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Application of Computer Numerical Control Machine Based on Internet of Things System

A Thesis
Submitted to the Department of ElectroMechanical Engineering University of Technology in Partial Fulfillment of the Requirements for the Degree of Master of Science in ElectroMechanical Systems Engineering

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صَدْقَ اللَّهُ الْعَظِيمِ

سورة طه الآية [١١٤]

Dedication

Special dedication to my father and mother for their prayers.

To those who seem far but we see them near....
To my sister and brothers
To my dear friends.

To those who supported this work with their patience smile and loyalty.

With my great love

Saif Aldeen Saad Obayes

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Praise be to **ALLAH**, his majesty for his uncountable blessings, and best prayers and peace be unto his best messenger **Mohammed**, his pure descendant, and his family and his noble companions.

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# ABSTRACT

A wireless controller for Computer Numerical Control machine based on Internet of Things have been designed and implemented in the present work. A case study has experimented and tested to express the completed stages of CAD/CAM system, starting from a proposed free form surface is introduced using Bezier technique with sixth order in two parametric variables. MATLAB and UG-NX10 software are used to generate the tool path and G-codes for the proposed surface. MATLAB uses linear interpolation (G01) code, whereas UG-NX10 uses circular interpolation (G02 and G03) code. The Direct Numerical Control software with the help of Embedded Wi-Fi modules and Internet of Things system are used to transfer the G-code data via WLAN to the CNC machine. The interface tools are RS-232 and RJ45 that has been used with the machines at University of Technology/ Workshop and Training center.

The results shows that the MATLAB file has faster transfer time than UG-NX10 file. A number of monitoring rules have been provided for CNC machine, each type of rules implemented to build an Internet of Things system for CNC machine monitoring. In order to collect and analyze data from different devices or location. The tool path with using MATLAB have longer linear distance, smaller arc distance, greater steps number and lower machining time as compared with that of using UG-NX10. The dimensional measurement of the machining models is done by using Digital 3D-Touch Probe. It is found that the machining models which is produced using G-codes of UG-NX and MATLAB are closest to AutoCAD model.

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LIST OF SYMBOLS

Symbol	Meaning	Units
r	cutter nose radius	mm
n	normal vector	mm
P	side-step length in physical domain	mm
h	scallop height	mm
R	radius of curvature	mm
DC	Direct Current	Amp.
AC	Alternating Current	Amp.

LIST OF ABBRIVIATIONS

Symbol	Meaning
3D	Three Dimension
ADC	Analog to Digital Convertor
AP	Access Point
API	Application Programming Interface
BLE	Bluetooth Low Energy
C^0	Zero order Parametric Continuity
C^1	First order Parametric Continuity
C^2	Second order Parametric Continuity
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CAN	Controller Area Network
CBDM	Cloud Based Design and Manufacturing
CC	Cutter Contact
CL	Cutter Location
CMM	Coordinate Measuring Machine
CNC	Computerized Numerical Control
CPU	Central Processing Unit
CSMA/CD	Carrier Sense Multiple Access with Collision Detection
DHCP	Dynamic Host Configuration Protocol
DNC	Direct/Distributive Numerical Control
ECMA	European Computer Manufacturers Association
EPROM	Erasable Programmable ROM
FTP	File Transfer Protocol
G-code	G programming language

GPIO	General-purpose input/output
GPS	Global Positioning System
HSS	High-Speed Steel
HTTP	Hypertext Transfer Protocol
IC	Integrated Circuit
IDE	Integrated Development Environment
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
IP	Internet Protocol
ISO	International Organization for standardization
IT	Information Technology
JSON	JavaScript Object Notation
LAN	Local Area Network
LED	Light Emitted Diode
MAC	Media Access Control
MATLAB	MATrix LABoratory
MCU	Machine Control Unit
MOSFET	Metal oxide semiconductor field effect transistor
MQTT	MQ Telemetry Transport
NC	Numerical Control
NEMA	National Electrical Manufacturers Association
NIC	Network Interface Controller
OTG	USB On-The-Go
PC	Personal Computer
PCB	Printed Circuit Board
P_{cc}	cutter contact point
P_{cl}	cutter location point
PSK	Pre-Shared Key
PWM	Pulse-width modulation
RAM	Random Access Memory
RGB	Red Green Blue
ROM	Read Only Memory
SDIO	Secure Digital Input Output
SoC	System on Chip
STL	STereoLithography
TCP	Transmission Control Protocol

TTL	Transistor–transistor logic
UARTs	Universal Asynchronous Receiver/Transmitter
UDP	User Datagram Protocol
UG-NX	Unigraphics Siemens PLM Software
WAN	Wide Area Network
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
WPA	Wi-Fi Protected Access
WSN	Wireless Sensor Networks

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CHAPTER ONE

INTRODUCTION & LITERATURE

CHAPTER ONE

INTRODUCTION AND LITERATURE SURVEY

1.1 Overview

The Computer Aided Design and Computer Aided Manufacturing (CAD/CAM), will be present the idea of product, generating the model and converting it into the Computer Numerically Controlled (CNC) for manufacture, preparing the numeric code programs and sending it to CNC-machine, which change the model into a product part. These machines include milling, routers, plasma, lathes or turning, lasers or burning machines, water-jet machines and 3D printers. All of these types are computerized machinery which able to cut and form materials dependent to CAD model. Essentially, having a machine with a computer built in, in which gets NC program and then the drives each motor axis. This is termed “Controller”. CAD/CAM software generates code or “G-code”, fed through RS-232 Communications cable to the machine controller. The operator is able to store the G-code program on a memory stick and bring it to the machine controller. By way of controllers keep on progressing, there are more decisions accessible for sending the projects to the CNC machines. Direct/Distributive Numerical Control (DNC) can be installed. Large wireless DNC networks created to relay NC programs from computer based CAM systems or DNC software products to their machines, which support the efficiency of a machine workshop. The basic CNC manufacturing stages are [1]:

1. Invention and design through the utilization of computer aided design programming.
2. Tool path simulation, and creating the NC Program using CAM software.
3. Sent G-code to the CNC machine.

4. Actual machining of the part that was originally designed. This requires various materials, tooling, work-holding and more that is performed by the machine and a "CNC Programmer" or Machinist by profession.

The term Computer Numerical Control (CNC) is a widely accepted and commonly used term in the machine industry. CNC enables an operator to communicate with machine through a series of numbers and symbols [1]. The main purpose of CNC machine is to machine parts with complex shape in a precise manner and increase productivity. The machine tool being the body of a CNC machine framework while the control unit is its mind, its operational center. All machines speeds, feeds, axes movements and many different activities are customized by a CNC programmer and controlled by a PC that is real part of the CNC machine. Some of conventional CNC machines as shown in figure (1.1) and non-conventional CNC machine as shown figure (1.2) [2]. CNC systems tend to utilize multiple CPUs relying upon the quantity of calculation tasks. Each CNC machine has a console as a screen for the administrator, and additionally portable storage units and fast communication ports for stacking NC projects and connecting to workstation networks [3].

The new age of CNC machines is how to integrate the communication system and the advancement in the information technology (IT) with it. The Internet has changed business and personal lives in the past years and continues to do so. The IoT becomes a foundation for connecting things, sensors, actuators, and other smart technologies. IoT is a term that has been introduced in recent years to describe objects that are able to communicate via the Internet [4].

Efforts have been made on the development, standardization, security, and application aspects of IoT. In the development of IoT, the integration of devices equipped with intelligent sensors with cloud-based Internet is a challenge, as it involves basic technology interfaces, and new standards [5].

(a) Milling Machine

(b) Turing Machine

(c) Machining Center

Figure (1.1): Conventional CNC machine.

(a) Electro Discharge Machine

(b) Electron Beam Machine

(c) Electro-Chemical Machining

Figure (1.2): Non-Conventional CNC machine.

Cloud Computing strategies virtualized computing, storage, and networking resources, over the Internet, to associations and individual consumers in a completely dynamic way. These cloud assets are less expensive, less demanding to oversee, and more adaptable than sets of local, physical, ones. This motivates clients to allot their applications and services to the cloud [6]. With the performance improvement 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 varying rapidly, producing important difference in WLAN architectures and implementation models. Cloud and Wi-Fi architectures either distribute controller functions (controller less) or they move the controller into the cloud. In some environments, this can be advantageous because it removes controller hardware at each location [7].

1.2 Data Communication System in Numerical Control

According to advancement in control, communication, computer and network technology, information technology in communication is quickly cover all levels of factory field equipment layer in management and control. At this point in time, Wi-Fi established on TCP/IP protocol is able to encounter the requirements of the industrial monitoring system and Data transfer. Industrial monitoring network established on Wi-Fi has unrivaled benefits. Wi-Fi has a higher bandwidth communication, that cover the needs of data communication growing. Monitoring and management are easily remote the field device using Wi-Fi, through TCP/IP protocol. Wi-Fi device is cheap, simple implementation and reduce the cost of monitoring and control system [8].

1.3 Concept of Internet of Things

The Internet of Things (IoT) is about interconnecting embedded systems. It brings together two evolving technologies: wireless connectivity and smart sensors. Combined with recent advances in low power microcontrollers, these new "things" are being connected to the internet easily and inexpensively, ushering in a second industrial revolution. These connected embedded systems are small microcontroller based computers that do not require a human interface. Instead of interacting with a human these systems use sensors or other advanced detection mechanisms. These sensors collect data, data that has value and that is part of a larger system. This data is then networked as part of a larger system. While the term "Internet of Things" implies that these sensors are networked via the world wide internet using Wi-Fi or Ethernet, the networking can also be performed using protocol such as ZigBee or Bluetooth that does not have an IP address. The networking protocol is selected based on the distribution of nodes and the amount of data to be collected. This data is sent over the network to the main hub or computer. This main computer collects and analyzes the data, storing it in memory and even making system decisions based on the results of the analysis [9].

A Wireless Sensor Network (WSN) consists in a large number of nodes where data are collected by distributed and smart sensors associated with the devices. The sensing data is gathered to a sink node that sends the data onto other computational devices, often more powerful, able to further processing the sensor produced data. As individual sensor nodes do not always have an Internet Protocol (IP) address, they cannot be directly accessible via Web [10].

In this case, an intermediate element is used: The Smart Gateways. A Smart Gateway performances as a proxy between the objects and the Web, by interconnecting with the objects (in this case, the sensor nodes) and making them accessible via Web. Besides providing WSN nodes with accessibility through the Web, Smart Gateways also performs other functions such as to translate from Internet protocols to WSN communication protocols (and vice versa), and to provide added value information on top of the produced raw sensor data. Figure (1.3) illustrates the main elements of a Wireless Sensor Network [11].

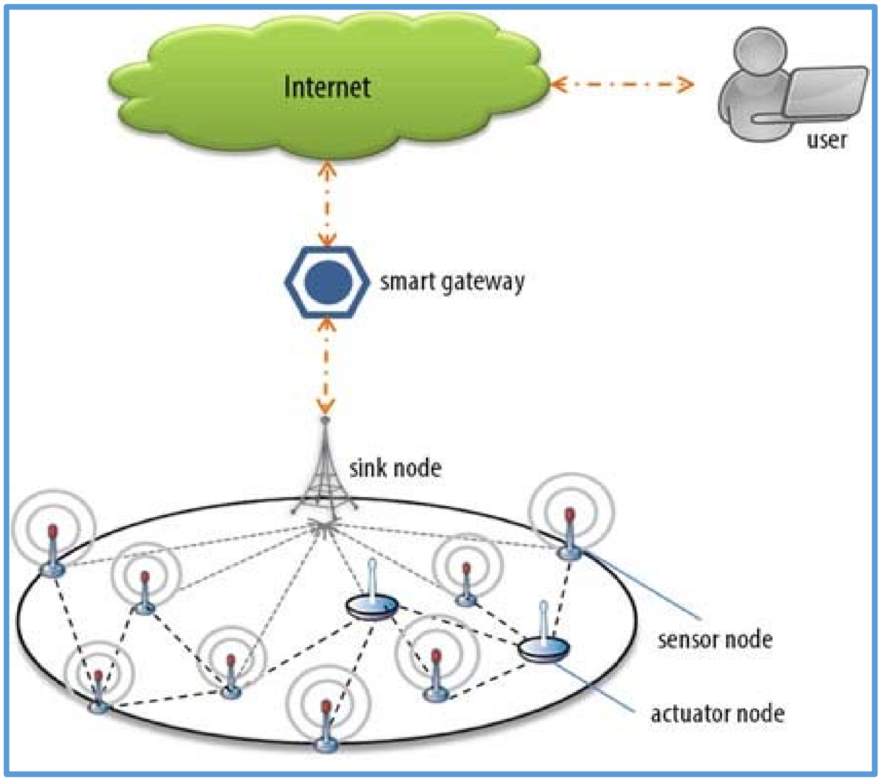

Figure 1.3: Elements of a WSN connected to the IoT [11].

1.4 Aim of Research

The main objective of this study is to design and implementation of wireless controller system for CNC machine.

1. Design a proposed surface based on Bezier technique with sixth order. Generating the tool path and get the G-code by using MATLAB and UG-NX10 software.
2. Design and manufacturing Concurrent Integration of wireless controlling system and CNC machines to get the advantage of sending and receiving data between the machines and main the computer or the server using Wi-Fi and WLAN are all references to the IEEE 802.11 for b and n.
3. Applying Internet of Things (IoT) concept to monitor CNC machine by using sensors at real time to read temperature, humidity, noise level, accelerometers, rotation and object detection.

1.5 Literature Survey

In this section, some researches will be reviewed and these research focus on wireless communication, monitoring system and generation of tool path for machining surfaces.

Young-Keun Choi et al. (2007) [12], presented a tool path generation method by using Bezier curves and surfaces for multi-axis machining. The tool path generation was consisting of forward-step and side step function. The determination of the maximum distance, between two points of cutter contact with a given tolerance in forward-step function. While, in side step function is the maximum distance between two adjacent tool paths with a given scallop height has been determined. To generate CC points for freeform surfaces and CL data files for post processing using Bezier curves and surfaces. Several parts are machined using a multi-axis milling machine. As part of the validation process, the tool paths generated from Bezier curves and surfaces are analyzed to compare the machined part and the desired part.

TAO Lin et. al. (2009) [13], presented real time communication based solution of an Ethernet for each level of DNC. Real time control protocol was design into the protocol stack of MAC and TCP/IP, for keeping Ethernet compatibility. As indicated by the primary components of DNC communication, a real time control police based on time slot mechanism with CSMA/CD are proposed. The plausibility of the arrangement has been tried by simulations and trials. For advanced manufacturing system, it gave a reference real time communication innovations.

Rui Lou (2009) [14], proposed a structures of DNC integrated manufacturing system in view of Ethernet and the CAN field bus. The data combination stage, which is controlled and overseen by the CNC machining gear was assembled, and the specialized support for the acknowledgment of objective allotments of assets, quick reaction to market and diminishing assembling expense of the items was given.

Li Boquan et al. (2010) [15], demonstrated the application of WLAN (Wireless Local Area Network) in organized DNC system. The networked DNC System has been built based on WLAN, and it mainly consists in computer, NC machine with RS232 interface, Network Interface Card as well as Wireless NIC. NC machine with RS232 interface is controlled by computer based on WLAN communication technology, and the Network Interface Card as well as Wireless NIC play an important role in communication between computer and NC machine, the key technology, including WLAN, networked DNC integration, communications protocol conversion and network wiring have been analyzed, and the test system for wireless channel performance, data transfer rate and response time has been set up. The results show that the WLAN network technology in DNC integration can meet the needs of manufacture automation in workshop, and based on this technology, the level of automation in CNC equipment has been greatly improved.

Guorong Xiao, Xuemiao Xu (2012) [16], studied Bezier curve generation algorithm. The parameter step length choice fundamentally influences the exactness and proficiency of the curve. The Bezier curve generation algorithm proposed the variable step length algorithm. By changing the parameter step length of the curve, it can significantly reduce the calculations of a large number of duplicate points in the point by point generation algorithm; the algorithm not only maintains a higher accuracy, but also significantly improves the efficiency generated in the curve, with better application.

Chalakorn Chitsaart et al. (2013) [17], proposed automatic generating codes for CNC milling operation. It assists the manufacturer during the operation to easily change the size and the geometric shape of the product where the time spent are reduced. By analyzing and evaluating the geometric information of the part, the algorithm implemented on MATLAB software was developed. To control the operations of the machine, codes are created rapidly. The developed algorithm can shortly generate and simulate the cutting profile of the part as compared to that obtained from CAM.

Zhongqi Sheng et al. (2013) [18], developed a wireless data acquisition and storage system of CNC machine tools based on LabVIEW graphical programming language and IEEE 802.11 wireless communication protocol, effectively expanded the ability to access and use the CNC machine status information; solved the problem of data collection caused by the environment complexity of manufacture workshop and the hardness of wiring; eliminated the dead zone of manufacture workshop for the processing of the data acquisition of state information about bottom processing equipment; made the bottom machining unit no longer was the information island for manufacturing enterprises.

Saif Aldeen Saad Obayes, et. al. (2017) [19], introduced practical control unit based on Raspberry Pi and Arduino for controlling CNC engraving machine. The developed controller enables the machine tool to be controlled based on wireless communication and NC data generated from CAD/CAM systems. Then, a computer vision component using a web camera is proposed for the NC machine tool monitoring. It is explained the position on the machining table. This newly designed wireless controller system can be widely used in electrical and medical industry for making small parts and engraving small features. Fabricated prototype wireless controller system was calibrated and tested under various self-testing procedures to meet industrial standard. Comprehensive cost analysis and profit estimation was conducted after completion of the prototype.

1.6 Concluding Remarks

From researches in literature review, it can be observed that the Ethernet communication integrated with DNC system or WLAN integrated with DNC system as a part of providing a reference for real time communication technologies of advanced manufacturing system. The CAD/ CAM consideration of Bezier surfaces and how can make investigation to generate the optimal tool path using different algorithms. In the present work, modeling a proposed surface using a mathematical model of Bezier technique with sixth order for two parametric variables, tool path and generated G-code is done by using MATLAB and UG-NX software, also, design or developed control unit for CNC machine with advantages of wireless communication and IoT system to monitoring and management a CNC machines in workshop.

1.7 Organization of Thesis

The study is organized in five chapters:

- Chapter one: covers a brief introduction to CAD/CAM and CNC machining, principle of IoT, literature survey, importance and aim of research.
- Chapter two: presents the theory and the calculation of Bezier surface points, MATLAB, UG-NX, Embedded system in wireless network, How IoT work.
- Chapter three: includes experimental arrangement and procedure.
- Chapter four: presents implementation work and discussions.
- Chapter five: consists of conclusions and suggestions for the future work.

CHAPTER TWO

THEORETICAL CONSIDERATIONS

CHAPTER TWO

THEORETICAL CONSIDERATIONS

2.1 Introduction

This chapter reveals a number of methods to represent curves and surfaces mathematically. In addition, an implemented tool path generation method has been investigated using MATLAB software based on the computing of cutter contact, cutter location, normal vector and curvature radius. The technique of embedded system will be validated to reach the solution of wireless communication. Lastly, the technique of IoT will be used to monitor the CNC machine to gather data, such as temperature, humidity, noise level, accelerometers, rotation and object detection.

2.2 Parametric Representation

In terms of a parameter; the parametric equations could have described the dependent and independent variables. Eliminating the dependent and independent variables from equation, will convert the equation into a non-parametric form. Parametric equations give more option and easily manipulated in constructing space curves.

The free form surfaces parametric equations are formulated with two variable parameters (u) and (w). The parametric vector function is used to represent the surface coordinate positions [20]:

$$P\ (u, w)\ =\ \{x\ (u, w), y\ (u, w), z\ (u, w)\}, u, w\ \in [1, 0] \quad .....(2\text{-}1)$$

Where: x (u, w), y (u, w) and z (u, w) are coordinate of point on the surface.

2.3 Types of Parametric Representations

Some parametric representation method of curve and surface are [21]:

1. Hermit method.
2. Bezier method.
3. B-spline method.

Here, the Bezier techniques to represent the proposed curve and surface were used.

2.3.1 Bezier Surface

Bezier patch surface is qualified to Bezier curve, in which frequently used in tryout. Initiate control points with (n + 1) × (m + 1) which expressed in rectangular grid [22].

Any point for a given value of the parametric pair is capable to locate on the Bezier surface by [23]:

$$P(u,w) = \sum_{i=0}^{n}\sum_{j=0}^{m} P_{ij} B_{i,n}(u)\, B_{j,m}(w) \quad \text{.......................................(2-2)}$$

i=0,………,n

n = the degree of Bezier surface.

i, j = the index.

u, w = the parametric of Bezier surface.

P_{ij} consist from control points (n+1) × (m+1) in a rectangular array defining the Bezier patch characteristic polyhedron vertices, that lies entire the convex-hull.

$B_{i,n}$(u) functions *and* $B_{j,m}$(w) functions which is a Bernstein base.

General Bezier patch matrix equation is [23]:

$$\mathrm{P(u,w)=U_{1,n}\,M_{B,n,n}\;\; P_{n,m}\;\; M^{T}_{B,m,m}\; W^{T}{}_{m,1}} \quad \text{................................(2-3)}$$

2.3.2 Properties of Bezier Surface

The most Bezier Surface properties are [24]:

1. In each direction, the surface degree is one less than the control point, while the continuity is two less than the control point.
2. The shape of the control net generally be as guide for the surface.
3. The resulting Bezier surface coincident with only control net corner points.

4. The convex-hull of the control mesh contains the surface as shown in figure (2.1).
5. The surface does not exhibit the variation-diminishing property. The variation diminishing property for bi-variant surfaces is both undefined and unknown.
6. Under an affine transformation the surface is invariant.

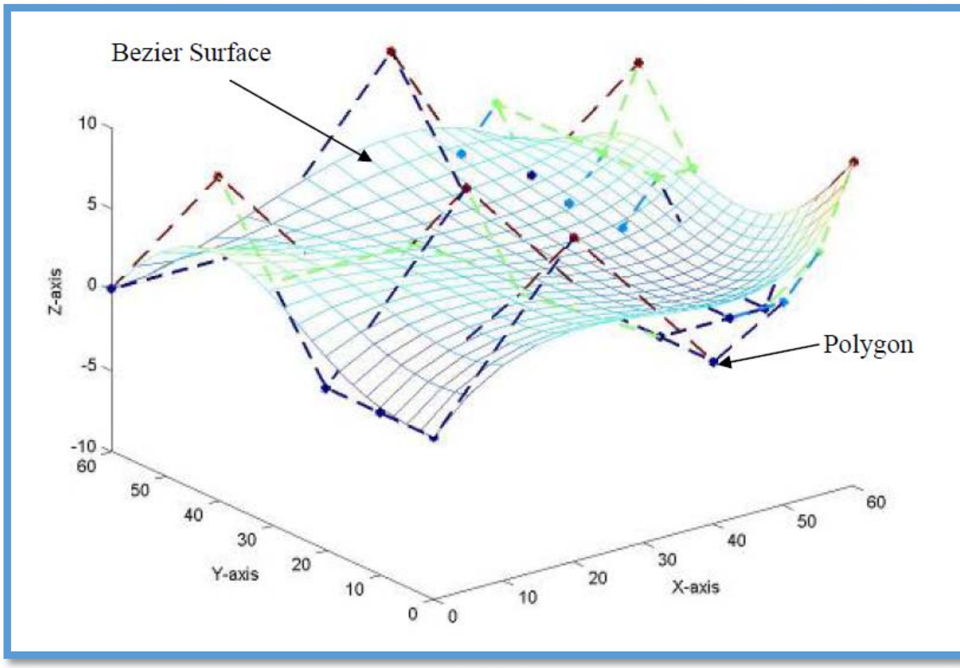

Figure 2.1: Bezier surface [24].

2.3.3 Curves Continuity

The analytical and interpolated curves are insufficient to meet the requirements of mechanical parts that have complex curved shapes, such as, propeller blades, aircraft fuselage, automobile body, etc. These components contain non-analytical, synthetic curves. Design of curved boundaries and surfaces to require curve representations that can be manipulated by changing data points, which will create bends and sharp turns in the shape of the curve. The curves are called synthetic curves, and the data points are called vertices or control points. If the curve passes through all the data points, it is called an interplant's (interpolated). Smoothness of the curve is the most important requirement of a synthetic curve. Various continuity requirements at the data point can be specified to impose various degrees of smoothness of the curve. A complex curve may consist of several curve segments joined together. That is, the values of x, y, and z evaluated at u, for the first curve section are equal, respectively, to the values of x, y, and z evaluated at u, for the next curve section [25].

In the case that the endpoint of one curve segment is coincident with the endpoint of another curve segment, the curves are said to exhibit ‘zero-order’ continuity (denoted C^0). While the first order continuity (denoted C^1) show a continuous slope. The tangent lines at their joining point is the same, which means the first derivatives of parametric equation of the two successive curve sections are equal. Whereas, 2nd order continuity (denoted C^2) affirms a continuous curvature. The situation is appearing that at the inter-section, the two curve sections for 1st and 2nd parametric derivatives are the same. Guarantee a C^2 curve. Higher order polynomials be likely to oscillate about the control points and need big memory to storage, so they are not used in CAD [25].

2.4 Tool Path Generation

The free form surfaces are relatively tough to machine because of their complex geometry. The machining primarily has two phases, the roughing and finishing. G-code is Generated to machine for any arbitrary freeform surfaces using 3-axis CNC milling machine with cutters type ball end. Due to their robustness and simplicity the ISO-planar zig tool paths is generated. A certain tolerance and surface finish specified on the surface comply with the tool paths [26].

The proposed surface, the strategy in figure (2.2) must be achieved to verify the tool path. The normal vector and curvature radius must be calculated when circular interpolation has been adopted.

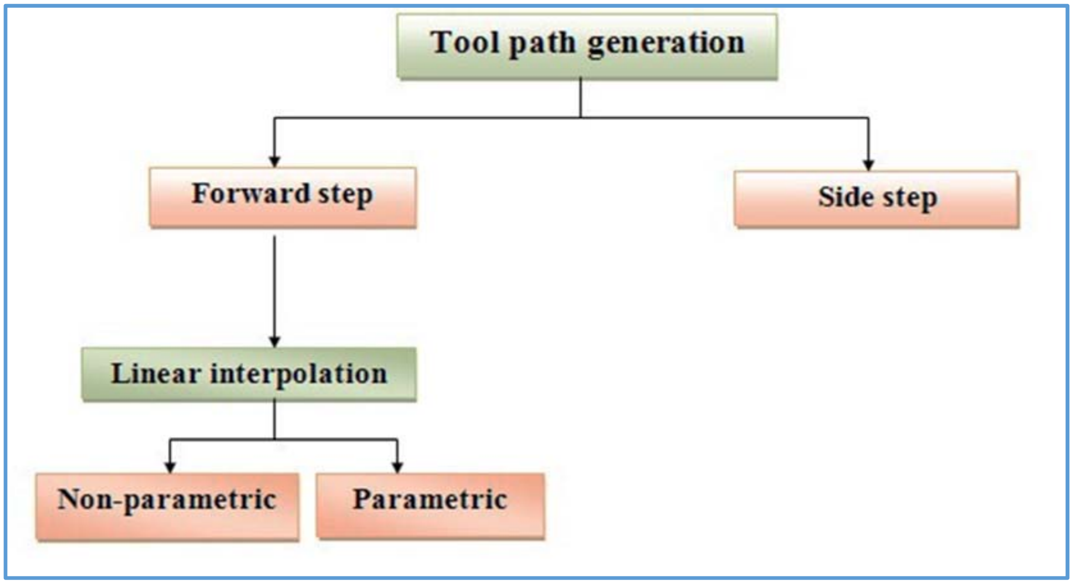

Figure 2.2: The proposed systematic tool path generation.

