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A Micro-Controller Web Based Design for 3D Intelligent Multi Axis Printer

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Abstract: - The main objective of the paper is to propose a new design for microcontroller web based 3D printer. In particular, the aim is to design a board which holds these parts, Arduino , Raspberry Pi microcontrollers and power electronics. The technology of the Fused Diffusion Modelling (FDM) will be applied in the design .The newly proposed system will be used to improve the current design and solve overheating problems that present in these devices. A flexible3D printer design is proposed in this paper to provide the user with a real control and video monitoring through a browser from anywhere. The Implementations based on having a reduced size computer Raspberry Pi which could replace a PC and printer server integrated in printer case with all benefits generated such as the Mobility. So, by adding such helpful features, the 3D printer will deliver more flexibility in use to the end user and it pretends to do it at more affordable pricing to bring this new technology to a larger number of users and to everyday uses.

Keywords: Fused Deposition Modelling (FDM), Pulse Width Modulation (PWM), Computer-Aided Design (CAD), STL (Stereo Lithography), SLS (Selective Laser Sintering).

1- Introduction

Recent Human History has been affected by the technology more than any other field, and that made our lives better in many ways and opened up new avenues and possibilities.

Nowadays 3D printer becomes one of the loveliest and friendly robot machines to deliver the needs of ability to print complex 3D objects that are difficult or expensive to be obtained by traditional means and bring them to life using microcontroller and power electronics [1]. 3D printing uses range from practical objects for everyday use to commercial products and parts used in manufacturing. A user-friendly interface is not overly complex, but instead is straightforward, providing quick access to common features [2-7]. In this paper a newly proposed system design will be introduced to give a quick access to common features and to lead to the best practice

2-Review of Literature

2.1 Background

The first 3D printing attempts are granted to Dr. Kodama for his development of a rapid prototyping technique in 1980. He was the first to describe a layer by layer approach for manufacturing, creating an ancestor for Stereo Lithography (SLA) in which a photosensitive resin was polymerized by an UV light [8,9].

Four years later, a French team of engineers was interested by the stereo lithography but abandoned due to a lack of business perspective.

In that time, Charles Hull was also interested in the technology and deposited a first patent for Stereo Lithography (SLA) in 1986 [8,9].

In 1988, Carl Deckard at the University of Texas, brought a patent for another 3D printing technique in which powder grains are fused together locally by laser using the Selective Laser Sintering (SLS) technology

In the meantime, Scott Crump, a co-founder of Stratus's Inc. filed a patent for Fused Deposition Modeling (FDM) over less than ten years, the three main technologies of 3D printing were patented and 3D printing was born.

In Europe, first EOS "Stereos" system for industrial prototyping and the 3D production applications was founded and created by the EOS GmbH .

In 1992, the Fused Deposition Modeling patent was issued to Stratus's, who developed many 3D printers for both professional and individuals [7].

From 1993 to 1999, the main actors of the 3D printing sector emerged with various techniques:

ZCorp and binder jetting: Based on MIT's inkjet printing technology, they created the Z402, which produced models using starch- and plaster based powder materials and a water based liquid binder Arcam MCP technology and Selective Laser Melting [3] .At the same time, CAD tools for 3D printing became more and more available and developed.

Starting from year 2010 the desktop technology invaded the market and made the industrial sector rethink about additive manufacturing as a reliable production technique [5].Figure 1 shows a model for the previous system 3D printer.

Figure 2. 3D Previous system printer

2.2Current Alternative Systems

2.2.1 Prusa i3 3D Printer

Prusa i3 (i3 stands for third iteration of the design) as shown in figure 2 is the latest design. There are countless variations of the design and it became a staple of 3D printing of thousands units worldwide.

Its open functional design allows for quick maintenance. This makes i3 great workhorse 3D printer for business [2].

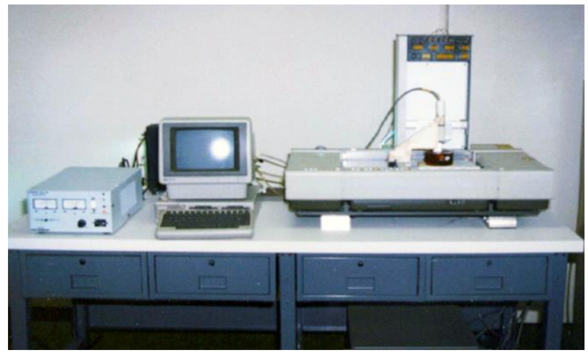

Figure 1. Current alternative system

The disadvantages of this printer:

- Using USB Connectivity only
- Only one Extruder Head

2.2.2 MakerBot 3D Printer

This printer is the 5th iteration of MakerBot's Replicator machine. It is one of the best designed, user-friendly 3D printers we've ever encountered [2].

