.

6. CONCLUSION

Based on the results from experimental and implementation works, the following clarifications can be concluded:

- IoT for monitoring CNC machines provided:
    a. Automated production data recording and this lead to eliminating paper work, assisted in decision making & overview, enhanced work efficiency.
    b. Predictive maintenance for machine tool by using recorded data and rule feature.
    c. Collected data used to enhancement occupational safety and health.
- The transferring data of proposed surface from MATLAB software to UG-NX10 have been achieved without distortion.
- Create DNC network by adding a wireless module. Lead to Eliminated the use of cabling to each CNC machine, centralization, scalable network, reduced machine downtime for program transfer, machine data collection and analysis.
- Wi-Fi 802.11n had the best transfer time according to speed rate (150 Mbps).

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