2.4.1 Calculation of Curvature Radius and Normal Vector

The curvature radius and the normal vector are the main calculations through the mathematical equation for each point of the surface in the present work. Normal vector can take directly from MATLAB program by using the function **surfnorm**.

$T = \dot{P}(u)$ Tangent ....(2-4)

$N = \ddot{P}(u)$ Normal ....(2-5)

$K = \frac{|TxN|}{|T|^3}$ curvature ....(2-6)

$R = \frac{1}{K}$ radius of the curvature ………..……..……………… (2-7)

The tool-path generation methods are classified either with the Cutter Contact (CC) or the Cutter Location (CL) based method depending on the type of the tool path generation [27].

2.4.2 Cutter Position and Step Over Detection

For free-form surfaces the tool paths will be represented by using parametric curves and surfaces. The point of cutter contact is related to the point of cutter location, which is used in CNC program generation as a reference point for tool movement.

1. **CC and CL Point:** The cutter contact point is the points positioned on the tool path, in which there is direct contact between the manufactured part and the tool. While the cutter location points are a fixed point on the tool which is taken as tool reference in moving along the tool path as shown in figure (2.3).

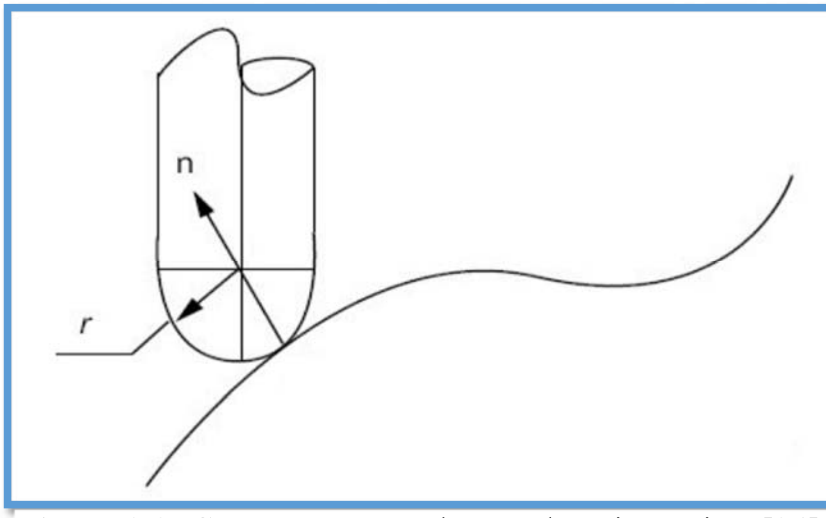

Figure 2.3: Cutter contact and cutter location points [24].

To minimize the manufacturing errors, the cutter contact point must be localized on the designed portion. Also, the CC points be able to transformed to CL points to reduce machining errors. With using ball cutter in 3-axis CNC milling machine, the CL point put along the typical direction of the surface's point. Thus, a CL point achieved from a cutter CC and the point of surface normal as shown in equation (2-8) [26].

$$\mathbf{P_{cl}} = \mathbf{P_{cc}} + \mathbf{r.n} \quad \text{(2-8)}$$

where,

r = cutter nose radius, n=normal vector for tool.

In this work, by using the **surfnorm** function from MATLAB program, the normal vector can be taken directly as in figure (2.4).

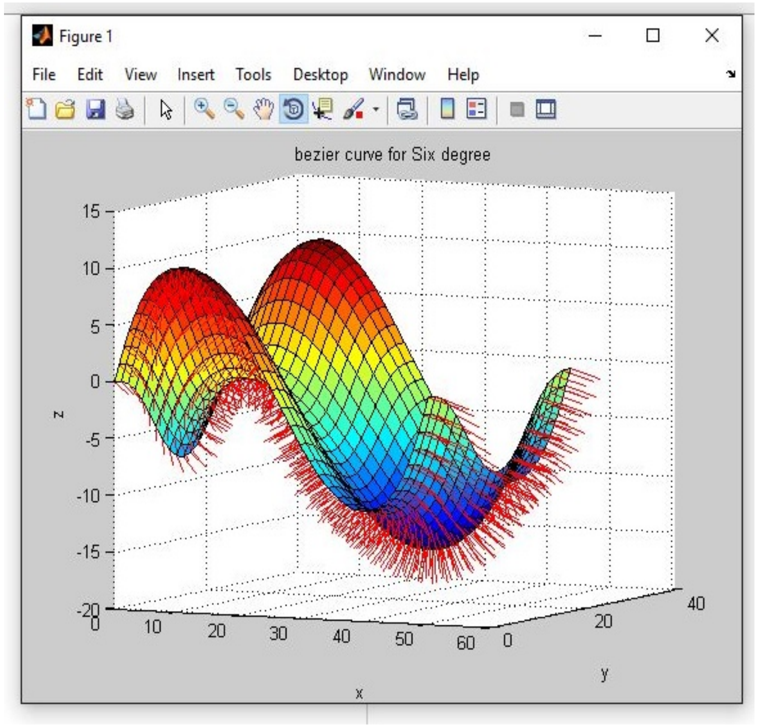

Figure 2.4: The normal vector showing.

2. **Side Step Calculation:** The distance between two adjacent tool-paths is called the side-step. The side-step varies along the machined surface and the un-machined region between the two adjacent tool paths is the scallop height. Typically, the desired value of the scallop height is given, from which the side-step is calculated. The side-step is a function of the scallop height, tool-radius and the local radius of the curvature. A new method is developed to calculate side step value with the given constraint of scallop height. The designed part's surface can be classified into convex, concave, and flat surface. The curvature of convex, concave, and flat surface are positive, negative, and zero, respectively [27].

a. **The convex surface (R<0):**

For a general convex surface, the maximum allowable path interval calculation is more complex than that of a flat surface. The path CC interval can be determined by the cutter size, surface curvature, and the height of the remaining permissible scallop on the surface as shown in figure (2.5).

$$P = \sqrt{\frac{8\times h\times r\times R}{R+r}} \quad \ldots\ldots (2\text{-}9)$$

where,

P= side-step length in physical domain, r = cutter nose radius, h = scallop height, R = radius of curvature.

b. The concave surface (R>0):

Similar to the convex case, in machining a concave surface the CC path interval can be derived as shown in figure (2.6).

$$\text{P} = \sqrt{\frac{8\times h\times r\times R}{R-r}} \quad \ldots\ldots (2\text{-}10)$$

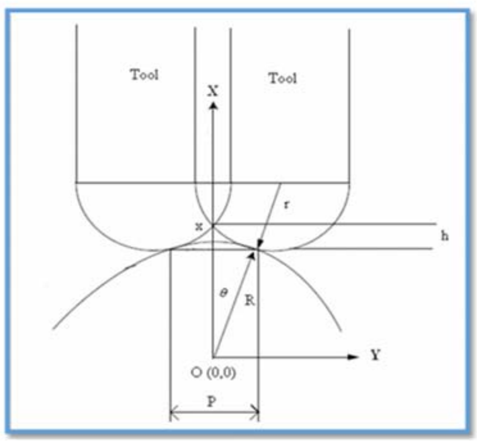

Figure 2.5: Tool position on convex surface [24].

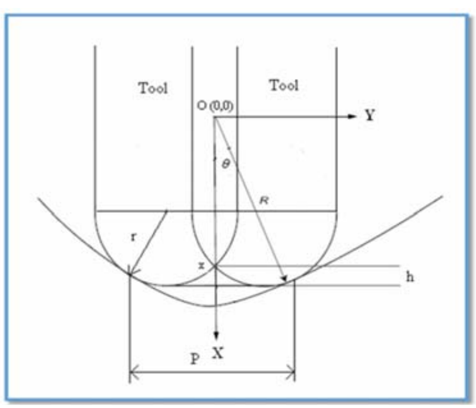

Figure 2.6: Tool position on concave surface [24].

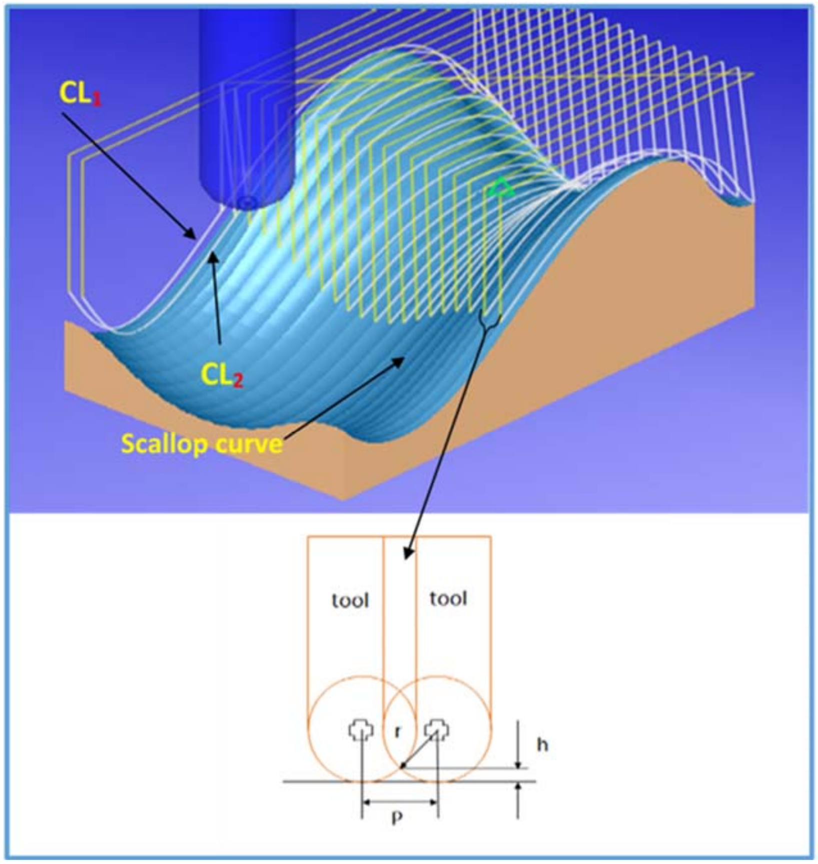

Figure 2.7: The workpiece machined showing the side steps.

2.5 Data Transport network

Data communications procedures are valuable for interfacing purposes since they can give a measured equipment structure which one can use to transmit data over generally long distances. Information interchanges procedures are principally used to exchange data starting with one PC then onto the next, yet in many occasions they can likewise be utilized to exchange information to and from remote sensors, actuators and transducers as presented in figure (2.8) [28].

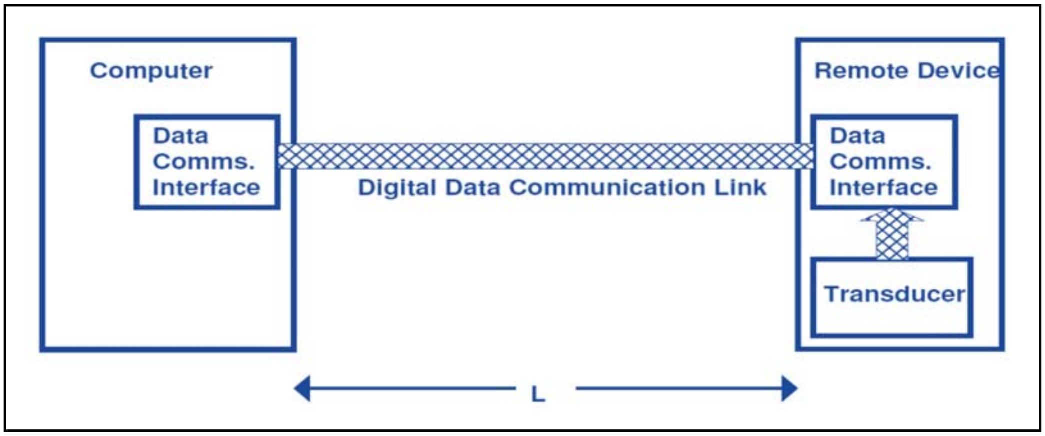

Figure 2.8: Point to Point Network.

2.6 Data Transfer Based on Wi-Fi Network

At the present time, wireless technologies have invaded all aspects of human life. However, the diversity of usage cases has created a variety of wireless standards such as Z-wave, Wi-Fi, and Bluetooth [29]. Table (2.1) illustrates a comparison between several well-known wireless technologies.

During the last decade, Wi-Fi has become one of the common standards in wireless-enabled devices such as computers, smartphones, peripheral devices, and network components. The plug-and-play capability, high speed, and medium propagation range along with supporting several network topologies (e.g. star, tree, and peer-to-peer) make Wi-Fi a unique solution for wireless local area networks [30].

Table 2.1: Typical short-range wireless standards.

Wireless Standards	Wi-Fi [31]	Bluetooth [32]	BLE [33]	ZigBee [34]	Z-Wave [35]	ANT+ [36]
Bandwidth	Up to 54Mbps	1-3Mbps	1Mbps	256Kbps	40Kbps	1Mbps
Range	>100m	<100m	<30m	<100m	<30m	<30m
Security	High	High	High	Medium	High	High
Cost	High	Medium	Very low	Low	Low	Very low

2.7 Wireless System in Industrial Environment

The manufacturing industry had completely changed by the introduction of CNC machines and DNC networking. In the meantime, the CNC machine controllers has the ability to execute stored programs in their existing memory without operator involvement, this led to reduce the number of machining steps that require human action.

Machining complex surfaces need big memory to store NC program. Some controllers of CNC machine has small memory to hold the machining program, so for that, the program is produced and saved in workstation and sent directly to the NC machine. It can distributes programs directly to different machines as requisite, in case of that workstation is linked to a number of machines, one block at a time through a DNC server [37].

Adding wireless capability on the workshop, it is possible to simplify installation, eliminate cabling, and make machine tools mobile with wireless networking. In addition, there is no need for re-running cable when CNC machines are moved, which is proper to constant workshop layout changes, as show in figure (2.9).

Unlike other conventional, expensive workshop data collection systems, the employees do not have to walk over to a fixed computer workstation and physically type in their information, leaving room for errors, and the loss of valuable production time. In case the current method of data collection is manual, wireless technology allied to automatic workshop data collection, eliminates the manual identification sheets, which are frequently damaged, lost, or misplaced.

Using encryption and spread spectrum technology it can be assured security and interference resistance to the wireless network. Thus, the deployment of wireless on the workshop gives flexibility that saves time and drives down costs while providing secure, mobile access to the networks.

This way, it is possible to increase workshop efficiency and employee productivity [38].

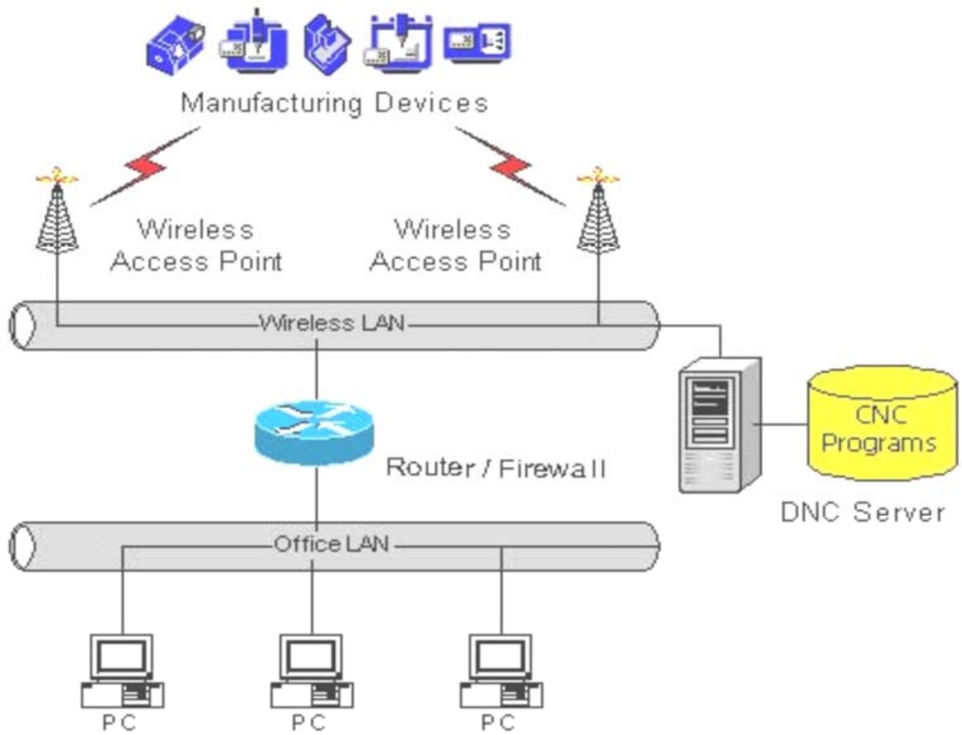

Figure 2.9: One possible configuration of a wireless network on the workshop [35].

2.8 Embedded System

The term "embedded system" is used to refer to an electronic system that is designed to perform a dedicated function and is often embedded within a larger system. An embedded system is a mix of computer equipment and programming, and sometimes mechanical components as well. Figure (2.10) gives a view of a generic embedded system architecture, where the microprocessor and the memory blocks are the heart and the brain, respectively. Embedded software is commonly stored in nonvolatile memory devices such as Read Only Memory (ROM), Erasable Programmable ROM (EPROM), and flash memory. The microprocessor also needs another type of memory, Random Access Memory (RAM) for its run time computation [39].

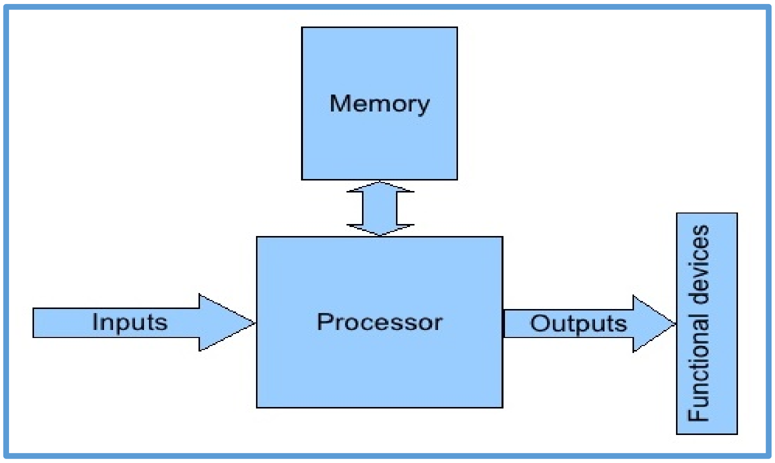

Figure 2.10: A generic embedded system architecture.

When an embedded system is powered on, its microprocessor reads software instructions stored in memory, executes the instructions to process input information from peripheral components (through sensors, signals, buttons, etc.), and produces output to meet the needs of the external embedding system. Embedded systems are widespread in consumer, industrial, medical, and military applications [39].

2.9 Internet of Thing from Concept to Application

The Internet of Things (IoT) imagines a self-designing and versatile complex framework made out of systems of sensors and smart things whose reason for existing is to interconnect "all" things, including each day and modern industrial in such an approach to make them intelligent, programmable and more fit for associating with people [40].

IoT is one of technologies that offer virtual physical systems and recognize vision of new areas data innovation application, for example, smart urban communities. Late mechanical advances empowered the development of IoT, for example, nanotechnology, versatile correspondence, remote sensor systems, and universal registering. In any case, there is still an arrangement of difficulties to be promotion wearing request to completely understand the IoT worldview, identified with the improvement of IoT applications managing heterogeneity emerging from the differences of equipment, sensors, actuators, and remote advances innate to environment [41].

2.10 Wireless Sensor Network Hardware and Software Platforms

Nowadays, there are a number of software platforms and hardware for WSN obtainable. JavaScript and Arduino, they are suitable to a WSN with a number of miniature and low power networked devices in communication [42]. The following are the descriptions of each one:

1. Arduino references to both a simple microprocessor board designed mostly for use by researchers, and the software system that is used to program the board. A large variety of peripherals at present time are existing for Arduino, for example, temperature, humidity, accelerometer, noise, light sensor, GPS receivers, and motor driver. Arduino interface connectors give guide associations with the microcontroller pins, for example, digital(I/O), analog(I/O), interrupts and UART TTL Level. Distinctive sensor interfaces can be immediately settled utilizing the scope of connectors. Arduino programming is consistently created utilizing an essential programming interface in view of the wiring scheme, and utilizing a straightforward Integrated Development Environment(IDE) [43].

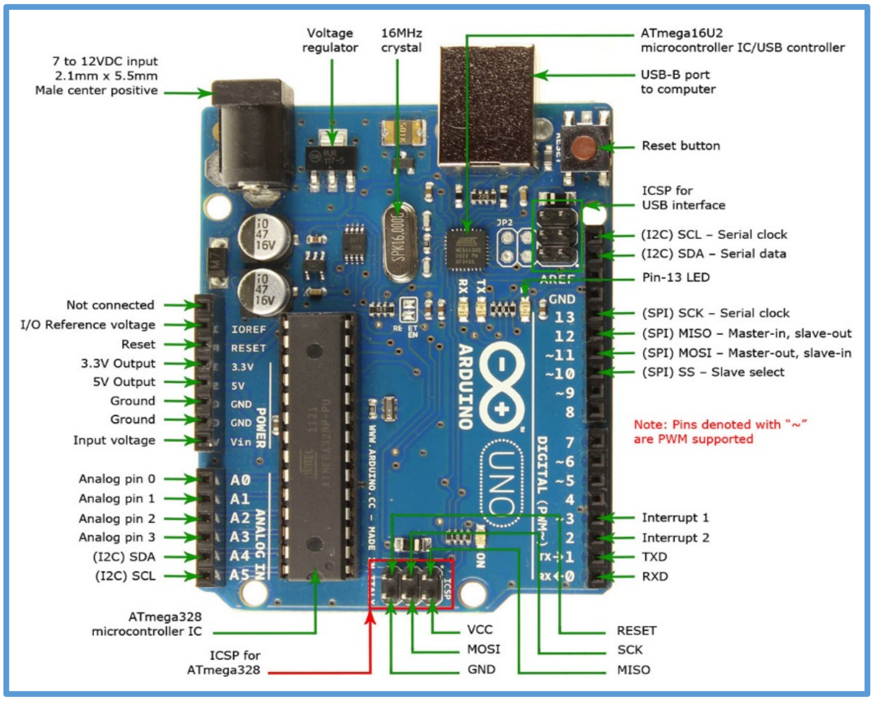

Figure 2.11: Arduino UNO Atmega 328[43].

2. JavaScript Object Notation (JSON) is a plain-content, information exchange organizes in view of a subset of the third release of the ECMA-262 standard. JSON is utilized as an instrument for serializing information structures into strings. These strings are frequently sent crosswise over systems, kept in touch with yield records, or utilized for troubleshooting. The key must be a string encased in twofold quotes. The configuration of the esteem relies on upon its information sort. Generic Example of a JSON Object [44]:

$$\{"key1": value1, "key2": value2, \ldots, "keyN": valueN\}$$

{
"meaning": " Temperature ","Patch": “Machine Tool”,
"valueSchema”: {“type": "integer”, “unit”: "Celsius",
"maximum": 2501 "minimum": -15}
}

2.10.1 Nodes of Internet of Things

IoT nodes are simple end points mono-function, ubiquitous, free-standing sensors and actuators. It's easier to talk about a node, rather than list different possible node types (sensors, actuators, meters, devices, gateways, etc.). Each node has a Node ID. Node ID is an ID uniquely identifying a node within its corresponding context [45].

There are three fundamental components that combine to form an IoT node: intelligence, sensing, and wireless communications. Wireless connectivity is vital because it will allow sensor nodes to be deployed quickly and easily without the requirement to route network cables to each location. There are a number of possible approaches for introducing low-power communications to an IoT node, ranging from purpose-designed protocols such as ZigBee to low-power variants of Bluetooth and Wi-Fi. Some of these protocols offer direct compatibility with the internet protocol (IP). Others rely on a gateway to map between IP packets and the leaner protocols used by the IoT sensor nodes [46].

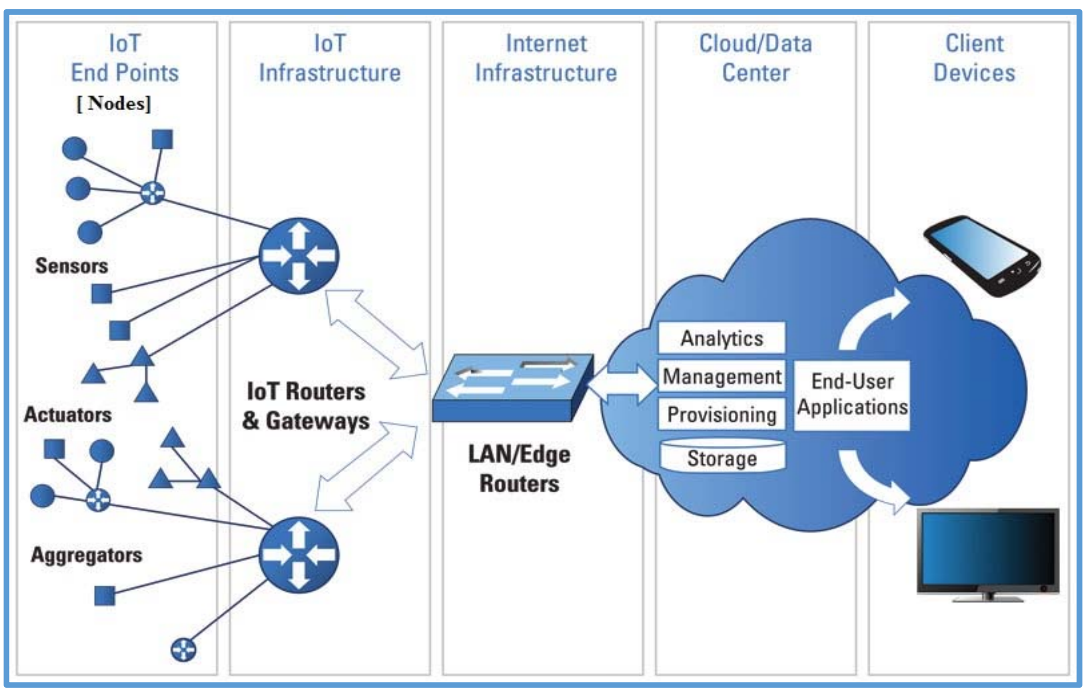

Figure 2.12: IoT Nodes[46].

2.10.2 Internet of Things Components

There are three IoT components:

1. Hardware which includes sensors, actuators and embedded communication hardware.
2. Middleware which consist of computing tools for data analytics and storage on demand.
3. Presentation which includes unique straightforward illustration and clarification devices which can be generally gotten to various stages and which can be intended for various applications.