The disadvantages of this printer:

- No heated platform
- Connectivity only using USB
- Noise Level

2.2.3 Ultimaker 3D Printer

The Ultimaker as shown in figure 3 is a multifunctional Dutch 3D printer. It is equipped with a heated platform and can print at a resolution of up to 20 microns [2].

The Advantages of this printer :

- Precision
- Ease of use
- Speed

Disadvantages of this printer:

- No dual extruder
- Connectivity only using USB port
- Price

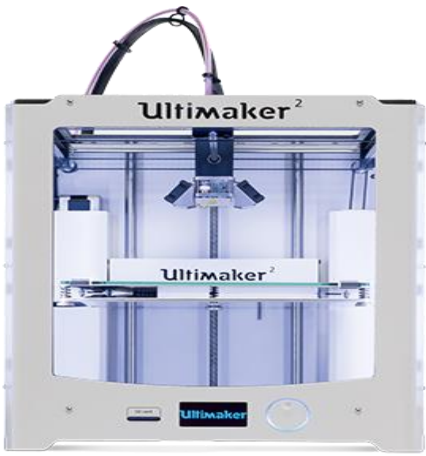

Figure 3. Ultimaker 3D Printer

3. The Newly Proposed System

As briefly mentioned above, the FDM system is used to form a piece by melting a thermoplastic material, which builds up layers for the solid creation.

In brief, the steps of the printing process are:

1. Obtaining the material (thermoplastic filament) from a coil.
2. Heating the material in the extruder.
3. Solidifying the material on a Surface/base.
4. Three dimensional movements in order to be able to reproduce an object [1,6].

So, the newly proposed system is used to enhance the logic of 3D printers by adding more features to control and monitor the printer remotely by using the powerful platform microcontroller. The Raspberry pi is connected to the internet via hosting site to overcome the static IP Address issue so that it can be reached through the web site. Also by using a friendly web interface it will be easy to reach the best practice of the designed prototype system to control, monitor the printing process, save the live data to be reference and to analyze the errors if exist, So an action could be taken until the printer is reached physically. Figure 4 shows the main block diagram of the proposed system.

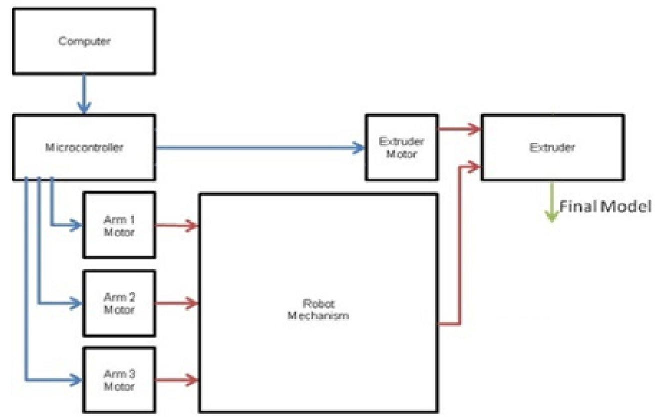

Figure 4. Block diagram of the proposed system

3.1 Hardware Description

3.1.1 1MKS Board

MKS Gen V1.4 as shown in figure 5 is made by a Chinese manufacturer Maker base. MKS (Maker base) are manufacturers of 3D Printer controller.

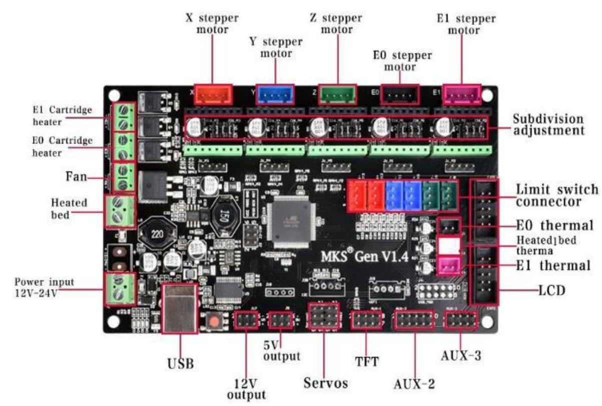

Figure 5. MKS Board

Figure 6. MKS LCD Screen

The board supports Stepper Drivers up to 1/16 micro steps such as A4988, DRV8825 and TMC2100 drivers. The MKS Gen 1.4 comes with limited connections for the 3D printer's extruder fans, board cooling fans and part cooling fans. .It also supports many Smart Controllers and Touch Screens as shown in Fig 6.