IoT middleware is programming that assists as an interface between parts of the IoT, making communication conceivable between components that couldn't generally be capable as shown in figure (2.13) [47].

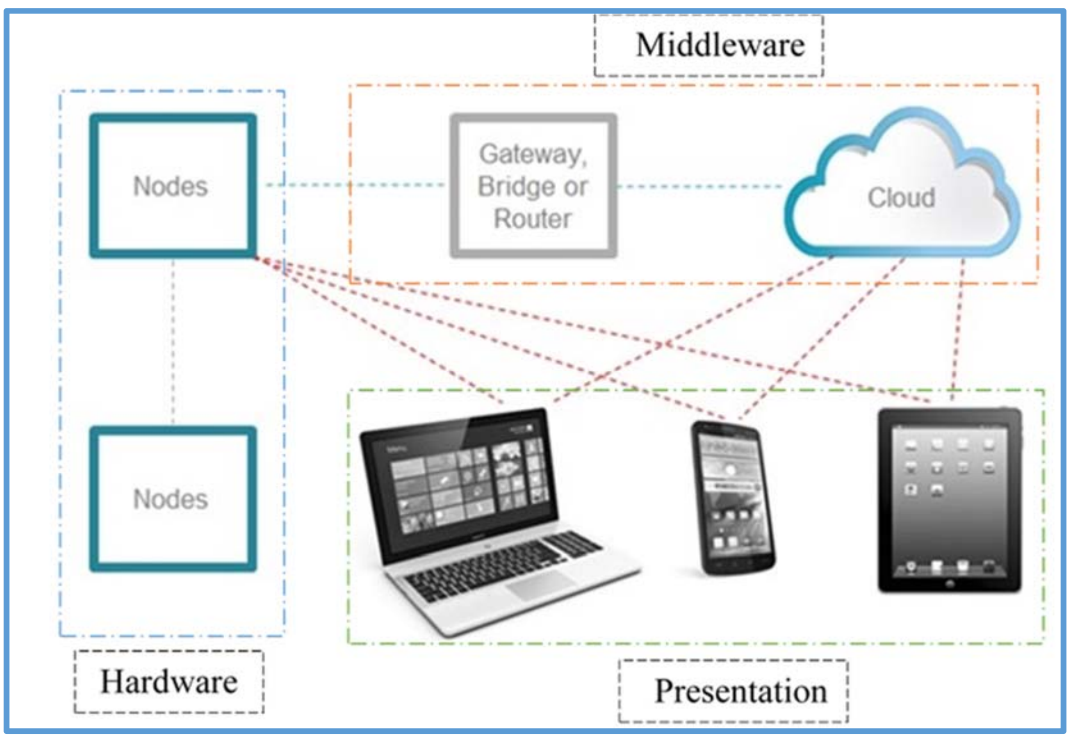

Figure 2.13: IoT components.

2.10.3 Wireless Connectivity in Internet of Things

At present, a microcontroller can pair with wireless rather than a larger and more power consuming microprocessor. The complexity of the networking stack and protocols is compressed and replaced with simplified Application Program Interfacing (API). This change is key for the IoT since most end-nodes will be powered by microcontrollers and will be wirelessly connected to the cloud in some way. More development kits, reference designs and evaluation modules are available to speed development. So whether can add Bluetooth Low Energy (BLE), Wi-Fi [48].

It is easier to connect to the cloud than ever before because there are several companies that offer IoT cloud services. However, semiconductor companies are working with these cloud service providers to port the cloud APIs to their microcontrollers and wireless connectivity devices to make it easier for customers to add cloud connectivity. In order for the IoT to be successful, it needs to be easy for consumers. Devices need to be easy to connect, configure and use otherwise they will not be successful. If the IoT is going to reach the anticipated 50 billion connected devices by 2020, easy is mandatory [49].

CHAPTER THREE

EXPERIMENTAL WORK

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3.1 Introduction

This chapter demonstrate the method of designing and manufacturing the wireless controller system. This wireless controller system gives an infra-structure for CNC machine as a unit of workshop to make a new generation of revolution depended on DNC and IoT. In a matter of CAD/CAM.

3.2 CNC Machine of Industrial Workshop

The University of Technology workshop contains a variety of CNC machines**.** Since, the purpose of this work is to make a wireless controller system which gives a new feature for the workshop to improve its efficiency and management. A hardware and software will be requiring for this improvement. A CAM system as hardware which consists of PC, CNC machine and a wireless system transferring NC program to CNC machine with IoT for monitoring. In software using MATLAB R2014a, Siemens PLM Software NX10 and CIMCO V5, which be demonstrated and discussed in the next chapter.

3.2.1 CNC- Milling Machine

CNC milling machine (C-TEK) model (KM80D) had been used in this research as shown in figure (3.1), and appendix (B) presents specification of it.

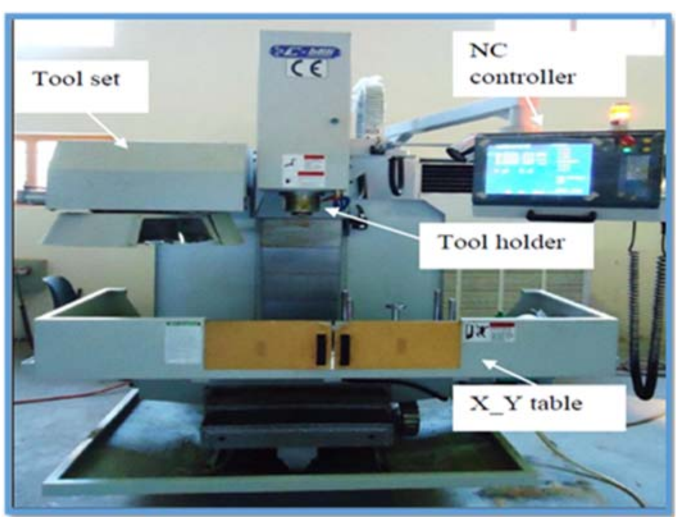


Figure 3.1: CNC C-TEK milling machine.

3.2.2 Wireless Controller System

This system consists of Central Computer and wireless devices that's connected to Machine Control Unit (MCU) of the machine to make Distributed Numerical Control.

Due to machine variety exist in the workshop. The current workshop machines had been limited with two types of connection (Ethernet RJ-45 or RS-232). In this case, to achieve the aims which to use a low cost embedded UART, Eth and Wi-Fi module (serial port, Ethernet and Wireless network) that offer Wi-Fi possibility to transfer data to different types of machines as shown in figure (3.2).

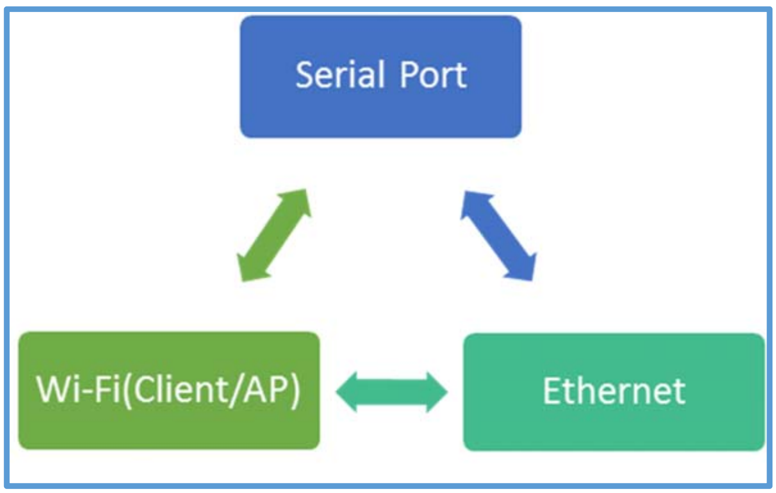


Figure 3.2: Conversion structure.

The embedded UART-Wi-Fi modules (HLK-M04) based on the universal serial interface network standard, integrated with Transmission Control Protocol (TCP) / Internet protocol (IP) protocol stack, enabling the user serial port, Ethernet, wireless network (Wi-Fi) interface between the conversions. The Technical Specifications of this module is shown in Appendix (B). It's shows that this module work with network standard:

1. Wireless: IEEE 802.11b, g, n.
2. Wired: IEEE 802.3u.

From these standards one can presume that a high data transfer rates of transferring data use and around from 11(Mbps) to 150(Mbps) with Wi-

Fi option and 100 Mbps for wired connection option. Wireless security function is important to keep data safe. This module uses WPA-PSK/WPA2-PSK, WPA/WPA2 security mechanism. The frequency range is 2.4 to 2.4835(GHz) and an antenna with 6 (dB) gain. This module makes a network management over a Remote Web management be applicable by using web browser. With keep in mind the Environmental standard is important in this working area, this module can work in harsh environments with operating temperature around (-20 to 70) ℃ and operating humidity around 10% to 90% Relative Humidity (noncondensing).

Figure (3.3) explain the parts of the embedded system that contain a microcontroller connected to HLK-RM04 IC and with the peripheral interface like internet LAN, WAN and the serial port RS-232.

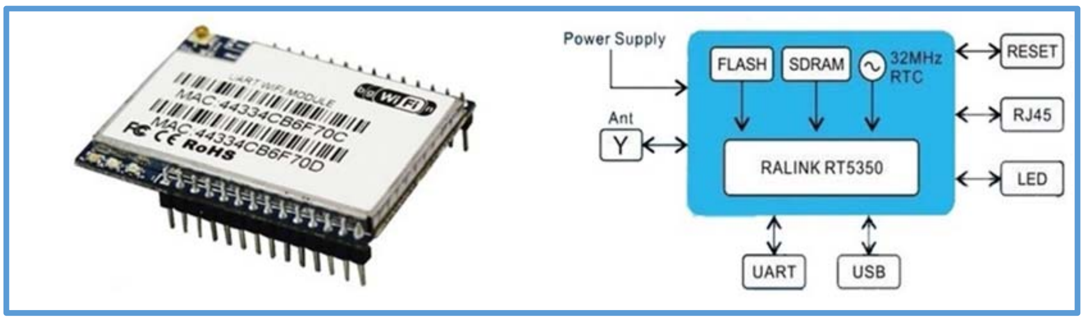


Figure 3.3: Embedded system.

The wireless connection divided into the following main modes:

1. serial to Ethernet.
2. serial to Wi-Fi Client.
3. serial to Wi-Fi Access Point (AP).
4. Default mode: This mode used in experimental work, the AP mode of module, Wi-Fi, ETH_1 and ETH_2 function enabled. ETH_1 works as WAN, ETH_2 works as LAN. Over the suitable settings, the data between COM_1 and network can reach mutual conversion. In this mode, any computer with wireless capability like (personal computer, laptop, Pad, pendent) be able to connect with the CNC machine and

turn into the device under WLAN and more of that have the capability to become a part with other network connected with internet through WAN. Dynamic IP address is the default IP for WAN. LAN and Wi-Fi for the same local area network, enabled by default DHCP server as shown in figure (3.4).

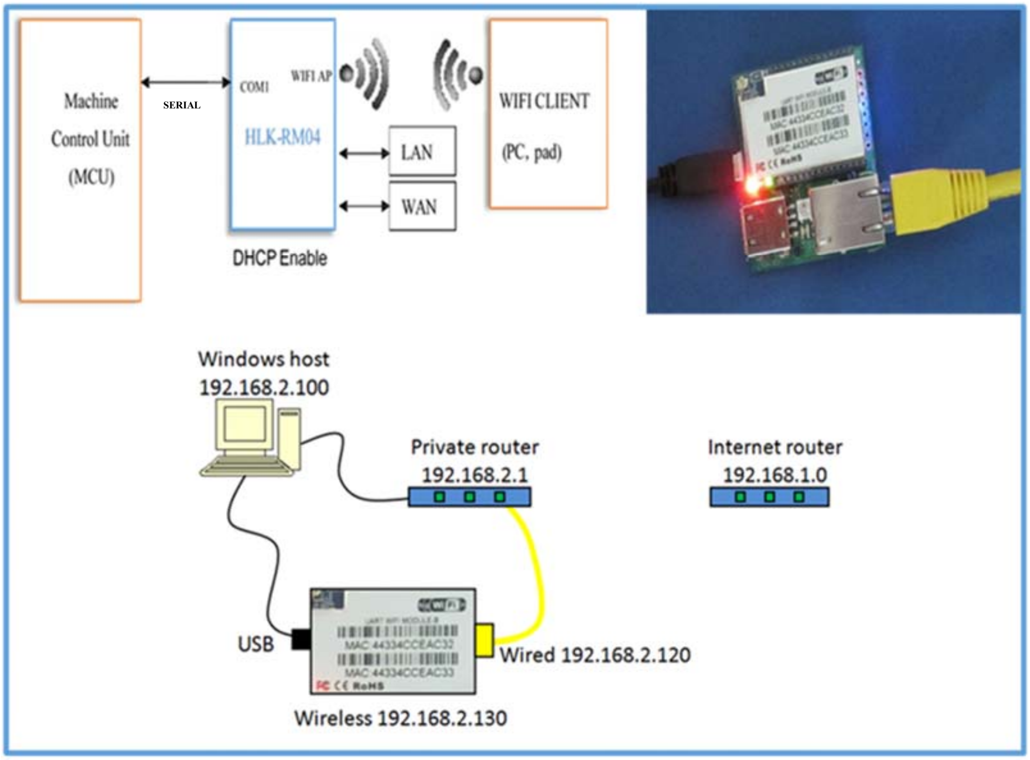


Figure 3.4: Default mode Block diagram and IP assignment.

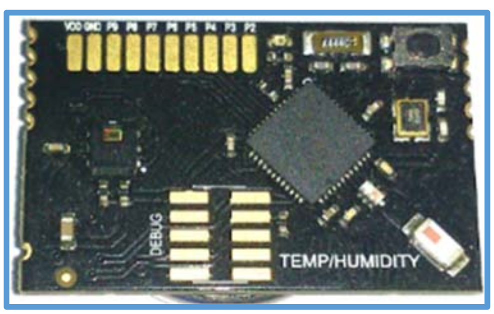
3.3 Internet of Things for CNC Machine Monitoring

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 consists from: sensors, middleware and application or user interface. The following subsections explain that.

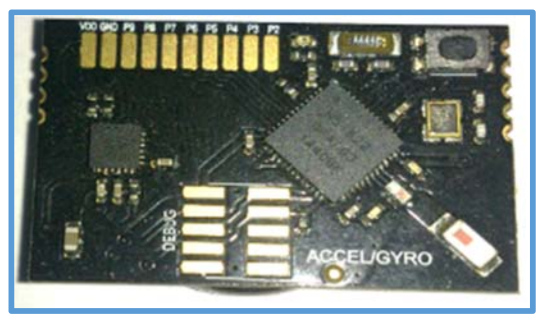
3.3.1 Sensing Unit

In sensing unit, each sensor consists from Bluetooth Low Energy chip, printed circuit board (PCB) and Li/ion coin cell battery. This unit consist from multiple sensors like:

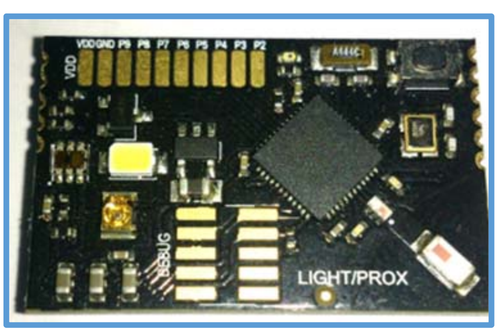
1. Temperature/Humidity: HTU21D(F) RH/T Sensor IC, a low power digital sensor of relative humidity and temperature with low power consumption and fast response time.
2. Accelerometers/Gyroscope: MPU-6500 Sensor IC, six-axis (gyroscope+ accelerometer).
3. Light/Proximity: TCS37717 Sensor IC, high sensitivity RGB color sensing and proximity detector with very high sensitivity. For proximity detection an external Infra-Red LED is used to emit light, which is then measured by the integrated light detector to determine the amount of reflected light from the object in the light path.
4. Microphone: SPQ0410HR5H-B Sensor IC, it is used as a sound level sensor.



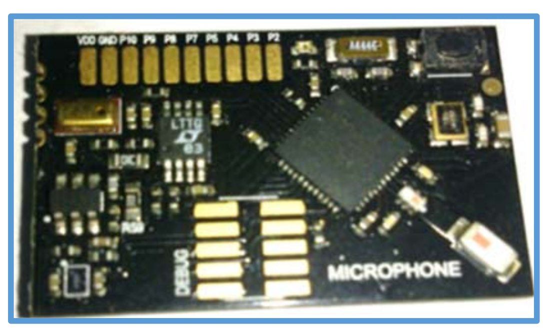
(a) Temperature/Humidity sensor.



(b) Accelerometers/Gyroscope sensor.



(c) Light/Proximity sensor.



(d) Microphone sensor.

Figure 3.5: Sensors Unit.

3.3.2 Middleware

All sensors will be connected to a master unit and by using BLE to create node, this node is connected to internet by Wi-Fi via gateway like wireless router. Master unit contain Main MCU: Freescale Kinetis-K, Wi-Fi module: Gainspan GS1500M, Nordic BLE v4.0: nRF51822, I/O: 12 exposed GPIO pads, including 4 ADC, I2C, SPI and SDIO, 3.3V regulator including Full-speed USB w/OTG controller and Li-Ion/Li-Po charger.

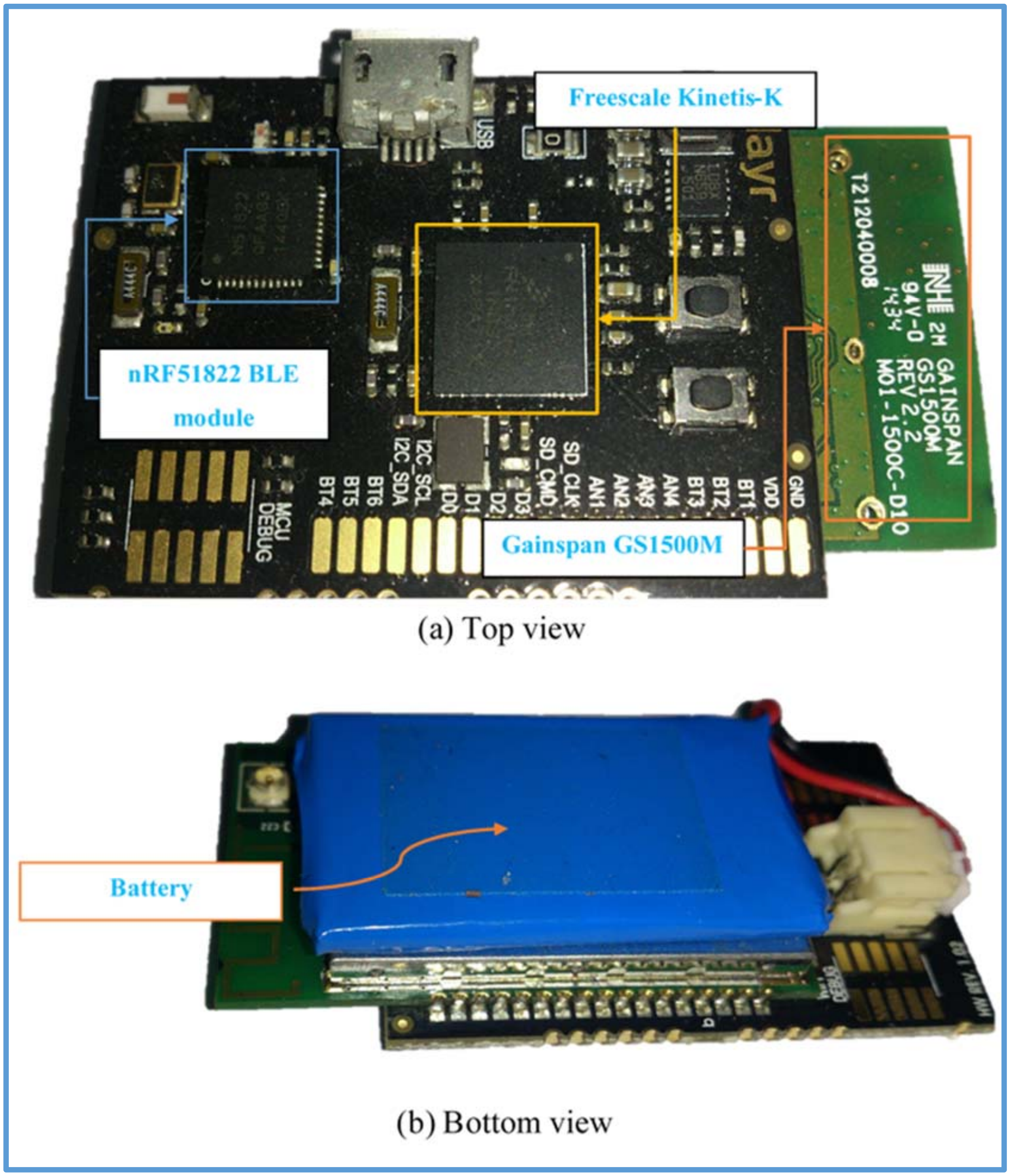


Figure 3.6: Master Unit.

3.3.3 Application and User Interface

The working concept in each of the sensor units has a Nordic Semiconductor nRF51822 System on Chip (SoC) which reads the sensor(s) on their board and uses Bluetooth LE (4.0) to communicate to the master unit after that will upload the data to the cloud server. The nRF51822 communicates with MQ Telemetry Transport (MQTT) which is a light weight publish subscribe protocol designed for actually low power IoT applications. The master unit uses a nRF51 for communication with the sensor, a Gainspan GS1500M connects to a local Wi-Fi network, and a Freescale Kinetis K-series process do all the heavy lifting (associate with networks, host MQTT server, authenticate with cloud server).

After connecting sensors with master unit and connected master unit with internet, sensor units must be defined to cloud server, create account in Relayr cloud server with an email as shown in figure (3.7), this account will pair 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 request and returns a set of IDs to be written to 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 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 to know if and how the devices are communicating and acting as a way to troubleshoot also view sensor data through the phone by using dashboard downloaded from google play as shown in figure (3.8).

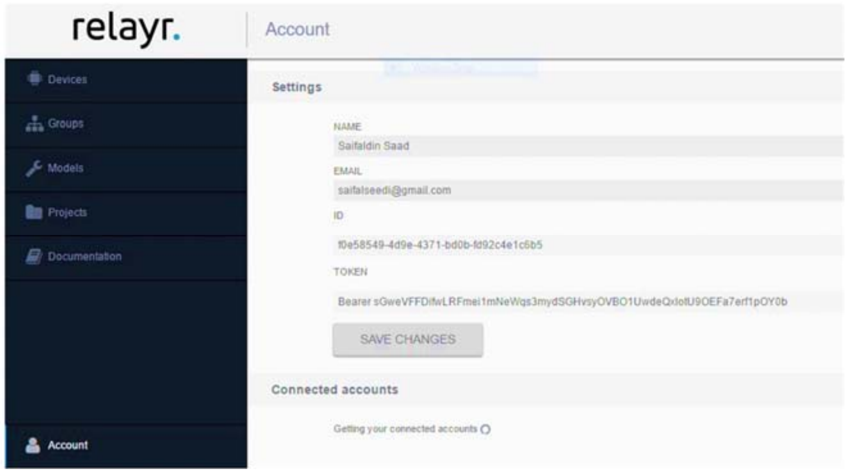


Figure 3.7: Account Information

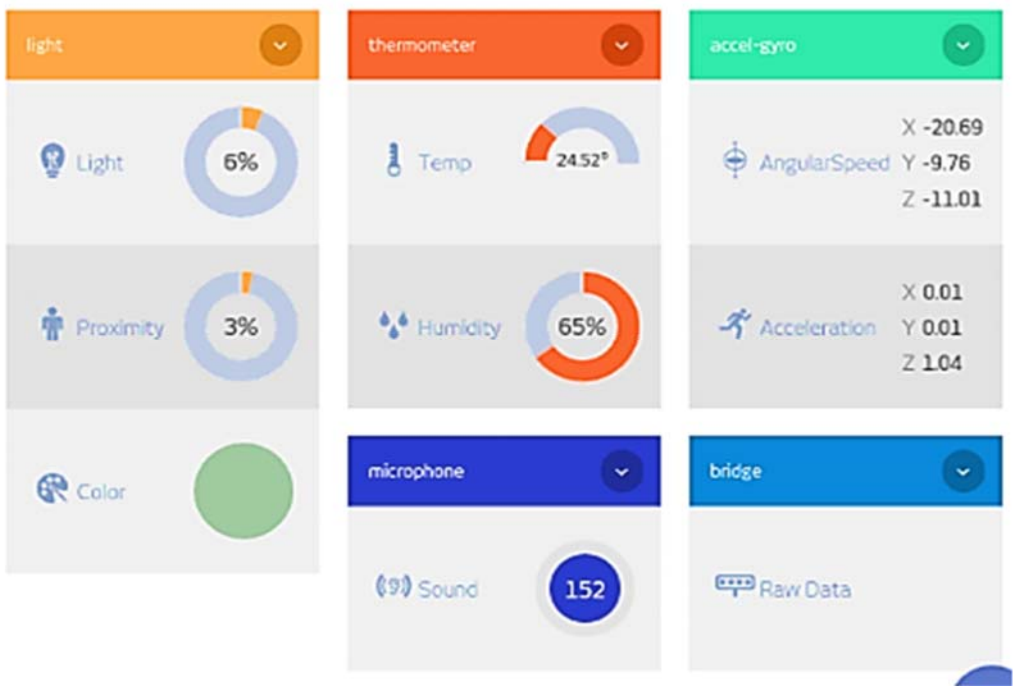


Figure 3.8: Android Phone User Interface

3.4 G-code Generating

After completing the design and representation of AutoCAD model, the implementations of these methods will be explained in chapter four. The process of tool paths generation was completed using two methods:

1. Using MATLAB software to generate G-code and use CIMCO edit V5 software to make tool paths simulation for generated G-code.

2. Using UG-NX10 to create an actual tool path. There are two steps of operation. The first step is to generate a tool path for rough machining, with selection of the required setting of this type, such as (strategy method, tool geometry, tool diameter, spindle speed and feed rate). Where, the second step is generating tool path for finish machining.

1.1 Cutting Tools and Workpiece

There are two types of cutting tools used in this work for C-TEK CNC milling machine:

1. Flat-end mill tool made from high-speed steel HSS, shown in figure (3.9) have been used for rough machining with (Ø10 mm) diameter, 40 mm flute length and four flutes.

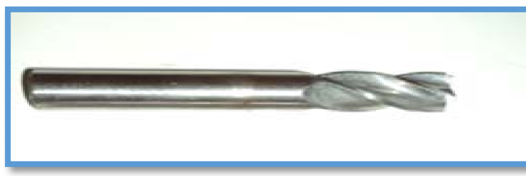


Figure 3.9: Cutting tools flat-end mill.

2. Ball-end mill tool made from HSS, shown in figure (3.10) is used for finishing operation with (Ø10 mm) diameter and four flutes.

Figure 3.10: Cutting tools Ball-end mill.

3. Work piece: Select the Aluminum alloy 7024 workpiece to be machined. The chemical composition of it is shown in table (3.1), was checked in the central organization for standardization and quality control.

Table (3.1): Aluminum 7024 alloy Chemical composition.

AL %	Ti %	Ga %	V %	Pb %	Cr %	Ni %
90.219	0.038	0.010	0.007	0.071	0.090	0.012
Si %	Fe %	Cu %	Mn %	Mg %	Zn %	Other %
0.163	0.422	2.14	0.216	1.55	4.93	0.132

The alloy had been cut into 2 work pieces with (30 mm × 60 mm × 40 mm) dimension, see figure (3.11):

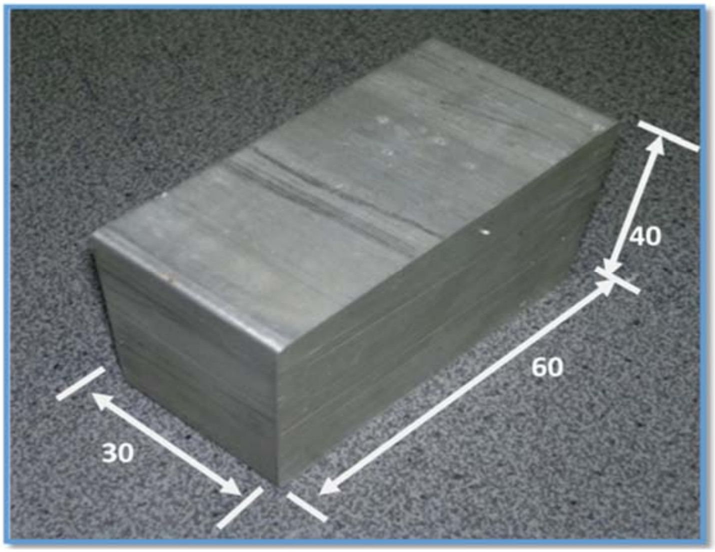


Figure 3.11: Dimension of work piece.

1.2 Important Considerations to Generate G-code in UG-NX10

The considerations can be divided into two phases that:

1. **Roughing phase:**
   - Mill planar type
   - Mill rough method
   - Flat tool with 10 mm diameter
   - Follow part path type
   - 70% step over
   - 500 mm/min feed
   - 1000 rpm Spindle speed

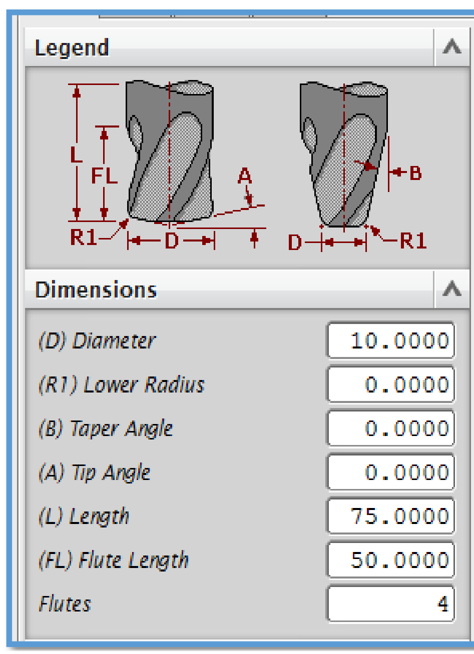


Figure 3.12: Dimension of tool for roughing phase (UG-NX10 software).

2. Finishing phase

- Mill contour type
- Milling area method
- ball tool with 10 mm diameter
- Zig path type
- O.4 mm step over
- 1000 mm/min feed
- 2500 rpm Spindle speed

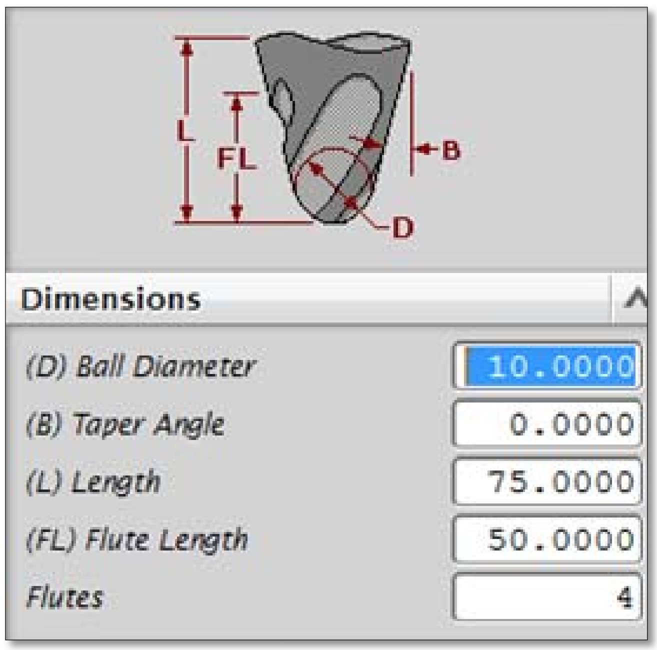
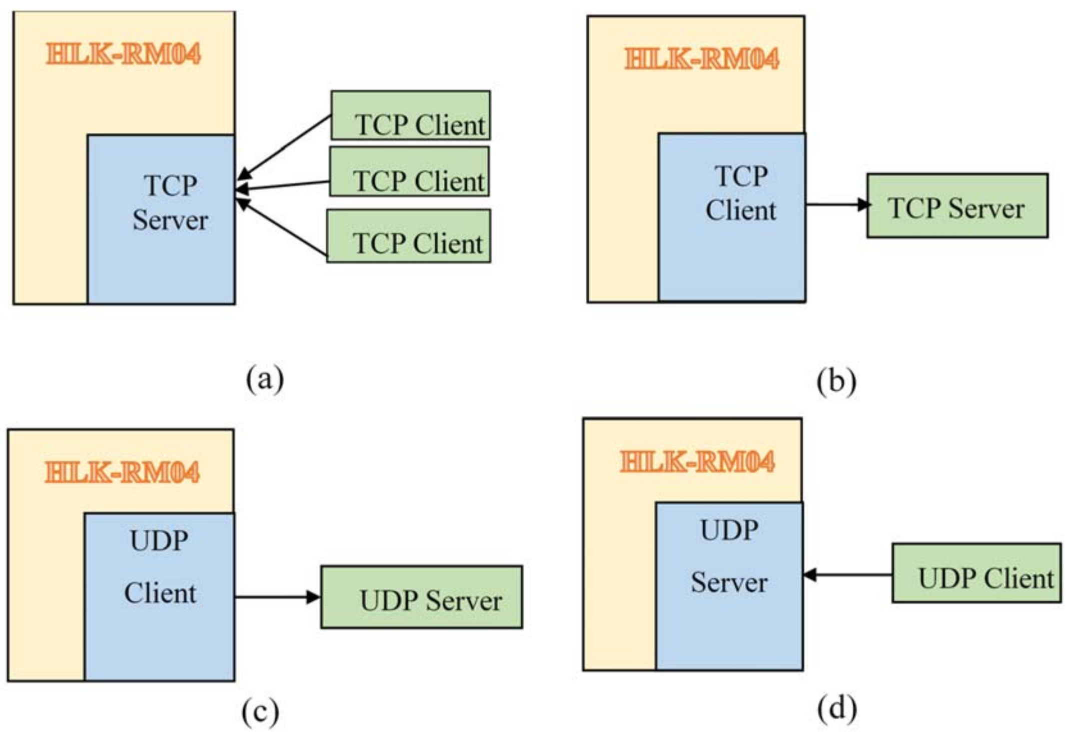


Figure 3.13: Dimension of tool for finishing phase (UG-NX10 software).

1.3 Experimental Work Steps

The experimental work of this study consist of multi steps. It can be summarized as follow:

1. At the beginning, the active modes of the module that's used in the research according to the MCU of the machine capability shown. There are four modes: TCP Server, TCP Client, UDP Server and UDP Client as shown in figure (3.14).



(a) TCP Server, (b)TCP Client, (c) UDP Client, (d) UDP Server.

Figure 3.14: Protocols and Connection Modes.

2. Parameters confirmation are setup using web page user interface. To get access to web configuration page, it needs the IP addresses of the module's confirmation page, in addition to the user name and password that requested by the web page as shown in figure (3.15).

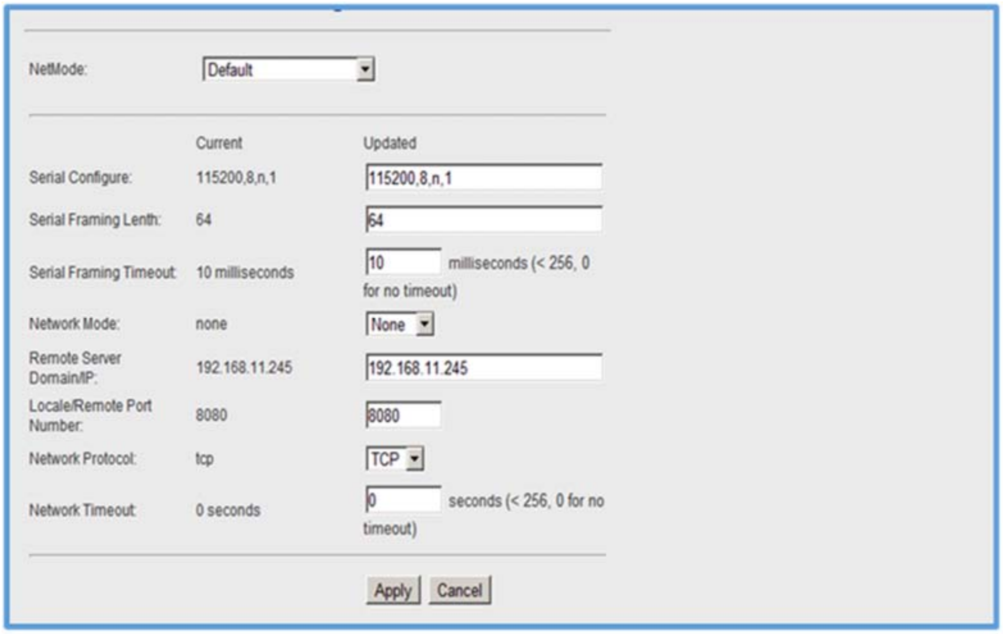


Figure 3.15: Web configuration page.

By using the correct module address, one can enter to the web configuration page (default address: http://xx.xx.xx.xx/ser2net.asp). This page is classified into three areas:

a. **Network configuration area:** In this area a different page shown depending on the selected work mode, Figures 3.16, 3.17, 3.18, 3.19 and 3.20 show the configuration setting.

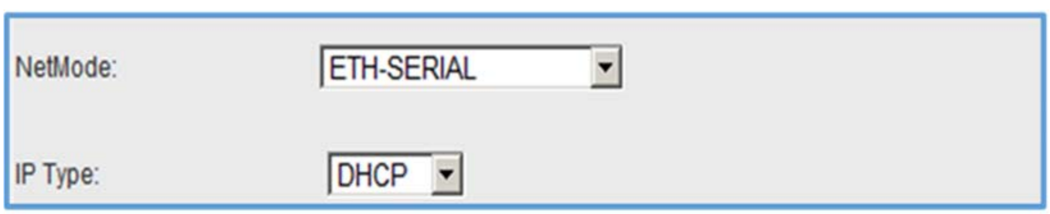


Figure 3.16: Serial to Ethernet and dynamic IP.

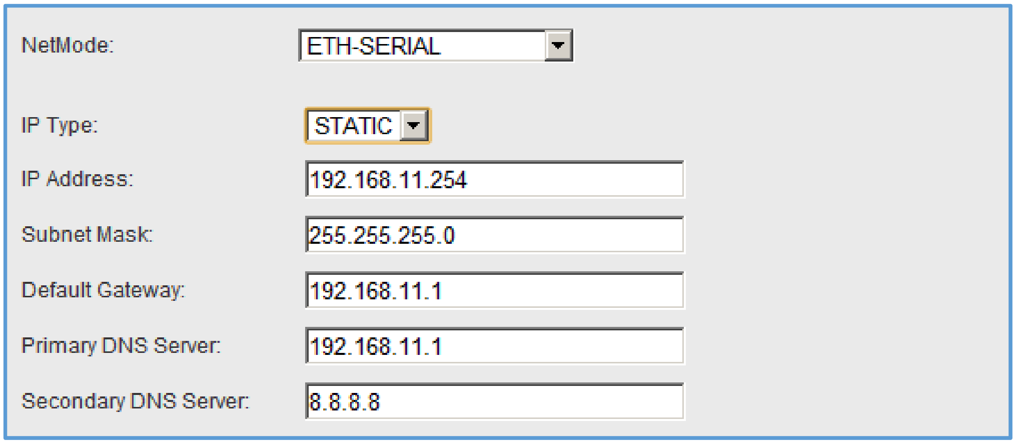


Figure 3.17: Serial to Ethernet and static IP.

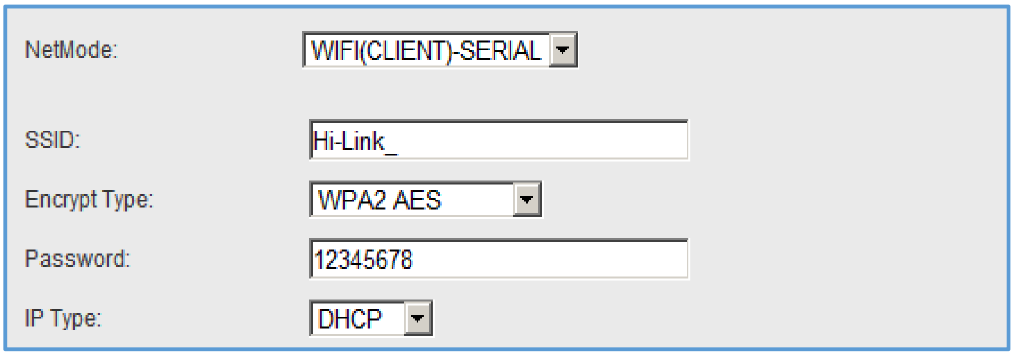


Figure 3.18: Serial to WIFI CLIENT and dynamic IP.

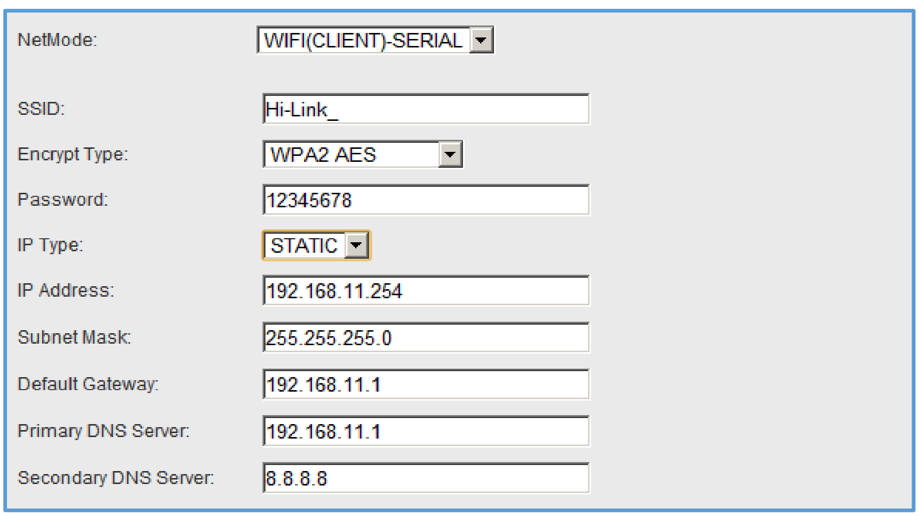


Figure 3.19: Serial to WIFI CLIENT and static IP.

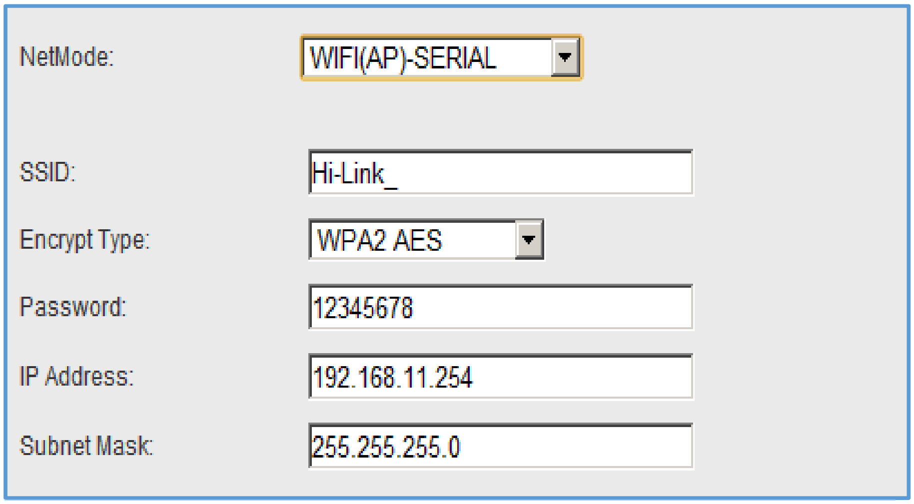


Figure 3.20: Serial to WIFI AP.

b. **Configuration serial function area:** A Serial Web configuration page (ser2net.asp) is made as shown in figure (3.21).

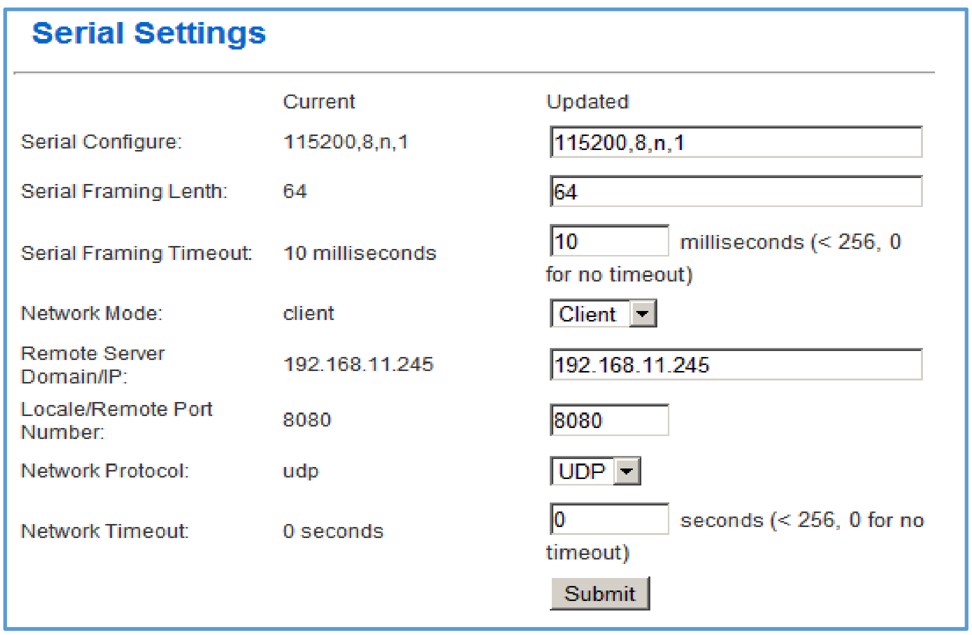


Figure 3.21: Configuration serial.

c. **Configuration submit area:** By clicking on button (Apply) to submit the configuration of the present page as shown in figure (3.15). The applying of parameters process could take about (25 s). If only modify the serial functional configuration, the submission process will be completed quickly. By clicking on button (Cancel) the page will be reload and the modified configuration will be lost.

3. Next step is to connect module to the serial port (RS-232) after that will activate the TCP server mode as shown in figure (3.22)

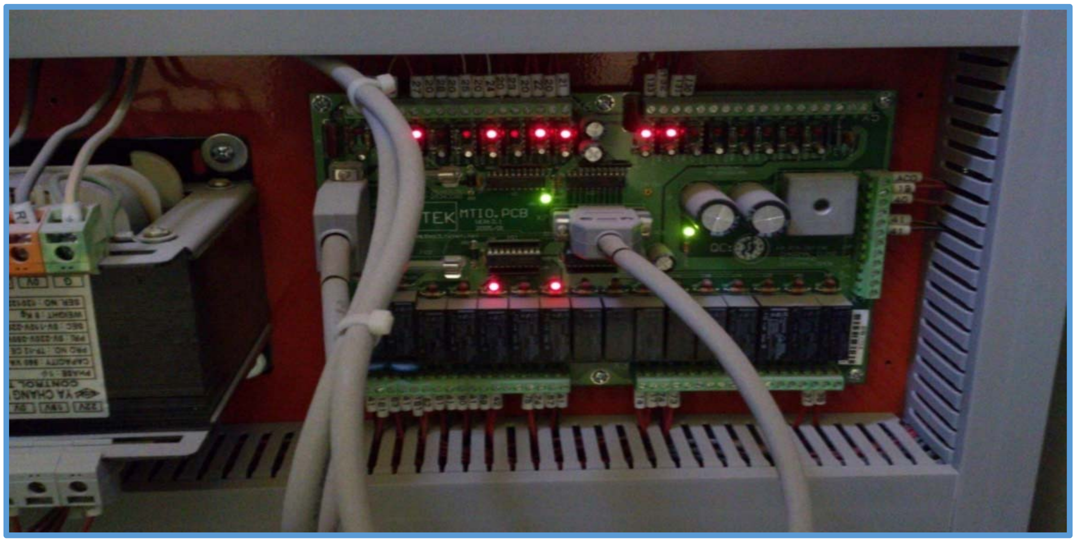


Figure 3.22: Serial port (RS-232) of C-TEk Milling machine.

4. Setup the central computer and Setting up the File Transfer Protocol (FTP) Server from control panel then network, In IP Address dialog box click Assigned IP address. And then key in 192.9.100.253 in the IP Address button and key in 255.255.255.0 in the Net mask button.

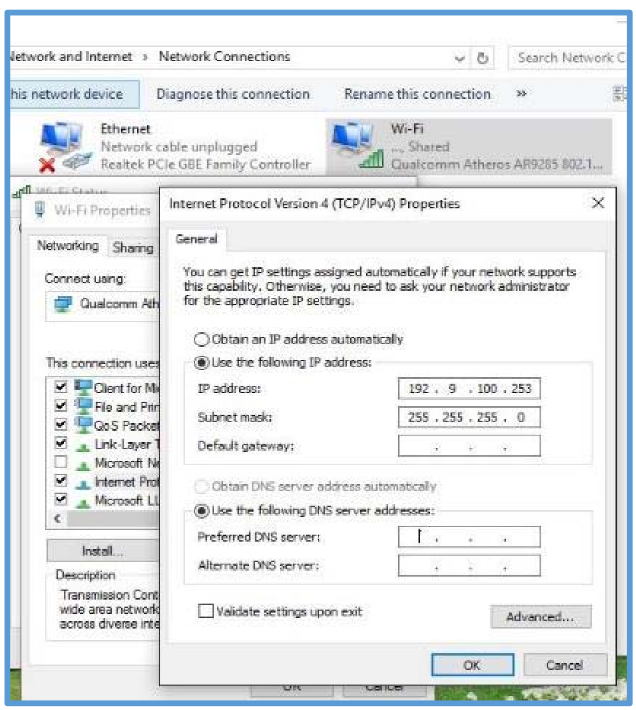


Figure 3.23: IP Address dialog box.

5. After assigned IP address the Server.exe need to be run, which is Self-Extractor File. When it has run, the words on the destination folder button should be C:\. After that will configure the FTP server as shown in figure (3.24).

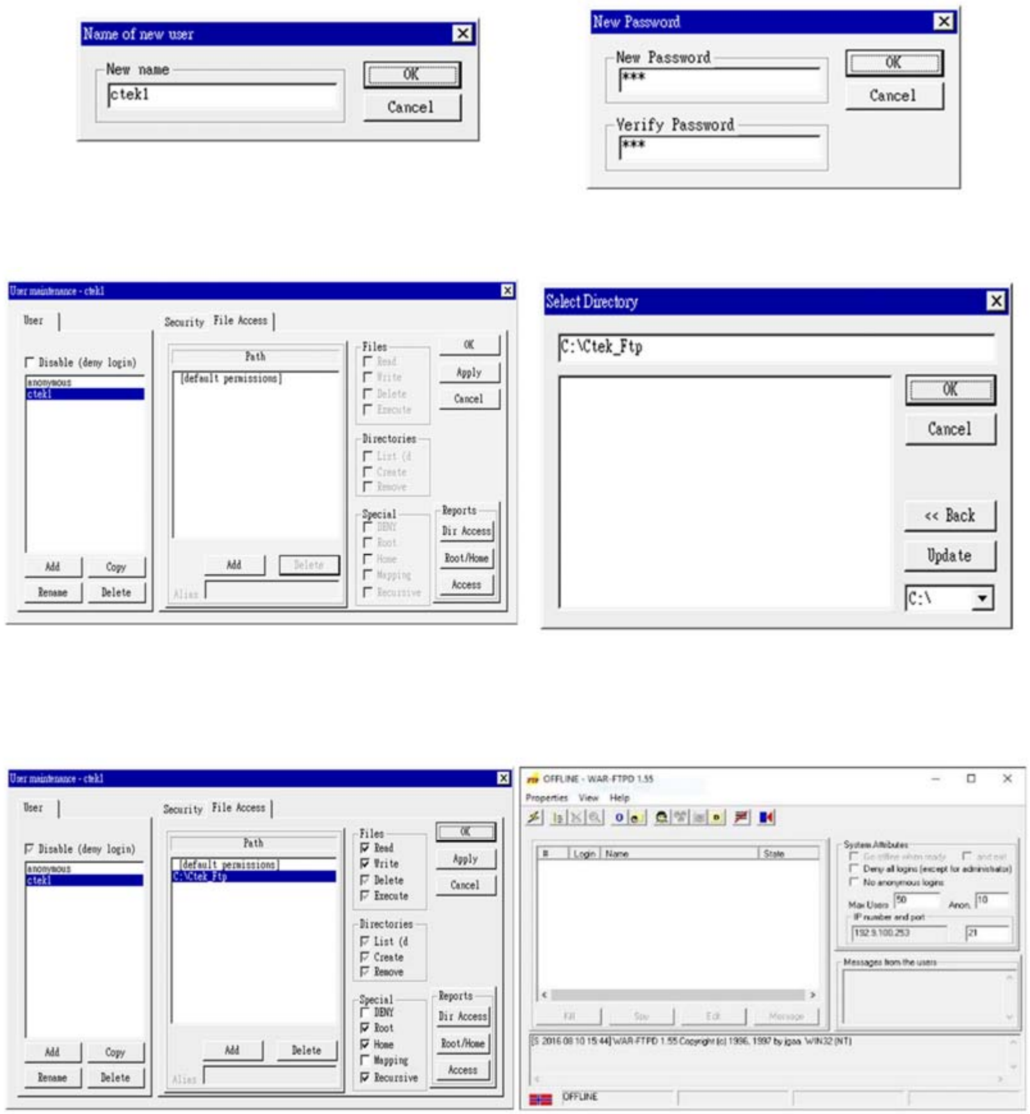


Figure 3.24: Configuration of FTP server.

6. The workpiece need to be setup and centroid with the machine home coordinate, making zero set for starting X-axis and Y-axis and Z-axis.

7. Placing sensors on the workpiece and placing the master module on the CNC machine as shown in figure (3.25).

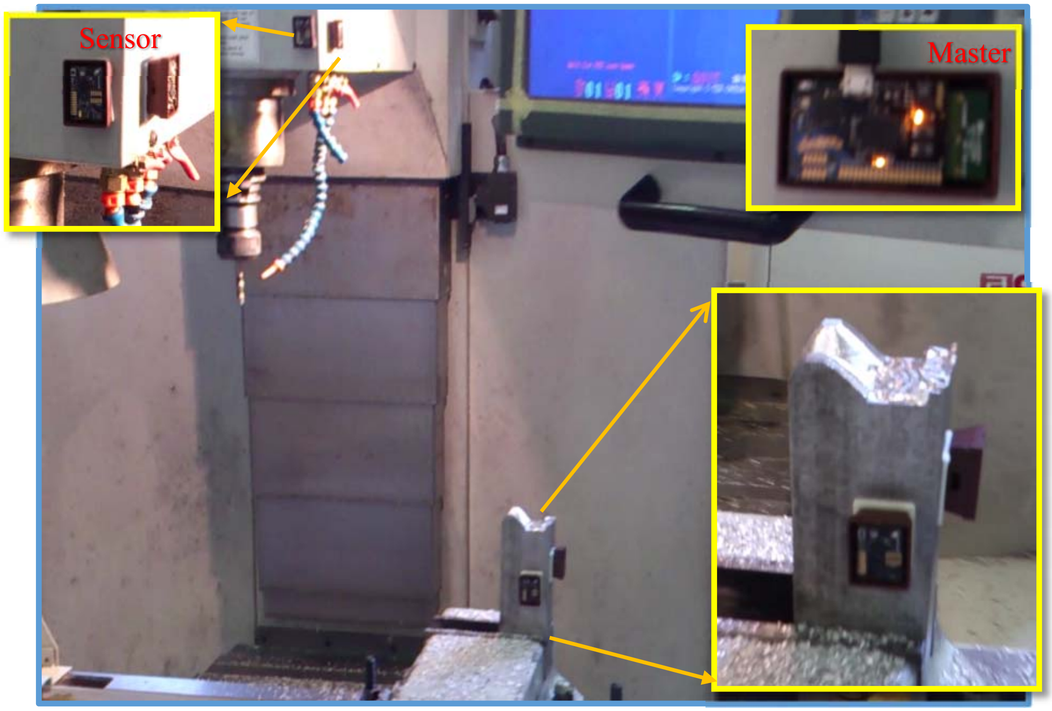


Figure 3.25: Install sensors on the workpiece.

8. The NC program has been transferred (wireless transmission) to the CNC machine by using FTP server program and receive it on the machine as shown in figure (3.26)

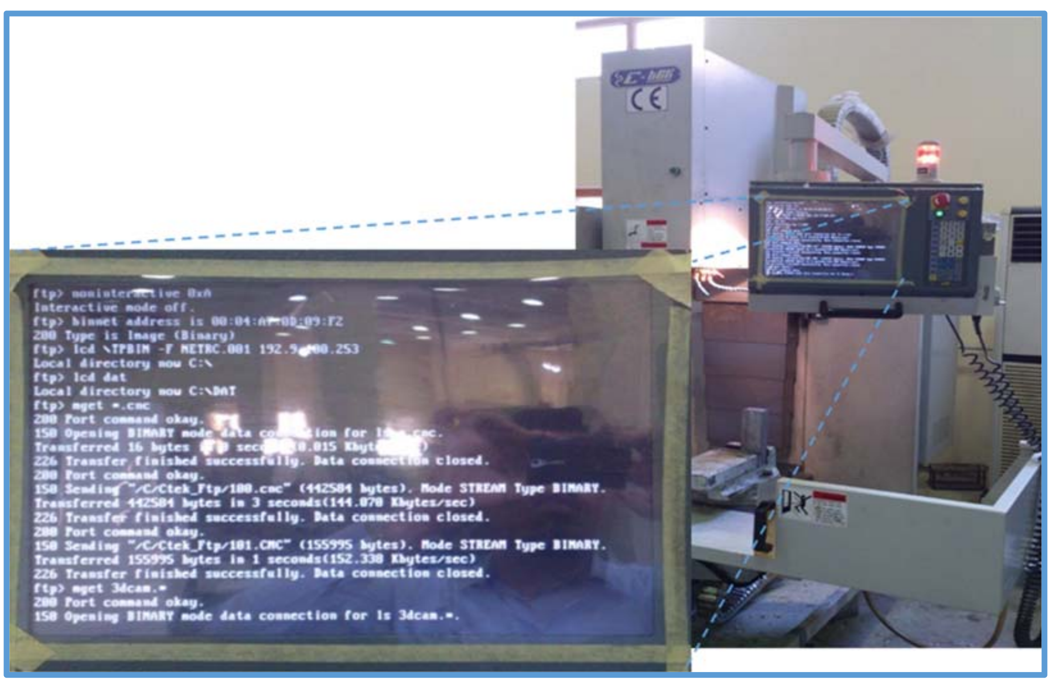


Figure 3.26: Screen of C-TEK Milling machine.

9. 3D simulation has been run to observe the processing of workpiece as shown in figure (3.27).

Figure 3.27: 3D simulation of Milling machine.

10. After checking the 3D simulation, a machining start, firstly start with roughing milling and then with finishing milling each process take about from (43-45) min as shown in figure (3.28).

Figure 3.28: Machining process.

11. Workpiece dimension measurements are estimated in the Metal Cutting Laboratory, Department of Production Engineering and Metallurgy, University of Technology. The accuracy of the 3D surface and models measured by using the digital readout of two axis (X&Y) Knuth MF1vertical milling machine with digital 3D touch probe. The machine is equipped with a digital touch probe that has an accuracy of (0.001) mm inserted instead of the tool in the Z-axis as shown in figure (3.29).

Figure 3.29: Workpiece dimensions measurement, (**a**) Digital 3D-Touch Probe, (**b**) Knuth MF1vertical milling machine.

CHAPTER FOUR

IMPLEMINTATION WORK AND

CHAPTER FOUR

IMPLEMINTATION WORK AND DISCUSSION

4.1 Introduction

This chapter concentrate on the applications of experimental work and discuss the results. These are done with two parts. The proposed surface, toolpath simulation and transferring NC program are presented in the first part. While, the second part deal with the advantage and the capability of the wireless controller system with IoT.

4.2 Derivative of Sixth Degree Bezier Curve

In the present work sixth degree of Bezier matrix curve has been driven from Bernstein polynomials as follows:

$B_{i,n}(u)=\binom{n}{i}\, u^i\ (1-u)^{n-i}$ .... (4-1)

$\binom{n}{i}=\frac{n!}{i!(n-i)!}$ .... (4-2)

$B_{i,n}(u)=\frac{n!}{n!+(n-i)!}u^i$ .... (4-3)

n=6 , i=0, 1, 2, 3, 4, 5, 6

$B_{0,6}(u)=\frac{6!}{0!+(6-0)!}u^0(1-u)^{6-0}=(1-u)^6$ ....(4-4)

$B_{1,6}(u)=\frac{6!}{1!+(6-1)!}u^1(1-u)^{6-1}=6u(1-u)^5$ .... (4-5)

$B_{2,6}(u)=\frac{6!}{2!+(6-2)!}u^2(1-u)^{6-2}=15u^2(1-u)^4$ .... (4-6)

$B_{3,6}(u)=\frac{6!}{3!+(6-3)!}u^3(1-u)^{6-3}=20u^3(1-u)^3$ .... (4-7)

$B_{4,6}(u)=\frac{6!}{4!+(6-4)!}u^4(1-u)^{6-4}=15u^4(1-u)^2$ .... (4-8)

$B_{5,6}(u)=\frac{6!}{5!+(6-5)!}u^5(1-u)^{6-5}=6u^5(1-u)^1$ .... (4-9)

$B_{6,6}(u) = \frac{6!}{6!+(6-6)!} u^6(1-u)^{6-6} = u^6$ .... (4-10)

$B_{0,6}(u)= 1-6u+15u^2-20u^3+15u^4-6u^5+6u^6$ .... (4-11)

$B_{1,6}(u)= 6u -30u^2 +60u^3-60u^4+30u^5-6u^6$ ....(4-12)

$B_{2,6}(u)= 15u^2-60u^3+90u^4-60u^5+15u^6$ ....(4-13)

$B_{3,6}(u)= 20u^3-60u^4+60u^5-20u^6$ ....(4-14)

$B_{4,6}(u)= 15u^4-30u^5+15u^6$ ....(4-15)

$B_{5,6}(u)=6u^5-6u^6$ ....(4-16)

$B_{6,6}(u)=u^6$ ....(4-17)

$p(u) = \sum_{i=0}^{n} N_{i,k}(u)P_i$ ....(4-18)

which can be expressed in matrix form as follows:

$P(u) = [U][M_B][P]$ .... (4-19)

$$P(u) = [u^5 u^4 u^3\ u^2 u\ 1]\begin{bmatrix} -1 & 5 & -10 & 10 & -5 & 1 \\ 5 & -20 & 30 & -20 & 5 & 0 \\ -10 & 30 & -30 & 10 & 0 & 0 \\ 10 & -20 & 10 & 0 & 0 & 0 \\ -5 & 5 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}\begin{bmatrix} p0 \\ p1 \\ p2 \\ p3 \\ p4 \\ p5 \end{bmatrix}$$

After first and second derivative and sub (u=1) in first curve & (u=0) in second curve:

The first curve:

$P(u) = [\; u^6 \quad u^5 \quad u^4 \quad u^3 \quad u^2 \quad u^1 \quad 1]$

$P(1) = [\; 1 \quad 1 \quad 1 \quad 1 \quad 1 \quad 1 \quad 1]$

$P'(u) = [\; 6u^5 \quad 5u^4 \quad 4u^3 \quad 3u^2 \quad 2u^1 \quad 1 \quad 0]$

$P'(1) = [\; 6 \quad 5 \quad 4 \quad 3 \quad 2 \quad 1 \quad 0]$

$P''(u) = [30u^4 \quad 20u^3 \quad 12u^2 \quad 6u^1 \quad 2 \quad 0 \quad 0]$

$P''(1) = [30 \quad 20 \quad 12 \quad 6 \quad 2 \quad 0 \quad 0]$

The second curve:

$P(u) = [\; u^6 \quad u^5 \quad u^4 \quad u^3 \quad u^2 \quad u^1 \quad 1]$

$P(0) = [\; 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 1]$

$P'(u) = [\; 6u^5 \quad 5u^4 \quad 4u^3 \quad 3u^2 \quad 2u^1 \quad 1 \quad 0]$

$P'(0) = [\; 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 1 \quad 0]$

$P''(u) = [30u^4 \quad 20u^3 \quad 12u^2 \quad 6u^1 \quad 2 \quad 0 \quad 0]$

$P''(0) = [0 \quad 0 \quad 0 \quad 0 \quad 2 \quad 0 \quad 0]$

First curve equal second curve to take C^0:

$Px_0^2 = Px_6^1$, $Py_0^2 = Py_6^1$, $Pz_0^2 = Pz_6^1$

First Derivative for first curve equal First Derivative for second curve to take C^1:

$Px_1^2 = 2 \times Px_6^1 - Px_5^1$

$Py_1^2 = 2 \times Py_6^1 - Py_5^1$

$Pz_1^2 = 2 \times Pz_6^1 - Pz_5^1$

Second Derivative for first curve equal second Derivative for second curve to take C^2:

$Px_2^2 = Px_4^1 - 4 \times Px_5^1 + 4 \times Px_6^1$

Py_2^2= Py_4^1-4×Py_5^1+4×Py_6^1

Pz_2^2= Pz_4^1-4×Pz_5^1+4×Pz_6^1

To apply these mathematical equations on case study in current research as follows:

1- **Convex region:**

$P_0^1(0,0,0)$, $P_1^1(2.5,0,5)$, $P_2^1(5,0,12)$,$P_3^1(10,0,12)$, $P_4^1(15\ ,0,12)$, $P_5^1(20,0,5)$, $P_6^1(25,0,0)$.

2- **Concave region:**

$P_0^2(25,0,0)$, $P_1^2(30,0,-5)$, $P_2^2(35,0,-12)$,$P_3^3(40,0,-12)$ $P_4^2(45\ ,0,-12)$, $P_5^2(47.5,0,-5)$, $P_6^2(50,0,0)$.

$$\left.\begin{array}{l} Px_0^2 = Px_6^1 = 25 \\ Py_0^2 = Py_6^1 = 0 \\ Pz_0^2 = Pz_6^1 = 0 \end{array}\right\} \quad \text{give } C^0$$

$$\left.\begin{array}{l} Px_1^2 = 2\times Px_6^1 - Px_5^1 = 2\times 25-20 = 30 \\ Py_1^2 = 2\times Py_6^1 - Py_5^1 = 2\times 0 - 0 = 0 \\ Pz_1^2 = 2\times Pz_6^1 - Pz_5^1 = 2\times 0 - 5 = -5 \end{array}\right\} \quad \text{give } C^1$$

$$\left.\begin{array}{l} Px_2^2 = Px_4^1 - 4\times Px_5^1 + 4\times Px_6^1 = 15-4\times 20+4\times 25 = 35 \\ Py_2^2 = Py_4^1 - 4\times Py_5^1 + 4\times Py_6^1 = 0-4\times 0+0 = 0 \\ Pz_2^2 = Pz_4^1 - 4\times Pz_5^1 + 4\times Pz_6^1 = 12-4\times 5+4\times 0 = -8 \end{array}\right\} \quad \text{give } C^2$$

4.3 Proposed Surface Simulations

The proposed surface was designed based on Bezier method with 7 control points and has been driven in section 4.2, so the control points are given below:

$$P_x = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2.5 & 2.5 & 2.5 & 2.5 & 2.5 & 2.5 & 2.5 \\ 5 & 5 & 5 & 5 & 5 & 5 & 5 \\ 10 & 10 & 10 & 10 & 10 & 10 & 10 \\ 15 & 15 & 15 & 15 & 15 & 15 & 15 \\ 20 & 20 & 20 & 20 & 20 & 20 & 20 \\ 25 & 25 & 25 & 25 & 25 & 25 & 25 \end{bmatrix}$$

$$P_y = \begin{bmatrix} 0 & 5 & 10 & 15 & 20 & 25 & 31 \\ 0 & 5 & 10 & 15 & 20 & 25 & 31 \\ 0 & 5 & 10 & 15 & 20 & 25 & 31 \\ 0 & 5 & 10 & 15 & 20 & 25 & 31 \\ 0 & 5 & 10 & 15 & 20 & 25 & 31 \\ 0 & 5 & 10 & 15 & 20 & 25 & 31 \\ 0 & 5 & 10 & 15 & 20 & 25 & 31 \end{bmatrix}$$

$$P_z = \begin{bmatrix} 0 & 0 & 0 & -25 & 0 & 0 & 0 \\ 5 & 5 & 5 & -25 & 5 & 5 & 5 \\ 12 & 12 & 12 & -25 & 12 & 12 & 12 \\ 12 & 12 & 12 & -25 & 12 & 12 & 12 \\ 12 & 12 & 12 & -25 & 12 & 12 & 12 \\ 5 & 5 & 5 & -25 & 5 & 5 & 5 \\ 0 & 0 & 0 & -25 & 0 & 0 & 0 \end{bmatrix}$$

AutoCAD has been used to design the proposed surface as shown in figure (4.1).

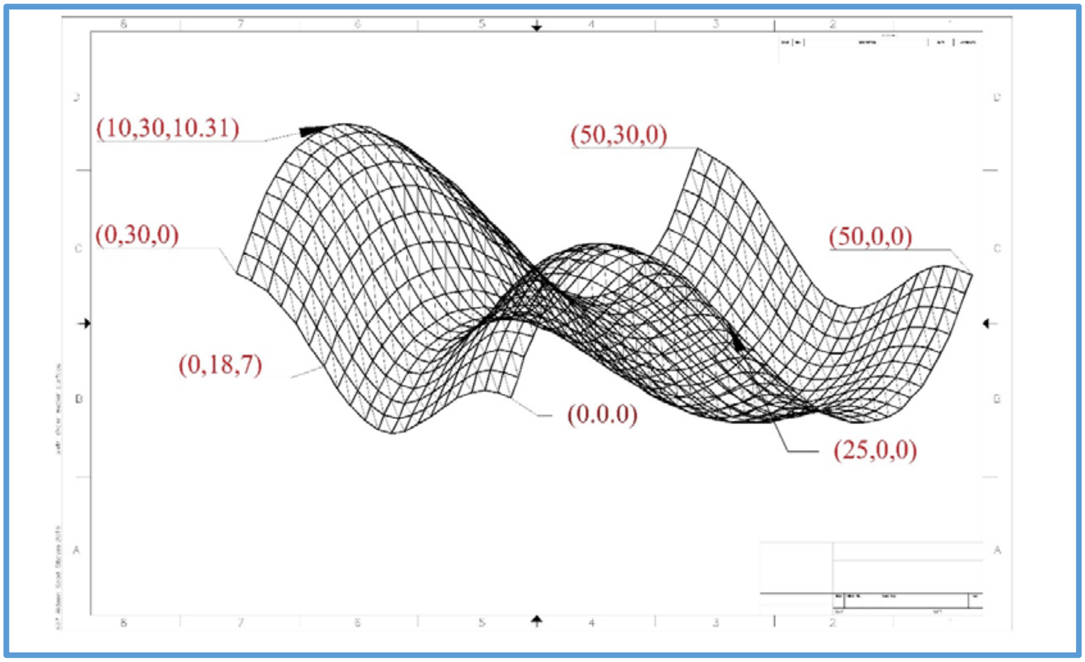


Figure 4.1: AutoCAD of Bezier surface design.

Also, the proposed surface was designed according to the following steps:

1. MATLAB software is used in the design of the proposed surface. It uses the Bezier matrix control points as input data. Figure (4.2), represents the flow chart of it.

Case study: consists from convex and concave region for free form surface.

a. Convex:

$$P_0^1\begin{bmatrix}0\\0\\0\end{bmatrix},\ P_1^1\begin{bmatrix}2.5\\0\\5\end{bmatrix},\ P_2^1\begin{bmatrix}5\\0\\12\end{bmatrix},\ P_3^1\begin{bmatrix}10\\0\\12\end{bmatrix},\ P_4^1\begin{bmatrix}15\\0\\12\end{bmatrix},\ P_5^1\begin{bmatrix}20\\0\\5\end{bmatrix},\ P_6^1\begin{bmatrix}25\\0\\0\end{bmatrix}$$

b. Concave:

$$P_0^2\begin{bmatrix}25\\0\\0\end{bmatrix},\ P_1^2\begin{bmatrix}30\\0\\-5\end{bmatrix},\ P_2^2\begin{bmatrix}35\\0\\-12\end{bmatrix},\ P_3^2\begin{bmatrix}40\\0\\-12\end{bmatrix},\ P_4^2\begin{bmatrix}45\\0\\-12\end{bmatrix},\ P_5^2\begin{bmatrix}47.5\\0\\-5\end{bmatrix},\ P_6^2\begin{bmatrix}50\\0\\0\end{bmatrix}$$

MATLAB software, program output is shown in figure (4.3):

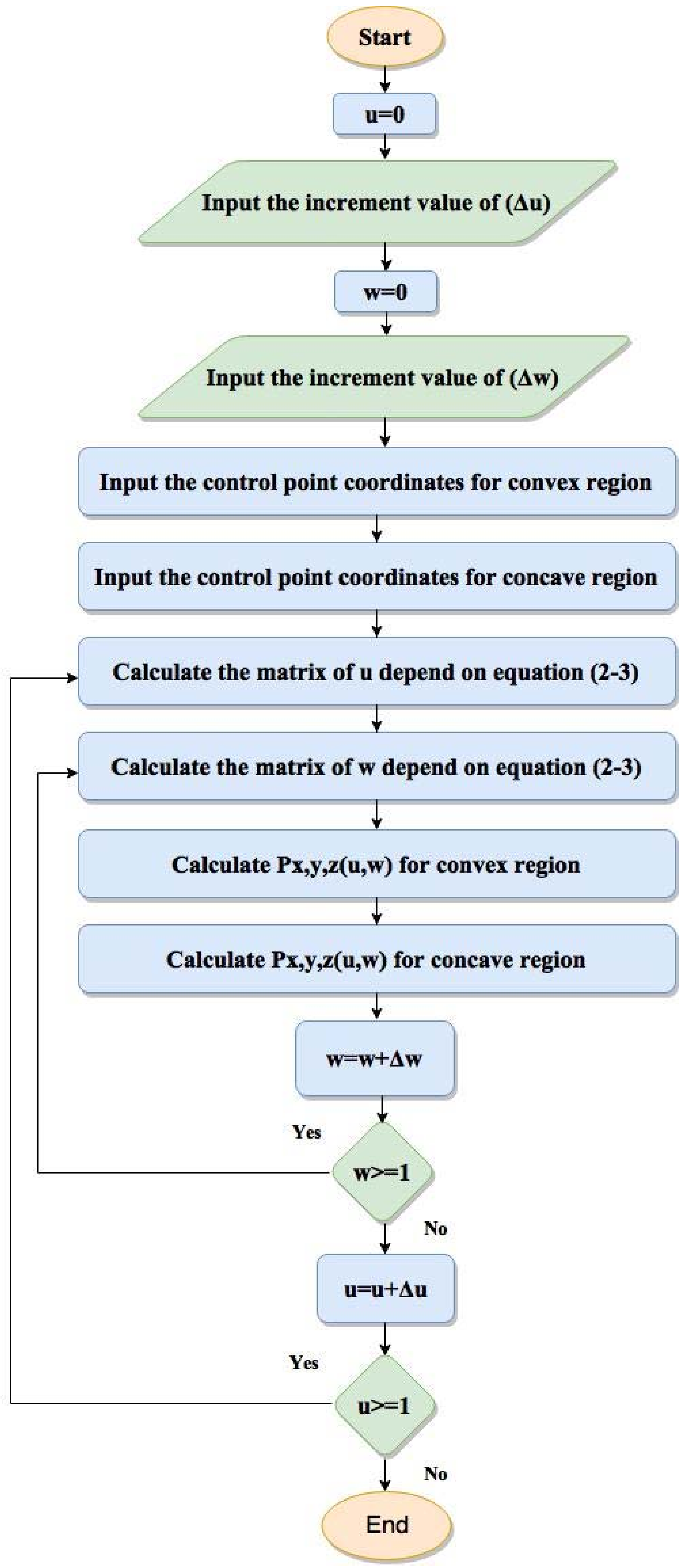


Figure 4.2: Flow chart of Bezier surface design.

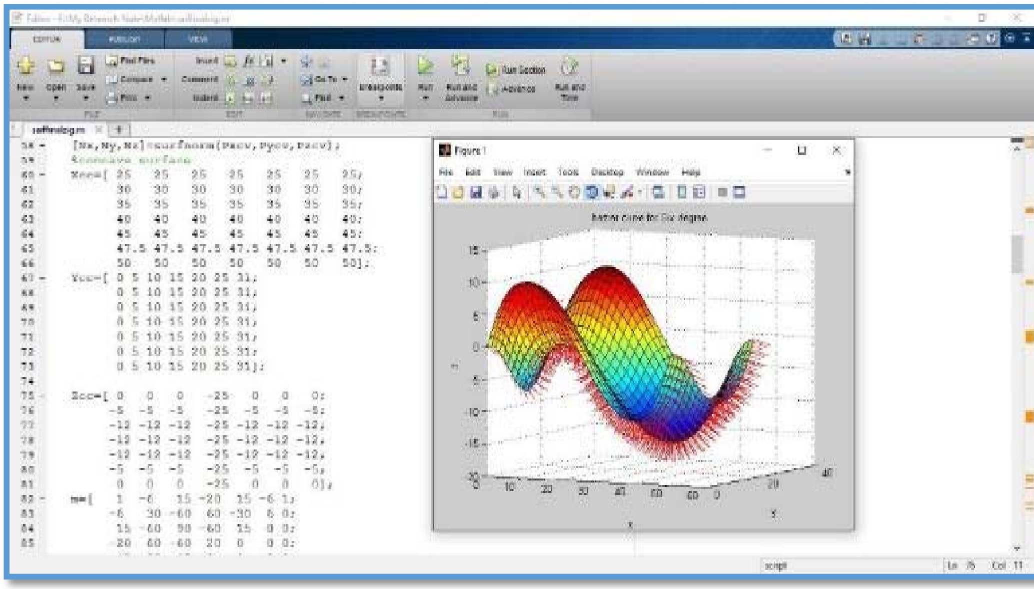


Figure 4.3: The Proposed surface using MATLAB software.

2. Continuity: There are three type of continuity as described in chapter 2 that C^0, C^1 and C^2. To verify these continuities on the proposed shape, the first and the second derivative of Bezier equations and the continuity can be implemented at any point on the surface and the Z-axis is unchanged as follows:

$$P(u) = [\; u^6 \quad u^5 \quad u^4 \quad u^3 \quad u^2 \quad u^1 \quad 1]$$

$$P'(u) = [\; 6u^5 \quad 5u^4 \quad 4u^3 \quad 3u^2 \quad 2u^1 \quad 1 \quad 0]$$

$$P'(1) = [\; 6 \quad 5 \quad 4 \quad 3 \quad 2 \quad 1 \quad 0]$$

$$P''(u) = [30u^4 \quad 20u^3 \quad 12u^2 \quad 6u^1 \quad 2 \quad 0 \quad 0]$$

$$P''(1) = [30 \quad 20 \quad 12 \quad 6 \quad 2 \quad 0 \quad 0]$$

By substituting u=1 in the first curve parametric equation and make this equal to the second curve parametric equation at (u=0).

C^0 can be taken as in figure (4.4) and get:

$$P_0^2 = P_6^1 \qquad \text{………………………………………………(4-20)}$$

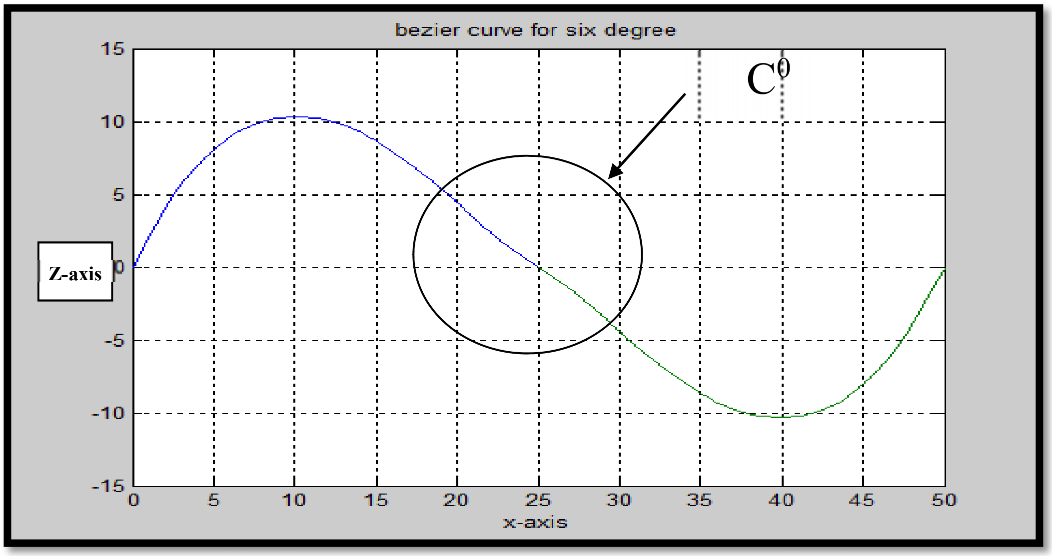


Figure 4.4: Continuity between two curves of C^0.

To verify C^1 as shown in figure (4.5), the first derivative of both curves parametric equation must be done, and substituting u=1 in the first curve parametric equation derivative and make this equal to the second curve parametric equation derivative at (u=0) to get P_1^2.

$$P_1^2 = 2\times P_6^1 - P_5^1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4-21)$$

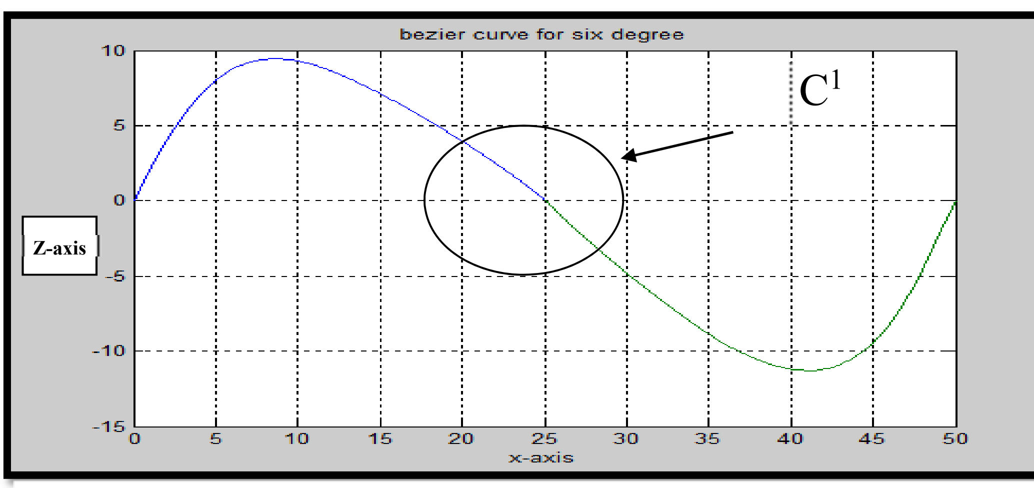


Figure 4.5: Continuity between two curves of C^1.

And to verify C^2 as shown in figure (4.6). The second derivative for both curves parametric equation can be done, then substituting u=1 in the first curve parametric equation second derivative and make this equal to other curve parametric equation second derivative at (u=0) to find P_2^2.

$$P_2^2 = P_4^1 - 4 \times P_5^1 + 4 \times P_6^1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4-22)$$

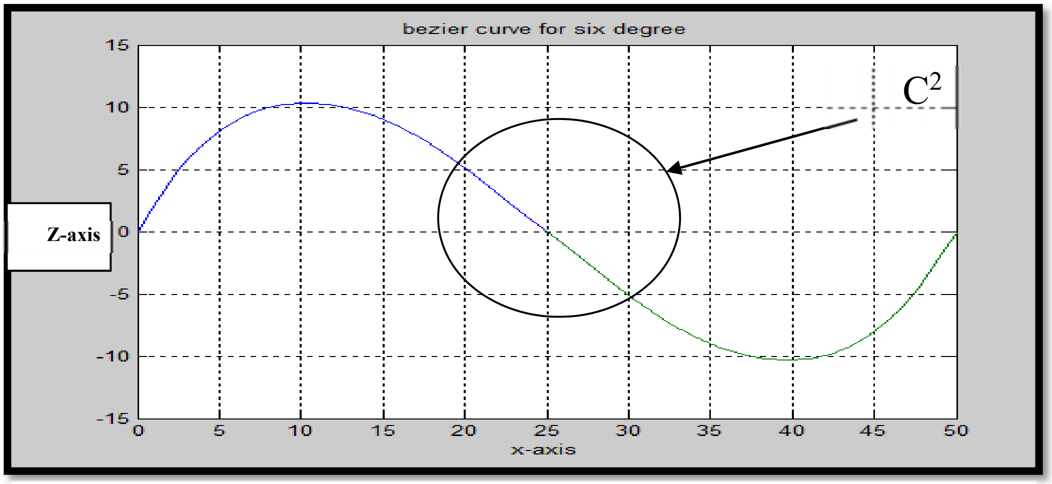


Figure 2.6: Continuity between two curves of C^2.

3. UG-NX10 software is used to create the proposed surface. It will be extract the results of surface's points from MATLAB software and save it as data file has extension (.dat) and open the data file in UG-NX10 software, the procedure can be divided into sub stages as follows:
   a. Using the following instructions to import from MATLAB files the dat-extension file and open it in UG-NX10 program as shown in figure (4.7).

Spline ⟹ Through points ⟹ Points from file

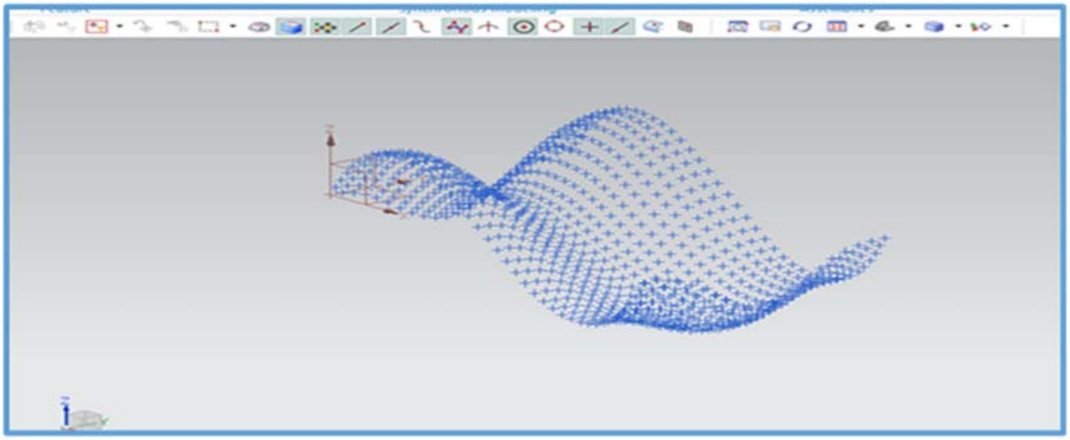


Figure 4.7: The surface points.

b. By clicking on **Chain with rectangle** and draw spline curve that passes through all points, as shown in figure (4.8).

Spline ⟹ Through points ⟹ Chain with rectangle

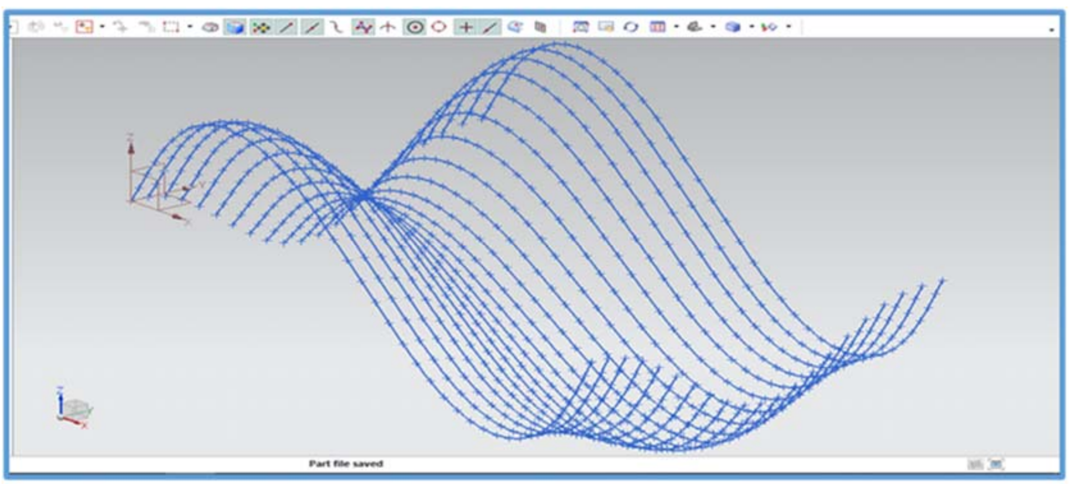


Figure 4.8: The splines curve.

c. Using **through curve** command to draw splines surface that passes through all curves.

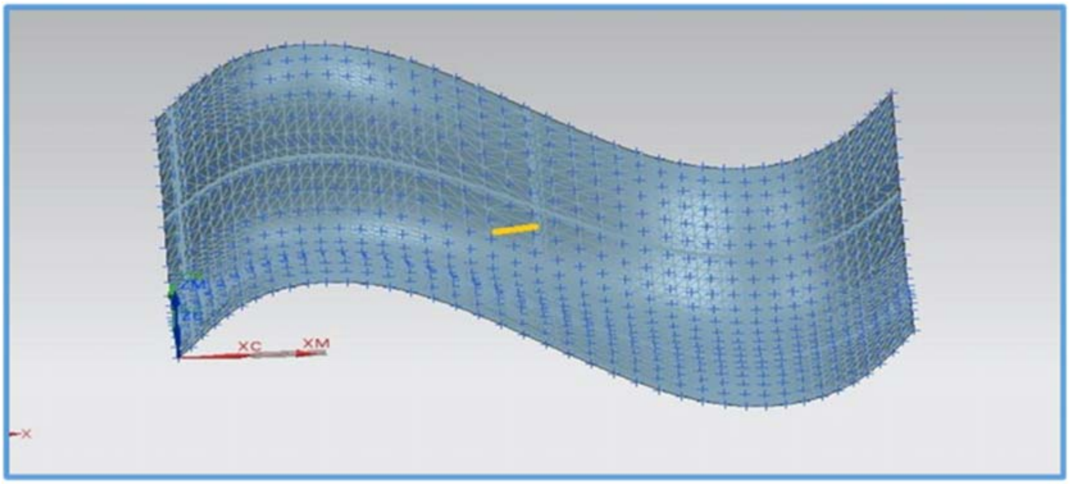


Figure 4.9: The splines surface.

d. Transform this surface to solid body by extruding the surface with **extrude** command as shown in figure (4.10).

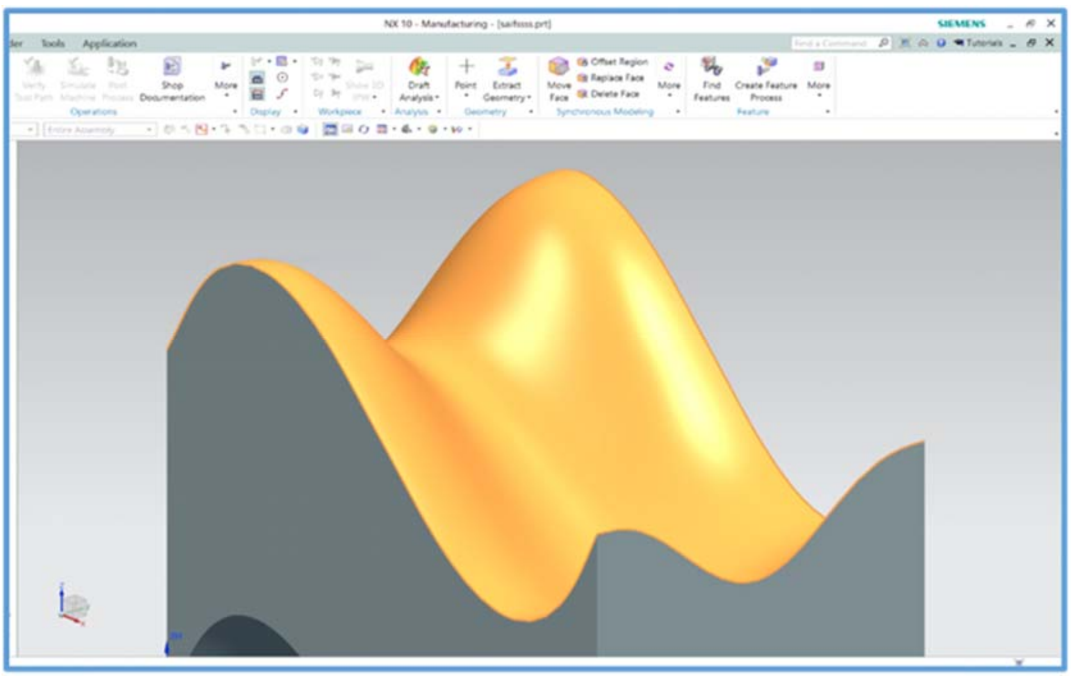


Figure 4.10: The solid body of the proposed surface.

4. The result of the proposed surface as observed is the same in both software, the reason for similarity is UG-NX10 software depended on extruded points of surface from MATLAB program to build solid body for proposed surface.

4.4 Generation and Simulation of G-code

The proposed surface has been created in both methods (MTLAB and UG-NX10 software). So the next process is generating the tool paths for the two methods.

4.4.1 MATLAB Method

This method will depend on G-code that generated from the proposed flow chart of tool path as shown in figure (4.11), the G-code has been generated as shown in Appendix (C) 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 as shown in figure (4.12).

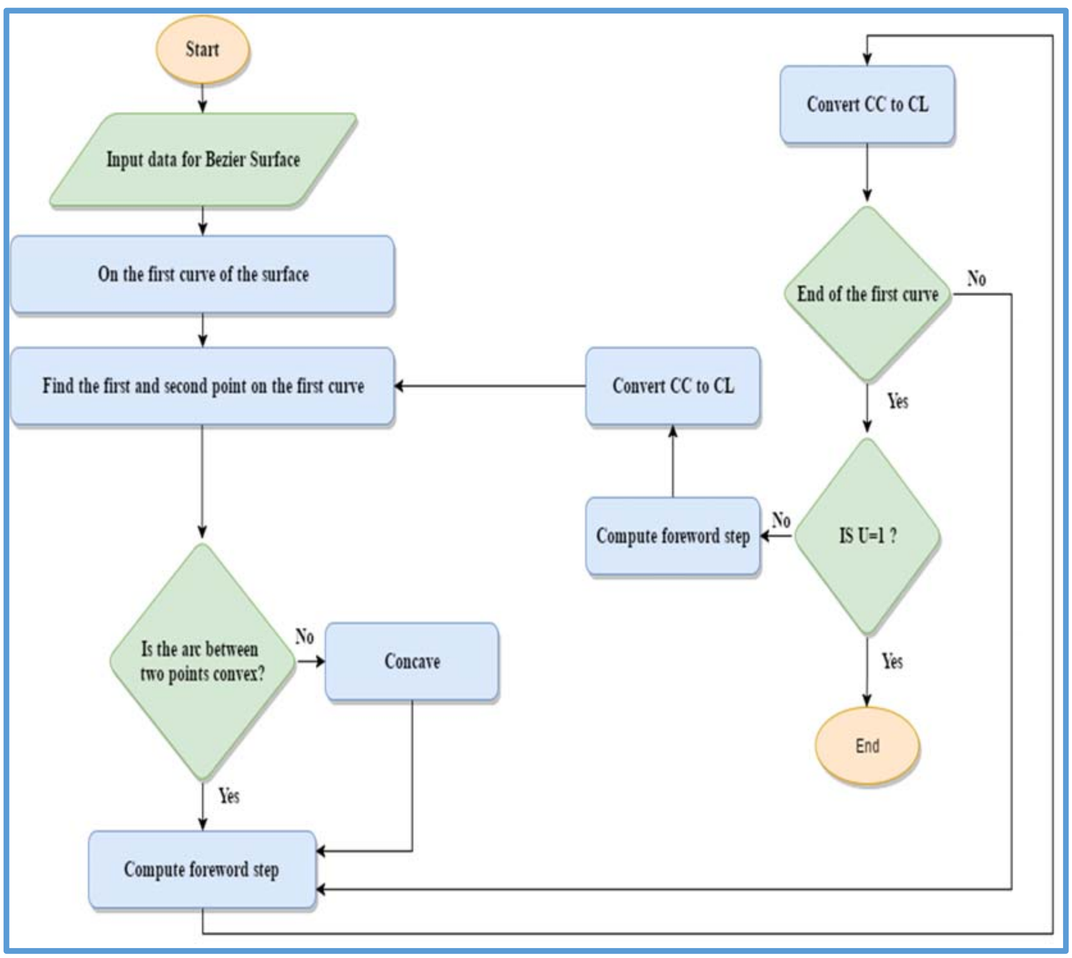


Figure 4.11: Tool path flow chart.

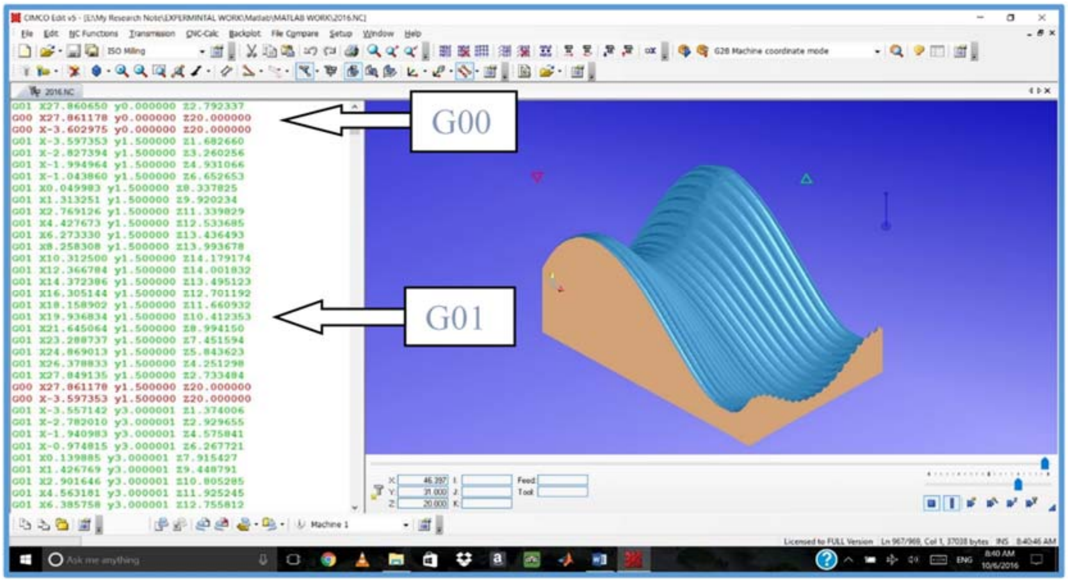


Figure 4.12: Main Screen of CIMCO edit V5.

4.4.2 UG-NX10 Method

This 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, rough and finish machining. Therefore, the first is to create tool path for rough machining. Several fundamentals are selected and identified in order to generate the tool path that are:

1. **Specifying operation type and method of machining** through setting mill-contour method with rough machining by cavity mill type, where the cutting takes the form of layers.
2. **Specifying tool type, geometry and diameter:** flat-end tool has been selected for roughing phase.
3. **Specifying side-step**, select tool diameter and change the Percent to 15 in roughing process and scallop height for finishing process.
4. **Specifying tool path strategy:** There are different options in which the tool can move.

For generating cavity tool path, the cutting conditions in cavity roughing for the model are illustrated in Table (4.1).

Table (4.1): The cutting conditions of cavity tough milling by UG-NX10 software.

Type of the tool	Ø10 flat end
Cut pattern	Follow Part
Stock Allowance	5 mm
Spindle speed	1000 r.p.m
Feed rate	750 mm/min
Side step or stopover	1.8 mm

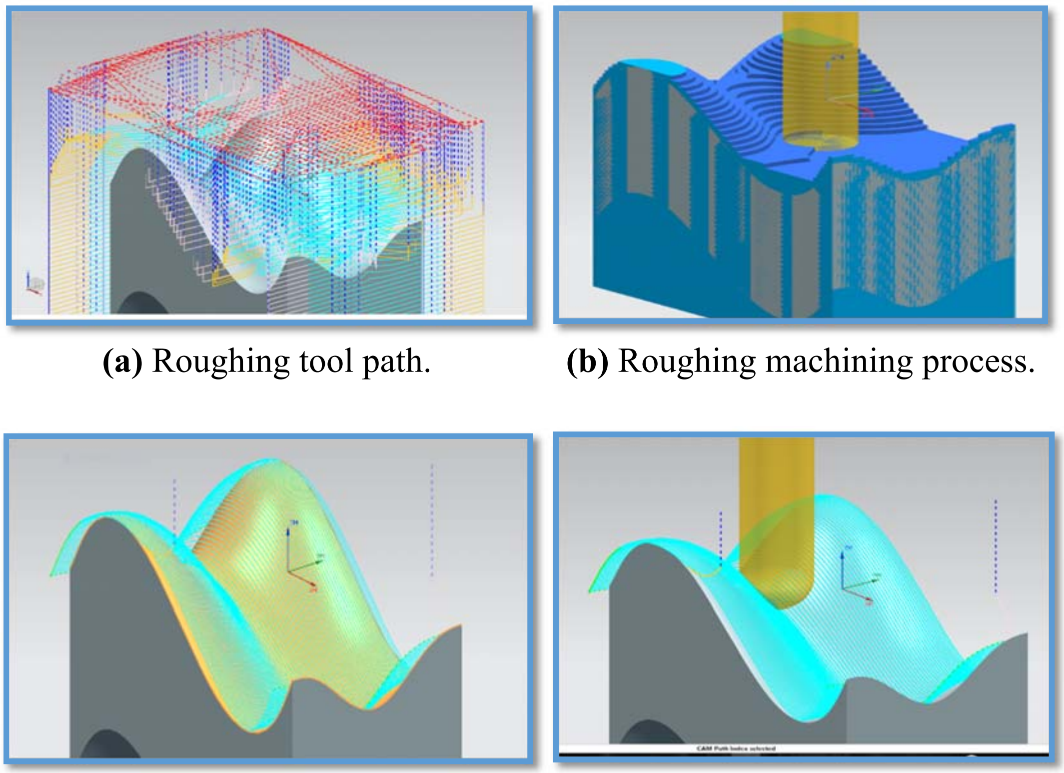
The cutting conditions for finishing tool path milling for the model are illustrated in Table (4.2).

Table (4.2): The cutting Conditions For Finishing Tool Path By UG-NX10 software.

Type of the tool	Ø10 ball end
Cut pattern	Zig zag
Forward step	1.4 mm
Spindle speed	1000 r.p.m
Feed rate	250 mm/min
Scallop high	0.01mm

The tool path generation for the model in UG-NX software can be shown in figure (4.13 a, b) and it illustrates the status of the part after rough machining using flat-end tool. After identifying machining parameters and selecting the required type of the tool path for rough machining, the software provides a simulation process to clarify the operation.

The second phase is the finishing process using ball-end tool (10 mm) in diameter. Cutting area has been performed according to the machining method and found that the side-step will be very small values as compared to the rough machining to achieve a smooth surface. Figure (4.13 c, d) shows the finishing process with a ball-end tool.



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

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

Figure (4.13): Tool path simulation by UG-NX.

4.4.3 Comparison between Methods of G-code Generation

After the completion of creating a program for each process, the G-code files were obtained for both operations using the post processing of the program. The tool path statistical for both methods can be shown in table (4.3); The following are the descriptions of each one:

1. The linear distance in MATLAB method for the roughing phase is longer than the roughing phase in UG-NX software because it is depended on a linear interpolation (G01) as explained in chapter two.

2. The arc distance in MATLAB method is zero because it is depended on a linear interpolation (G01) but in UG-NX method one can see in roughing phase the arc distance appeared because UG-NX use a circular interpolation (G02 and G03) for this phase.
3. Machining times for both methods is close to equality due to the tool path length of same cutting time and the rapid length diverges (small for this model).
4. Cutting time in MATLAB is less than UG-NX10 because the cutter path is connecting adjacent CL points by straight line segment due to linear segmentation of the curved path in the forward direction.
5. Number of steps of G-code in MATLAB method for roughing phase are greater than in UG-NX method for the same phase because the linear interpolation takes more steps to simulate arc shape.
6. Cutting time and Number of steps of G-code in MATLAB method for finishing phase are equal to UG-NX method for the same phase because there is no arc distance and both used linear interpolation.

Table(4.3): 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

4.5 The Implementation of Internet of Things

To implement the system, it need some steps starting from connecting sensors with master unit to build a node in machine. This node is connected to a cloud server via a wireless local area network. The data collected from the machine will stored in cloud server and this give the capability to reach and analysis the data from different devices or location. In the present work, it has been created a CNC monitoring system that allows to implement rules and identify patterns for CNC workshop development.

4.5.1 Sensor Unit Configuration

The most important step in IoT system is to make a unique identity for a device, to do that there are two main parameters in sensor unit need to be configured before can connecting it to a cloud server as shown in figure (4.13). At the beginning of the configuration on the readings, it 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 let to differentiate between the multiple readings/commands/configurations with similar meanings/names.
- *Value type:* Tells the cloud what type of value is being sent by this reading/command/configuration.

After that the model details are configured and the following information for the device model is entered:

- *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.

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

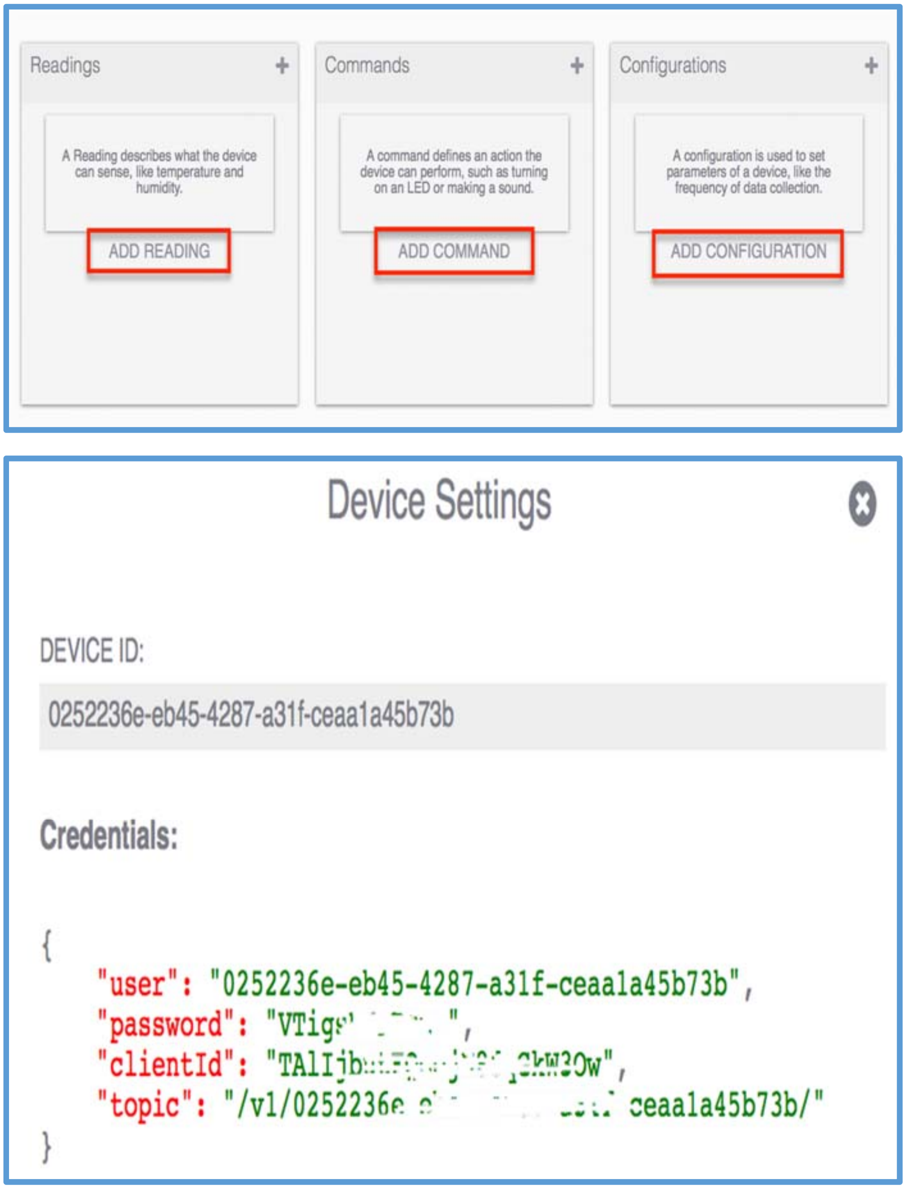


Figure (4.14): Device configurations.

4.5.2 Create Monitoring Rule

In this work two rules had been used. Rules are customizable events that trigger an action on a device when one or more conditions are met. A rule takes an input (a reading) from a device, and sends an output (a command) to another device in the cloud. For example, if want to trigger an alert when the temperature in a piece of equipment reaches a dangerous level, then can create a rule: when temperature from the equipment in question reaches too high of value, then a buzzer activates or a push notification is sent to someone who can take care of the problem. Currently the rules engine functions similarly to the web service IFTTT, which lets you define conditional statements that trigger actions among other web services you use.

1. **Machine tool temperature rule:** One of the important monitoring parameter in CNC machine is the machine tool temperature. A machine tool temperature alert has been created. This role was coded in JSON Schema. JSON Schema describes existing data format, clear for human and machine readable documentation. The code structure is shown in figure (4.15) and figure (4.16).

```
{
  "title": "Person",
  "type": "object",
  "properties": {
        "firstName": {"type": "string"},
        "lastName": {"type": "string"},
        "age": {
              "description": "Age in years",
              "type": "integer",
              "minimum": 0
        }
  }
```

Figure (4.15): Code structure for JSON.

After the device is created, the control step “Role” has been setup. This role gives an alert when temperature get higher than 100°, the alert can be sound or signal send to the device to do an action as shown in figure (4.17).

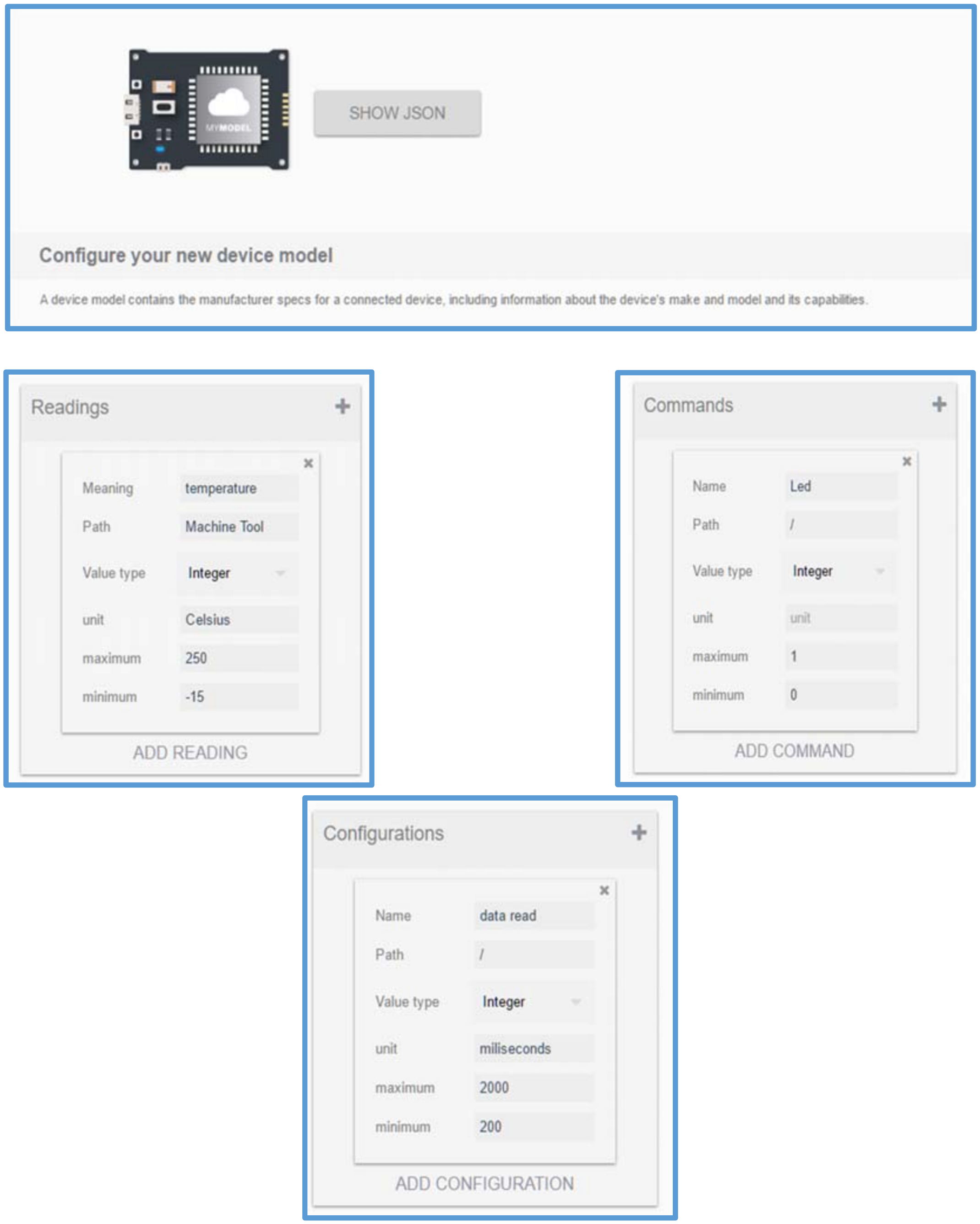


Figure (4.16): New device model configuration.

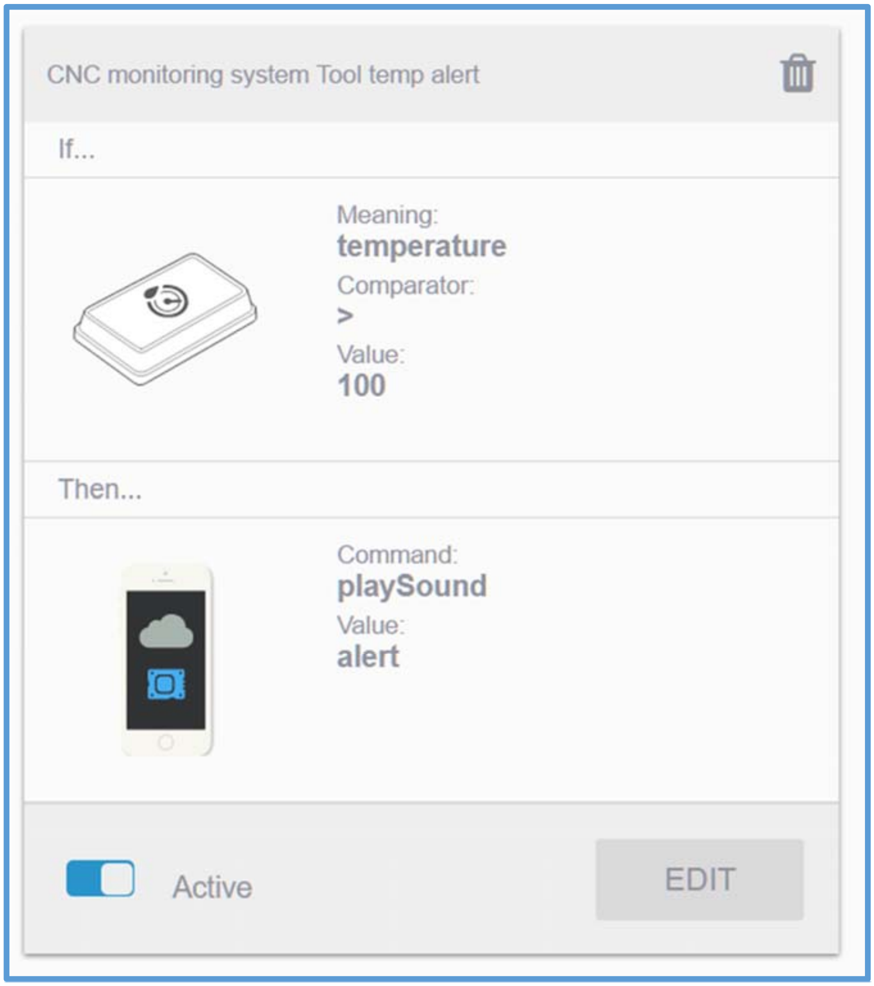


Figure (4.17): Machine tool temperature rule.

2. **Rapid movement in the Z-axis rule:** This rule is created for monitoring the movement of an axis or its location. In the present work, this role is named rapid movement in the Z-axis depended on the acceleration sensor as shown in figure (4.18).

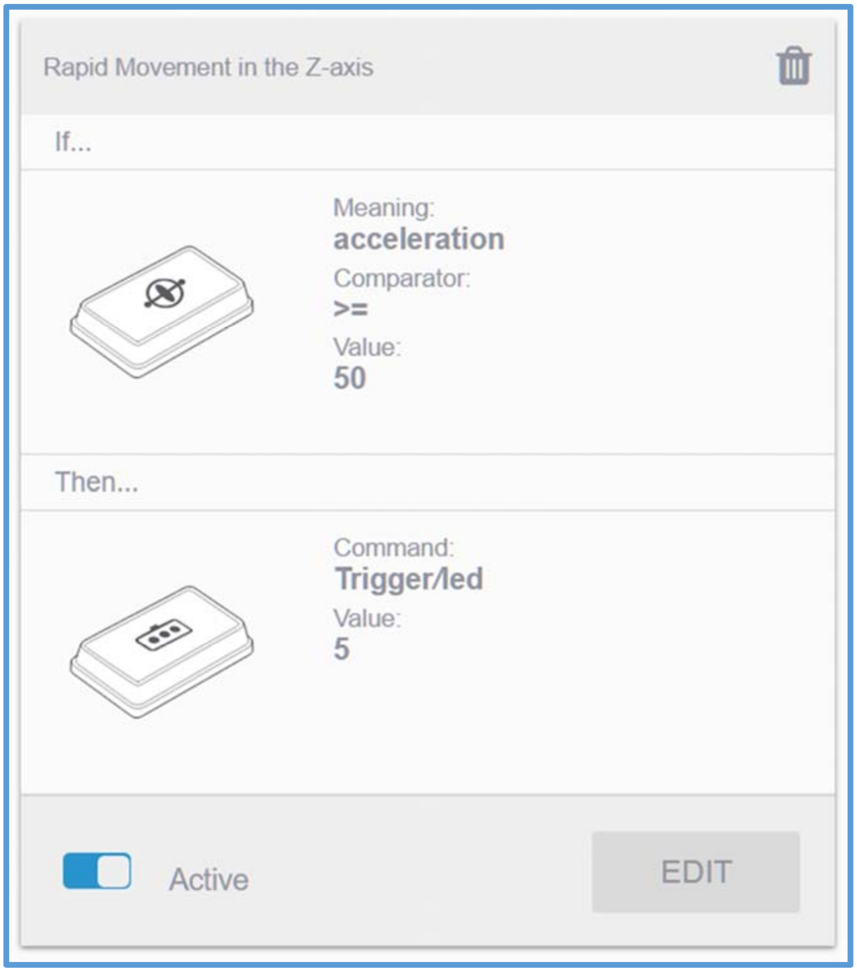
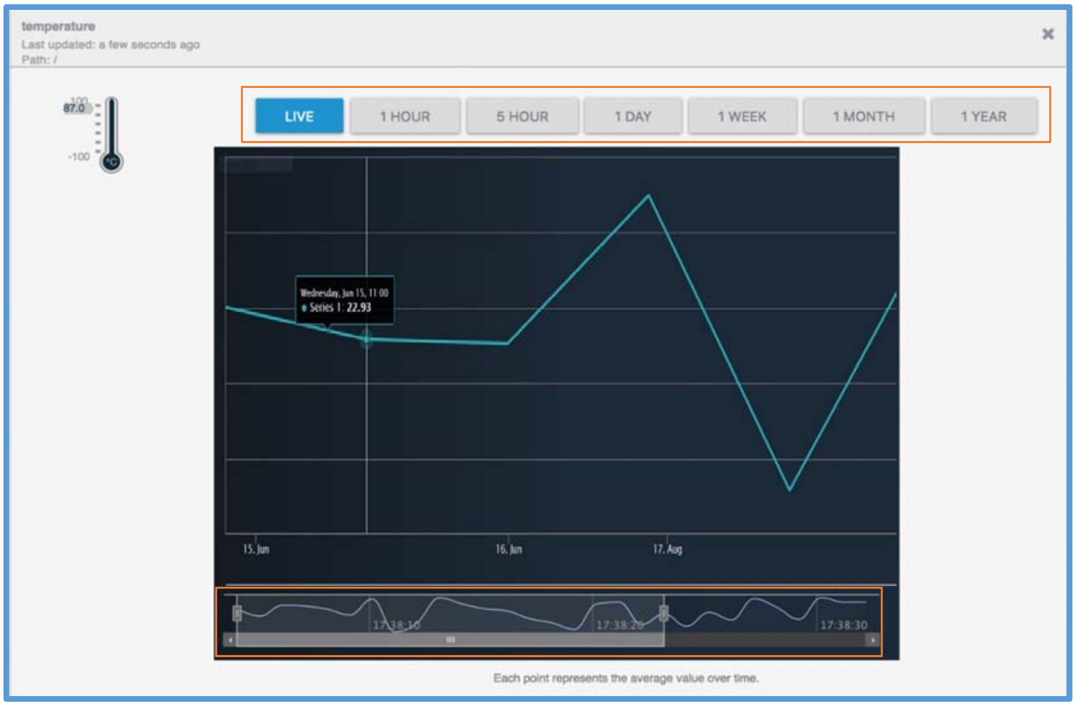


Figure (4.18): Rapid movement in the Z-axis rule.

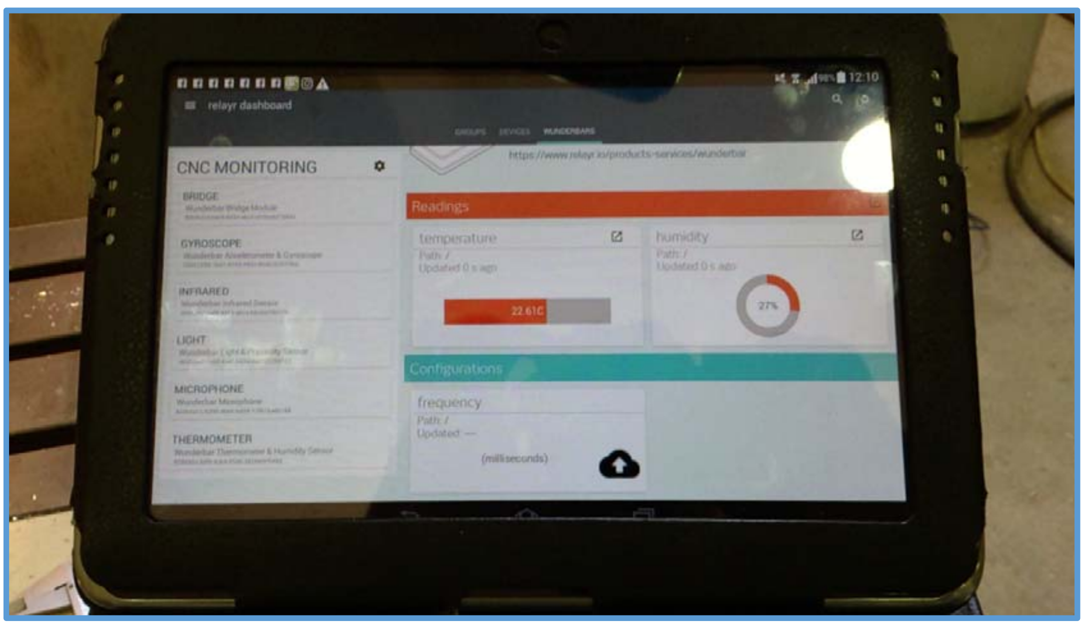
4.5.3 Visualizing Device Data

All data of CNC monitoring system can be visualizing from control panel. The data visualization interface displays data in a format based on the type of the value being read by the sensor. Some charts can display life data being read from the sensor, and some charts can only display data that has already been read at the time and chart was generated.

All readings, regardless of the type, can be visualized over a specific time interval, which can be chosen at the top of the chart area as shown in figure (4.19).



(a) Temperature chart for specific time.



(b) Thermometer reading displayed in Android Tablet.

Figure (4.19): Visualizing Device Data.

4.6 Transferring NC Program to CNC machine

In the present work a wireless system is used to upgrade the workshop machine to new technology level staring from transferring NC programs via Wi-Fi network and make a DNC communication between the host and CNC machines.

4.6.1 FTP Transfer Method

As explained in chapter three, the connection is wireless. The data is transferred form CAD/CAM Center to CNC machine using FTP protocol. In this method will transfer NC program from computer to CNC machine using a war-ftpd program. This method applied to C-tek KM-80D Vertical Machining Centers that exist in Training and workshop center university of technology. This type of machine has a low memory input issue (floppy disk). If a machining part has a large numbers of G-code lines, this lead to big size of data that must be transferred to machine using RS-232 port. The connection to the RS-232 port of a machine may be impossible for some computer, so a wireless communication is used, the NC program had transferred successfully as shown in figure (4.20).

Figure (4.20): C-tek KM-80D Vertical Machining display shows information about wireless file transfer.

4.6.2 DNC Transfer Method

A DNC communication system is created by using the designed method and a DNC software. In this method one can connect different machine types to a Central Computer. To implement this method, it need to connect every machine with a wireless system and setup it to connected with computer like laptop via Wi-Fi connection as shown in figure (4.21).

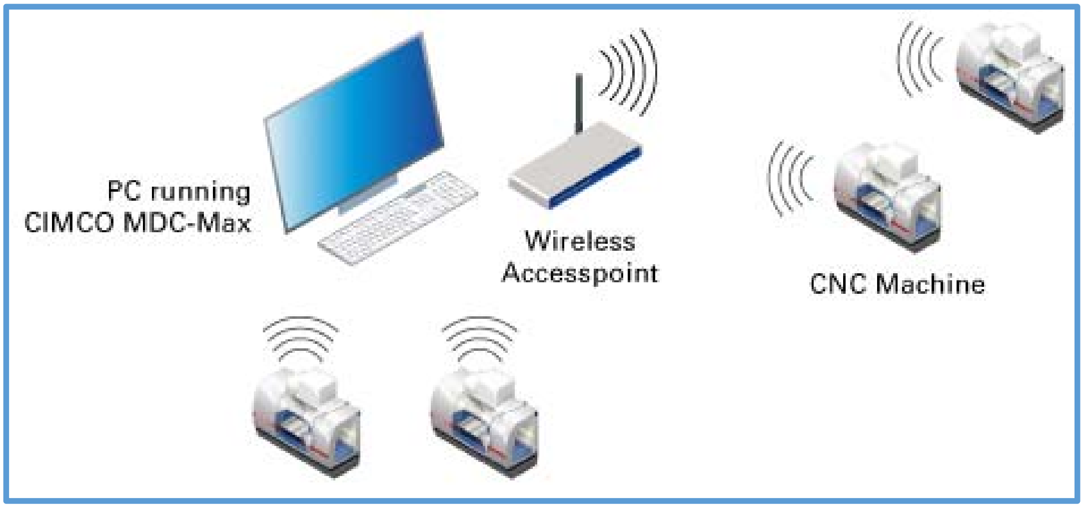


Figure (4.21): CIMCO DNC Network.

Here, HLK-RM04 module is used and setup by using a wireless serial device. At the beginning, the module is powered and one wait for the booting up system which take about 30-60 seconds. Setup CNC machine with an IP address for DNC network. The implementation steps are:

1. The Wi-Fi MAC address of the module is added to the workshop router. The Wi-Fi MAC address is the top on the module label while the second is for the Ethernet port.
2. From control panel of the Operating System (Windows) and networks settings; Connect to network button is clicked, then the "DNC_NETWORK" router network name is selected which is appeared in the network list.
3. The password of network is entered.
4. At this moment, it will be capable to use ping command to test the capability of the source computer to reach the router at address

(192.168.16.254). The Command Prompt command (CMD) terminal from the windows Start menu is selected then (ping 192.168.16.254) is typed.

5. In the search bar of web browser, (http://192.168.16.254/Serial2Net.asp) is typed and by clicking enter, a dialogue appears that request username and password, "admin/admin" is used for the user and password. At this time the default web interface is shown in the browser.

Install CIMCO DNC software on the laptop to create and setup DNC-Max Server V7 that made the laptop as a local server and addressed it with a local host IP. A connection with the machines is created using DNC-Max Client V7 as shown in figure (4.22) and figure (4.23).

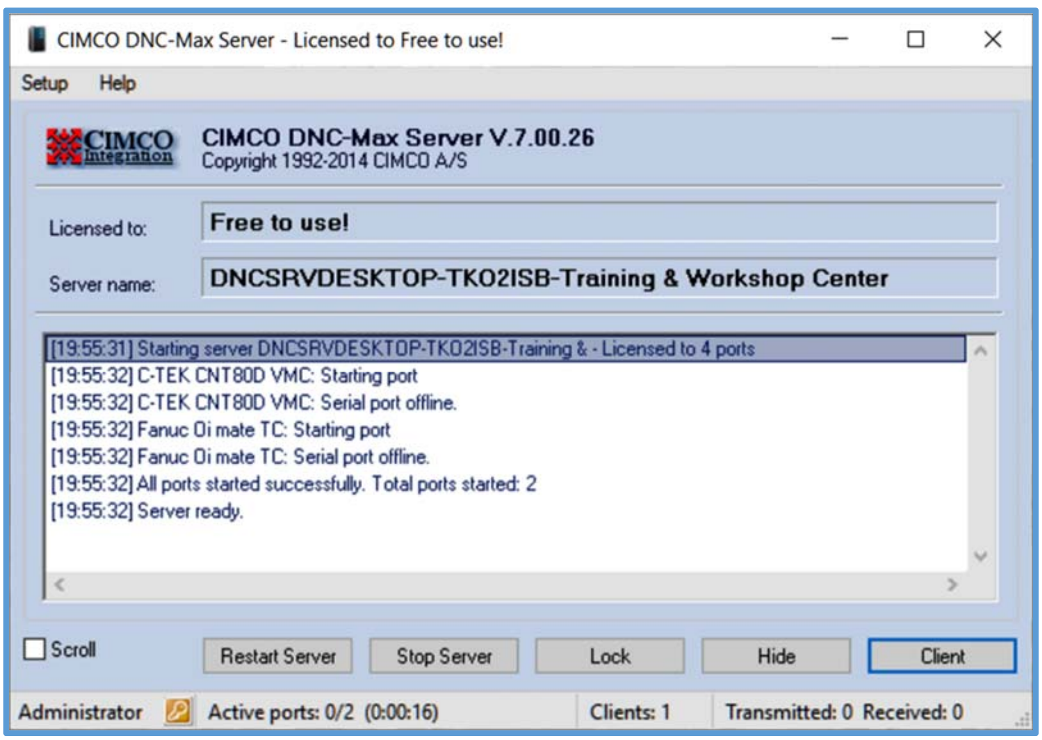


Figure (4.22): DNC-Max Server V7.

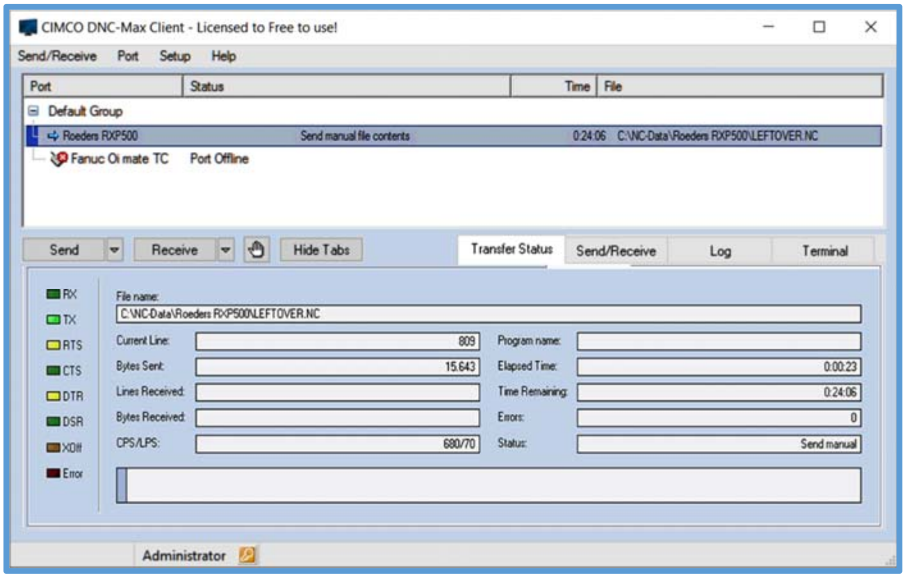


Figure (4.23): DNC-Max Client V7.

4.6.3 Analysis of Transferring NC Program

The DNC software with the help of the wireless system gives an information about the machine working time (online, offline), part machining time. The advantages of transfer G-code data via WLAN to CNC machine can be categorized as:

1. Remotely: Because it can connect directly via Wi-Fi, there is no need to direct handle it, provides long distance control to the 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 and create folder.
2. Send a message via the network: can send a message to the DNC device from software, the staff can receive and follow.
3. Security: It lock USB port or other ports and not allow retrieving data out, so when the operator control software try to run the file that transfer to the CNC machine, the staff will not know which is unable to copy files, so the information will be secured.
4. No wires, easy to connect, scalable network.

5. With the built-in report functions, one can easily display and visualize the data, in order to explore productivity information to evaluate the work. Real time report of CIMCO-MAX displays information about machine name, parts progress, time, operation condition as shown in figure (4.24). Table (4.4) show the time spent for transferring a MATLAB file and an UG-NX file.

Table (4.4): 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	39050	28975
Ethernet	100	43	32
Wi-Fi 802.11b	54	79	59
Wi-Fi 802.11n	150	28	21

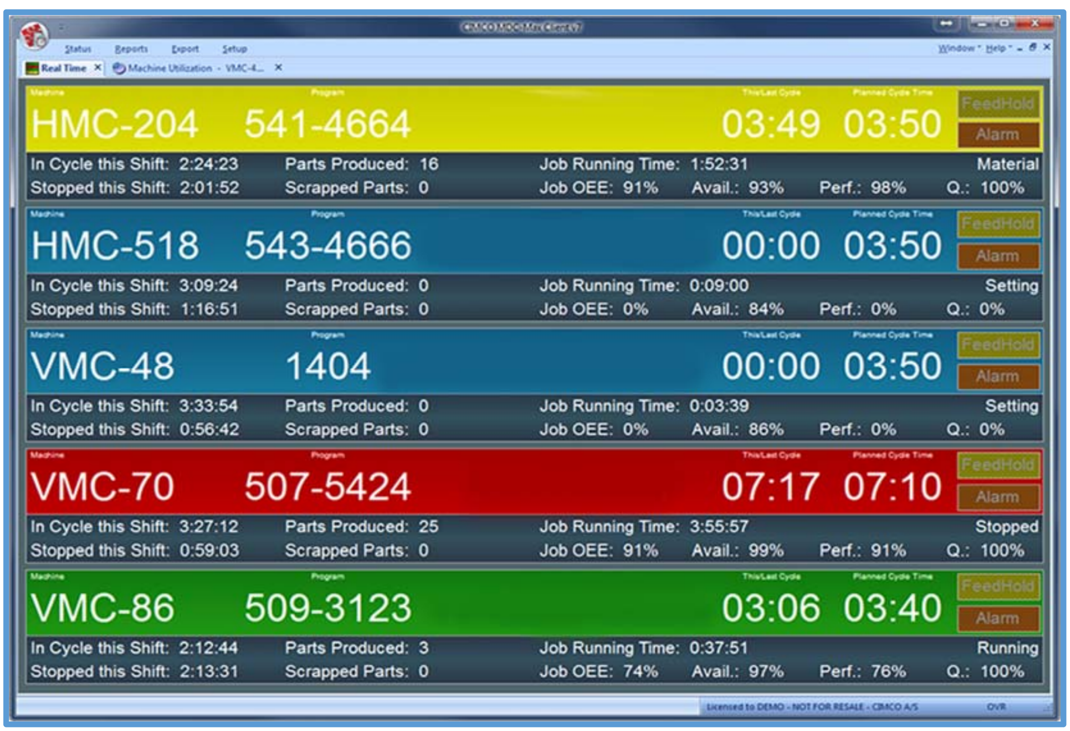


Figure (4.24): CIMCO-MAX: Real time report.

4.7 Machining Workpiece

The results of machining workpiece are:

1. Workpiece is machined according to MATLAB NC program with long line tool path extended from starting to the end of the workpiece based on the proposed algorithm using a linear interpolation (G01) as shown in figure (4.25).

Figure (4.25): Workpiece using MATLAB software.

2. Workpiece is machined using UG-NX10 NC program with zig zag cut pattern of the workpiece as shown in figure (4.26).

Figure (4.26): Workpiece using UG-NX10 software.

4.8 Measurement of the Machining Workpiece

Measuring the dimensional of the workpiece have been done in the Metal Cutting Laboratory, Department of Production Engineering and Metallurgy. The measuring machine is digitally controlled through three axes (X, Y, Z), so it is capable to measure the dimensional of the 3D models. At the beginning of the measurement, a clamping device is calibrated and fixed on the table of the milling machine to clamp the workpiece for measurement, then the measurement of the model is worked by moving the probe of indicator instrument on the surface of the model in a selected point to read and record the Cartesian coordinates of each selected point as shown in figure (4.27) and table (4.5). There is difference between the theoretical and practical error and the reason for that can be summarized as:

1. Surfaces dimensional are measured using digital Probe for both work pieces, Since the proposed surfaces in the present work designed with high curvature in some regions, it is difficult to fix the probe on the regions with high curvature or convex regions because the work piece material is (Aluminum alloy) which has a smooth surface. This smoothness aided a slipping to the probe over the machined surface especially over the convex regions. The error is increased in an elevated region more than others. So for this explanation and from the experimental work it is obvious that the measuring process has the large ratio of errors. This is because of using the probe instead of Coordinate Measuring Machine (CMM).
2. The design error has a little ratio because the surfaces are designed according to the mathematical basics and theories.
3. The machining error also has a little ratio. These errors came from the machine vibrations and the accuracy of the stepping movement of the axis.
4. The work piece produced from UG-NX and MATLAB are closest to the AutoCAD. This is because the tool path formed from proposed algorithm is generated by offsetting the (CC-points) of the surface and using the linear interpolation algorithm.

5. While there is a deviation between the machined proposed surface and the AutoCAD. It's clear that these deviations are acceptable for all the tested models.

Table (4.5): Dimensional Measurement

	AutoCAD			**UG-NX10 model**			**MATLAB model**		
No.	X-axis	Y-axis	Z-axis	X-axis	Y-axis	Z-axis	X-axis	Y-axis	Z-axis
1	11.210	0.000	10.230	11.210	0.000	10.620	11.210	0.000	10.860
2	11.220	12.180	0.380	11.220	12.180	0.880	11.220	12.180	0.380
3	40.880	15.620	-14.770	40.880	15.620	-14.000	40.875	15.620	-14.385
4	40.870	0.570	-10.220	40.870	0.570	-10.250	40.875	0.575	-10.230
5	40.870	28.210	-10.350	40.870	28.210	-10.830	40.875	28.210	-10.360
6	12.040	28.200	9.760	12.040	28.200	10.500	12.040	28.200	10.610

Figure (4.27): Workpiece dimensional measurement.

CHAPTER FIVE

CONCLUSION AND SUGGESTION FOR FUTURE WORK

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5.1 Conclusions

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

1. The transferring data of the proposed surface from MATLAB software to UG-NX10 have been achieved without distortion.
2. In roughing phase, MATLAB method has longer linear distance than UG-NX10 method. But the arc distance is verse versa. Whereas, in finishing phase both methods have approximately the same distance.
3. Using MATLAB present greater steps number of G-code and lower machining time as compared with that of using UG-NX10.
4. Creating DNC system by adding a wireless module, is leaded to Eliminate the use of cabling to each CNC machine, centralization, scalable network, reduced machine downtime for program transfer, machine data collection and analysis.
5. The dimensional measurement of the proposed surface models showed that, the machining models produced by UG-NX and MATLAB were closest to the AutoCAD model.
6. IoT for monitoring CNC machines provide:
    a. Automated production data recording and this lead to eliminate the paper work, helps in decision making & overview, improves 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.

5.2 Suggestions for Future Work

Further future work is needed as an extension and improvement to the work presented in this research:

1. Integrate sensors with actuators in CNC machine to move for new generation of automation systems in industry.
2. Integrate 3D laser scanner and wireless controller system to create Automate CAD/CAM system to produce a medical component like teeth or bones etc.
3. Use cloud computing for CAD/CAM software and integrate it directly in MCU of CNC machine to create Cloud Based Design and Manufacturing (CBDM).

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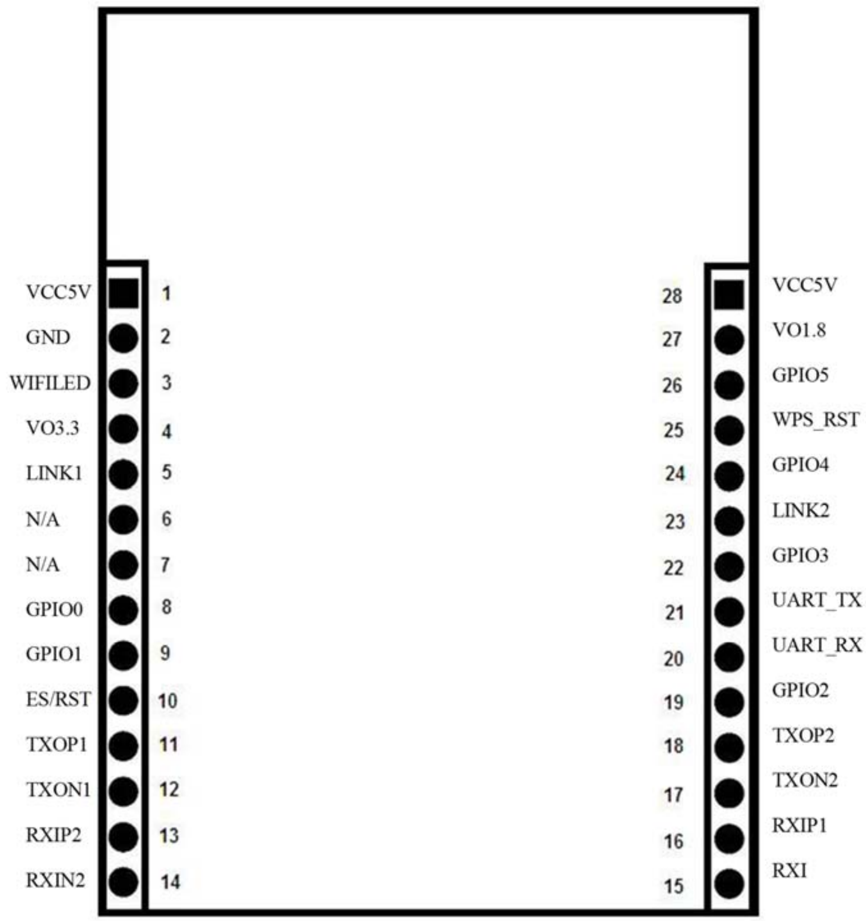
C-TEK CNC milling machine specifications.	
Table surface	305*1270mm
T- Slot (W*N)	18/3T
Table load capacity	400kg
Travels	
X travel	800mm
Y travel	500 mm
Z travel	500mm
Spindle center to column	530mm
Feed	
Rapid on X,Y&Z axis	10000mm/min
Motor	
Spindle motor	7.5HP
AC servo motor	1KW
Spindle	
Taper of spindle nose	BT40 or CAT40
Spindle speed	6000rpm
General	
Power required	12KVA
Net weight	2600kg
Gross weight	3000kg

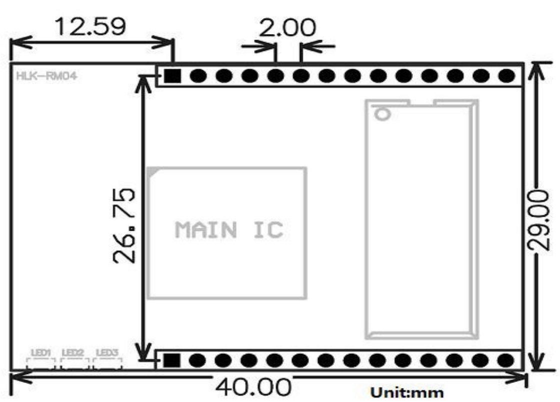
HLK-RM04 DataSheet

1. **Specifications:** The parameters are defined here. VDD=5.0V@ +25°C

Typical DC Characteristics		Notes
Only Wi-Fi current	140mA	Wi-Fi to serial AP mode or Client mode
One rj45 current	120mA	Serial to RJ45.
Two rj45 current	135mA	One is Wan anther is LAN
Wi-Fi and two rj45	160mA	Default Mode/Factory Mode
Centre frequency accuracy	+/-25ppm	Additional +/-15ppm allowance
Typical RF Characteristics		Notes
Receive sensitivity	-70dBm	Use Iq view to adjust
Maximum Transmit	18dBm/15dBm/13.5dBm	802.11b/g/n
RF Port impedance	50 ohm	2.4 - 2.5GHz
VSWR (max)	2:1	2.4 - 2.5GHz
Centre frequency accuracy	+/-25ppm	Additional +/-15ppm allowance
Peripherals		Notes
UART	2pins	1200-500kbps
RJ45(WAN)	4pins	Support pppoe
RJ45(LAN)	4pins	Support dhcp
3.3V Out	1pins	Support almost 300mA/3.3V
1.8V Out	1pins	Support almost 300mA/1.8V

2. Pin Configurations





3. Pin Assignment

Pin No	Signal Type	Description
1	VCC5V	Supply Voltage, 5V+/-10%
2	GND	Analogue Ground
3	WIFILED	WLAN Activity LED
4	VO3.3	3.3V Output (Support Almost 300mA)
5	LINK1	10/100 PHY Port #1 activity LED
6	N/A	Reserved
7	N/A	Reserved
8	GPIO0	General GPIO Reserved
9	GPIO1	General GPIO Reserved
10	ES/RST	Exit transparent transmission mode/Restore factory value
11	TXOP1	10/100 PHY Port #1 TXP
12	TXON1	10/100 PHY Port #1 TXN
13	RXIP2	10/100 PHY Port #2 TXP
14	RXIN2	10/100 PHY Port #2 TXN
15	RXIN1	10/100 PHY Port #1 RXN
16	RXIP1	10/100 PHY Port #1 RXP
17	TXON2	10/100 PHY Port #2 OXN
18	TXOP2	10/100 PHY Port #2 OXP
19	GPIO2	General GPIO Reserved
20	UART_RX	UART RXD.
21	UART_TX	UART TXD.
22	GPIO3	General GPIO Reserved
23	LINK2	10/100 PHY Port #2 activity LED
24	GPIO4	General GPIO Reserved
25	WPS/RST	Wi-Fi Protected Setup /Restore factory value
26	GPIO5	General GPIO Reserved
27	VO1.8	1.8V Output (Support Almost 300mA)
28	VCC5V	Supply Voltage, 5V+/-10%

MATLAB G-code for Roughing phase

```
%
N0010 G40 G17 G90 G70
N0020 G91 G28 Z0.0
N0030 T00 M06
N0040 G00 G90 X1.2649 Y.0302 S2000 M03
N0050 G43 Z.6031 H00
N0060 Z.3275
N0070 G01 X1.2763 Y.0716 Z.316 F35.4 M08
N0080 X1.2516 Y.1533 Z.2931
N0090 X1.2081 Y.1974 Z.2765
N0100 X1.1267 Y.2233 Z.2536
N0110 X1.0441 Y.2018 Z.2308
N0120 X.9857 Y.1395 Z.2079
N0130 X.9774 Y.1097 Z.1996
N0140 X.9594 Y.0485
N0150 X.9392 Y-.0119021733
```

```
N45044 X.3343 Y.0947 Z-.6429
N45046 X.2976 Y.0639 Z-.6557
N45048 X.2587 Y.0257
N45050 X.2258 Y-.0178
N45052 X.2684 Y-.0717
N45054 X.3208 Y-.116
N45056 X.381 Y-.149
N45058 X.4267 Y-.1145
N45060 X.4588 Y-.0671
N45062 X.4741 Y-.0119
N45064 X.4544 Y.0384
N45066 X.4228 Y.0822
N45068 X.3813 Y.1167
N45070 X.3377 Y.0932
N45072 X.2976 Y.0639
N45074 Z-.5376
N45076 G00 Z.6031
N45078 M02
%
```

MATLAB G-code for Finishing phase

```
%
N0010 G40 G17 G90 G70
N0020 G91 G28 Z0.0
N0030 T00 M06
N0040 G00 G90 X-.0948 Y-.6131 S2000 M03
N0050 G43 Z.8 H00
N0060 Z.2925
N0070 G01 X-.1201 Z.2634 F35.4 M08
N0080 X-.1507 Y-.6132 Z.2398
N0090 X-.1852 Y-.6133 Z.2226
N0100 X-.2224 Y-.6134 Z.2124
N0110 X-.2609 Z.2098
N0120 X-.2992 Y-.6135 Z.2146
N0130 X-.3358 Y-.6136 Z.2269
N0140 X-.3693 Y-.6137 Z.246
N0150 X-.4417 Y-.6139 Z.2975
N0160 X-.5142 Y-.614 Z.3394
N7017   G03 X42.632993 Z-3.190471
R19.733438
```

```
N1400 X.0178 Y.0005 Z-.4132
N1410 X.0177 Y-.0024 Z-.4139
N1420 X-.0796 Y-.0028 Z-.3428
N1430 X-.1769 Y-.0031 Z-.2713
N1440 X-.2742 Y-.0034 Z-.1997
N1450 X-.3715 Y-.0037 Z-.1367
N1460 X-.4017 Y-.0038 Z-.1126
N1470 X-.4266 Z-.0832
N1480 X-.4453 Y-.0039 Z-.0494
N1490 X-.457 Z-.0126
N1500 X-.4613 Z.0257
N1510 X-.4581 Z.0642
N1520 X-.4474 Z.1013
N1530 X-.4297 Z.1355
N1540 G00 Z.8
N1550 M02
%
```

UG-NX G-code for Roughing phase

```
N0010 G40 G17 G90 G70
N0020 G91 G28 Z0.0
N0030 T00 M06
N0040 G00 G90 X1.2663 Y.0126 S2000 M03
N0050 G43 Z.6031 H00
N0060 Z.3275
N0070 G01 X1.2722 Y.0919 Z.3062 F35.4 M08
N0080 X1.2342 Y.1627 Z.2849
N0090 X1.1657 Y.2046 Z.2635
N0100 X1.0854 Y.2063 Z.2422
N0110 X1.0152 Y.1673 Z.2209
N0120 X.9773 Y.0974 Z.1996
N0130 G02 X.9415 Y-.0166 I-1.7181 J.4768
N0140 X.9754 Y-.127 I-1.7084 J-.5838
N0150 G01 Z.3177
N0160 G00 Z.6031
N0170 X.9773 Y.0974
N0180 Z.3177
N0190 G01 Z.1996
N0200 G03 X.9733 Y.2353 I-.987 J.0403
```

```
N7290 G01 X.3798 Y-.1496 Z-.5374
N7300 X.4101 Y-.1336 Z-.5466
N7310 X.4678 Y-.0564 Z-.5724
N7320 X.4746 Y-.0228 Z-.5816
N7330 X.4697 Y.0118 Z-.591
N7340 X.4462 Y.0597 Z-.6052
N7350 X.4107 Y.0995 Z-.6195
N7360 X.3805 Y.117 Z-.6289
N7370 X.3374 Y.0981 Z-.6415
N7380 X.3323 Y.0949 Z-.6431
N7390 X.2963 Y.0646 Z-.6557
N7400 G03 X.2243 Y-.0186 I.2254 J-.2678
N7410 X.3798 Y-.1496 I.2893 J.1857
N7420 X.4746 Y-.0228 I-.0864 J.1633
N7430 X.3805 Y.117 I-.1908 J-.0268
N7440 X.2963 Y.0646 I.1413 J-.3203
N7450 G01 Z-.5376
N7460 G00 Z.6031
N7470 M02
%
```

UG-NX G-code for Finishing phase

```
%
N0010 G40 G17 G90 G70
N0020 G91 G28 Z0.0
N0030 T00 M06
N0040 G00 G90 X-.0948 Y-.6131 S2000 M03
N0050 G43 Z.6031 H00
N0060 Z.0957
N0070 G01 X-.1201 Z.0665 F35.4 M08
N0080 X-.1507 Y-.6132 Z.0429
N0090 X-.1852 Y-.6133 Z.0257
N0100 X-.2224 Y-.6134 Z.0156
N0110 X-.2609 Z.0129
N0120 X-.2992 Y-.6135 Z.0178
N0130 X-.3358 Y-.6136 Z.03
N0140 X-.3693 Y-.6137 Z.0492
N0150 X-.4417 Y-.6139 Z.1007
N0160 X-.5142 Y-.614 Z.1426
N0170 X-.5504 Y-.6141 Z.1598
N0180 X-.5866 Y-.6142 Z.1744
N0190 X-.6229 Y-.6143 Z.1864
```

```
N1380 X-.2568 Y.0014 Z-.4065
N1390 X-.1652 Y.0011 Z-.475
N1400 X.0178 Y.0005 Z-.61
N1410 X.0177 Y-.0024 Z-.6108
N1420 X-.0796 Y-.0028 Z-.5397
N1430 X-.1769 Y-.0031 Z-.4682
N1440 X-.2742 Y-.0034 Z-.3966
N1450 X-.3715 Y-.0037 Z-.3335
N1460 X-.4017 Y-.0038 Z-.3095
N1470 X-.4266 Z-.28
N1480 X-.4453 Y-.0039 Z-.2462
N1490 X-.457 Z-.2095
N1500 X-.4613 Z-.1711
N1510 X-.4581 Z-.1327
N1520 X-.4474 Z-.0956
N1530 X-.4297 Z-.0613
N1540 G00 Z.6031
N1550 M02
%
```

Crown tooth G-code

```
%
N100 (FILENAME: CrwonTooth.nc)
N102 G21
N104 M6 T1
N106 G0X0.0000Y0.0000Z2.5400
N108 G0X18.1425Y22.3329
N110 G1Z-1.9617F10.0
N112 G1F3000.0
N114 X17.2730Z-1.6333
N116 Y21.1151Z-1.9101
N118 X18.1425Y22.3329Z-1.9617
N120 X18.5012Y22.3190Z-2.1059
N122 X18.7755Y22.6329Z-2.1642
N124 X17.6940Z-1.7121
N126 X16.9730Z-1.4740
N128 Y20.0795Z-2.0562
N130 X17.2657Y20.5886Z-2.0237
N132 X17.8834Y21.4538Z-2.0389
N134 X18.5012Y22.3190Z-2.1059
N136 X18.7271Y22.1216Z-2.2342
N138 X19.4359Y22.9329Z-2.3869
N140 X17.8571Z-1.7191
N142 X16.6730Z-1.3418
N144 Y21.7380Z-1.5885
N146 Y18.9498Z-2.2531
N148 X17.5099Y20.4144Z-2.1332
N150 X17.9968Y21.0973Z-2.1421
N152 X18.7271Y22.1216Z-2.2342
N154 X18.9531Y21.9242Z-2.3412
N156 X20.0964Y23.2329Z-2.5808
N158 X19.3517Z-2.3118
N160 X17.8623Z-1.6608
N162 X17.1177Z-1.4028
N164 X16.3730Z-1.2427
N166 Y21.6365Z-1.5448
N168 Y17.6456Z-2.4835
N170 X16.7265Y18.4380Z-2.3730
N172 X17.7543Y20.2404Z-2.2384
N174 X18.7133Y21.5875Z-2.3045
N176 X18.9531Y21.9242Z-2.3412
N178 X19.1790Y21.7269Z-2.4484
N180 X20.5031Y23.2425Z-2.7062
N182 X20.8127Y23.5329Z-2.7810
```

```
N84680 X18.7560Z-24.3893
N84682 X18.5869Z-24.1948
N84684 X18.5489Z-24.1644
N84686 X18.1177Z-23.9499
N84688 X17.9486Z-23.8817
N84690 X17.5935Z-23.7012
N84692 X17.4413Z-23.6611
N84694 X16.9847Z-23.5670
N84696 X16.8410Z-23.5583
N84698 X16.2914Z-23.4983
N84700 X15.9363Z-23.4369
N84702 X15.7503Z-23.4422
N84704 X15.4798Z-23.4178
N84706 X15.2261Z-23.4344
N84708 X14.3976Z-23.5616
N84710 X14.1270Z-23.6119
N84712 X13.7212Z-23.7706
N84714 X13.4379Z-24.0520
N84716 X13.4295Z-29.0280
N84718 X8.1749
N84720 X8.4749Y41.7730
N84722 X14.2486
N84724 X14.2529Z-24.4314
N84726 X14.2952Z-24.3629
N84728 X14.5407Z-24.0441
N84730 X14.6381Z-24.0102
N84732 X14.8074Z-23.9705
N84734 X14.9767Z-23.9570
N84736 X15.4000Z-23.8651
N84738 X15.5524Z-23.8550
N84740 X15.6201Z-23.8616
N84742 X16.1111Z-23.9816
N84744 X16.3778Z-24.1172
N84746 X16.5641Z-24.1352
N84748 X16.5725Z-24.1417
N84750 X16.5768Z-24.3967
N84752 X16.7165Z-24.3059
N84754 X16.7715Z-24.2885
N84756 X17.2117Z-24.3395
N84758 X17.2286Z-24.3479
N84760 X17.2329Z-29.0280
N84762 X32.8568
N84764 G0Z2.5400
N84766 (END)
N84768 (OF PROGRAM)
```

الخلاصة

في هذا العمل تم تصميم وتنفيذ وحدة تحكم لاسلكية لمكائن التحكم العددي بواسطة الحاسوب بناءً على نظام إنترنت الأشياء. وقد تم تجربة واختبار دراسة حالة للتعبير عن المراحل الكاملة من نظام كاد / كام، بدءاً من توليد سطح حر باستخدام تقنية بيزير من الدرجة السادسة في متغيرين بارامتريين. وتم توليد مسار العدة واستخراج G-code للسطح المقترح باستخدام برنامج الماتلاب و UG-NX10 . يستخدم الماتلاب شفرة الاستكمال الداخلي الخطي (G01)، بينما يستخدم UG-NX10 تقنية الاستكمال الدائري (G02) و(G03) .وباستخدام برامج التحكم العددي المباشر مع مساعدة من وحدات Wi-Fi المضمنة ونظام إنترنت الأشياء لنقل البيانات G-code عبر شبكة محلية لاسلكية إلى مكائن التحكم العددي بواسطة الحاسوب عن طريق RS-232 و RJ-45 و التي تم استخدامها مع مكائن التحكم العددي بواسطة الحاسوب في الجامعة التكنولوجية / مركز التدريب والمعامل.

أظهرت النتائج أن ملف الماتلاب لديه وقت نقل أسرع من ملف UG-NX10 وقد تم توفير عدد من أوامر التحكم لمراقبة لمكائن التحكم العددي بواسطة الحاسوب. كل نوع من أوامر التحكم المنفذة تمت من خلال نظام إنترنت الأشياء وذلك من أجل جمع وتحليل البيانات من مكائن أو المواقع متنوعة. مسار العدة لبرنامج الماتلاب يمتلك مسافة خطية اطول، مسافة مقوسة اقل، أكبر عدد من الخطوات وأقل وقت بالقطع مقارنة مع استخدام برنامج UG-NX10 . تم قياس الأبعاد لنماذج المنتجة بواسطة الطرق اعلاه باستخدام مجس رقمي ثلاثي الابعاد. ومن خلال القياس تبين أن النماذج التي يتم إنتاجها باستخدام G-code من UG-NX10 و الماتلاب هي الأقرب إلى نموذج أوتوكاد.

جُمْهُورِيَّةُ العِرَاقِ
وِزَارَةُ التَّعْلِيمِ العَالِي وَالبَحْثِ العِلْمِيِّ
الجَامِعَةُ التِّكْنُولُوجِيَّةُ

تَطْبِيقَاتُ المكائن المُبَرْمَجَةُ بِنَاءً عَلَى نِظَامِ أنترنيت الأَشْيَاءُ

رِسَالَةٌ تَقَدَّمَ بِهَا المُهَنْدِسُ الأَقْدَمُ

سيف الدين سعد عبيس الكاظم

إِلَى قِسْمِ هَنْدَسَةِ الكهروميكانيكية - الجَامِعَةُ التِّكْنُولُوجِيَّةُ
وَهِيَ جُزْءٌ مِنْ مُتَطَلَّبَاتِ نَيْلِ دَرَجَةِ المَاجِسْتِيرِ
فِي عُلُومِ هَنْدَسَةِ النُّظُمِ الكهروميكانيكية

بِأَشْرَافِ

الأستاذ المساعد الدكتور
أبتسام رحيم كريخي

الأستاذ المساعد الدكتور
فرج محل محمد

١٤٣٨ هـ

٢٠١٧م