The power Metal Oxide Semiconductor Field Effect Transistors (MOSFETS) are electronic components that allows to control high currents. This has three output terminals that are called: Drain, Source and Gate (D, S ,G). The main current passes between Drain and Source (IDS) while the control of this current is obtained by applying a voltage on the Gate terminal (relative to the Source terminal), known as VGS. Minimum voltage is required to start driving a MOSFET. This definition is called "threshold voltage" or Vth.

The main problem about the MOSFETS circuits is that it overheats and ends up hurting. A power MOSFET (N-channel) which is controlled by a Pulse Width Modulation (PWM) signal is used in the proposed system .The PWM as shown in figure 7 allows variable control over the current flowing through the circuit, allowing modifying the heat delivering, and consequently the temperature.

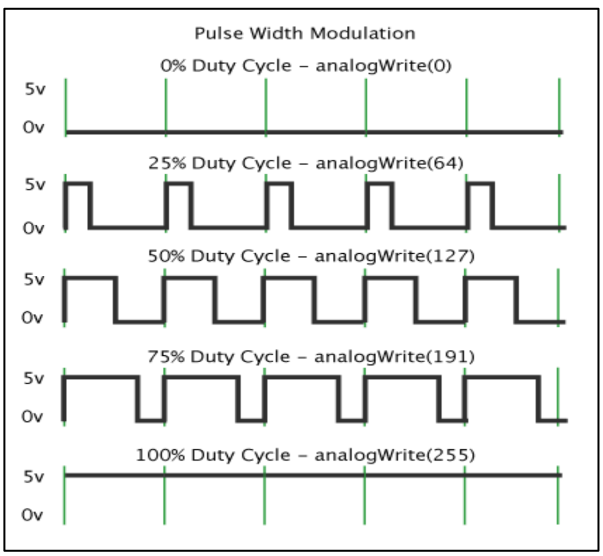

Figure7. PWM Circuit diagram

As shown in figure 8 the Signal resistance (R2) is situated at the Gate terminal and its value allows the MOSFET dissipates in greater or lesser extent, and consequently more or less heat.

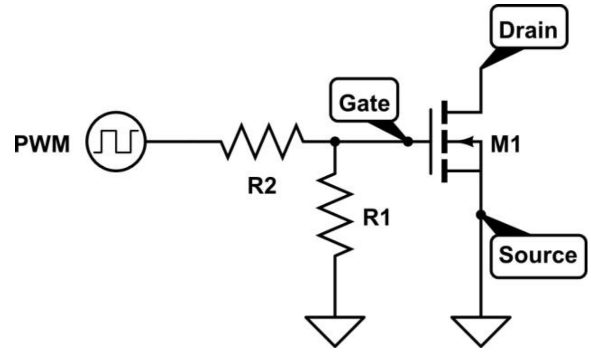

Figure 8. Limit Switch Circiut Diagram

3.1.2 Stepper Motor

The stepper motor is an electromechanical device that converts electrical impulses from a microcontroller to discrete angular displacements.

This type of motor consists of a rotor with permanent magnets and a number of coils on the stator. There are different types of stepper motors. In the proposed design the bipolar stepper will be used, which has two windings inside.

Bipolar motors have 4 output wires; these correspond to the outputs and the inputs of two separate windings. To control the motor, it is necessary to reverse polarity of each of the coils in the proper sequence

A stepper motor always has a fixed number of steps. Micro stepping is a way of increasing the number of steps by sending a sine/cosine waveform to the coils inside the stepper motor. In most cases, micro stepping allows stepper motors to run smoother and more accurately. Figure 9 shows the structure of the stepper motor

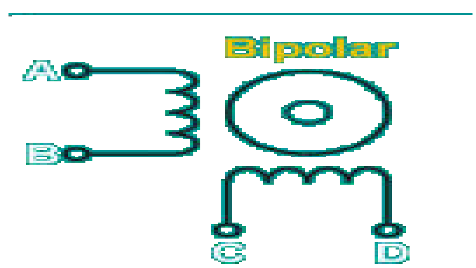

Figure 9.Structure of Stepper Motor

Stepper motors do not offer as much torque or holding force as comparable to DC servo motors or DC gear motors. The advantage over these motors is the positional control. Whereas DC motors require a closed loop feedback mechanism, as well as support circuitry to drive them, a stepper motor has positional control by its nature of rotation via fractional increments.

3.1.3. Motor Driver

For the control of stepper motor it is required a driver. The most used control drive is Allegro A4988 breakout board, which allows intensity up to 2A per coil, and could be adjusted by a potentiometer as shown in figure 10.

It also allows micro-stepping 5: full-step, half step, quarter-step, eighth-step and sixteenth-step.

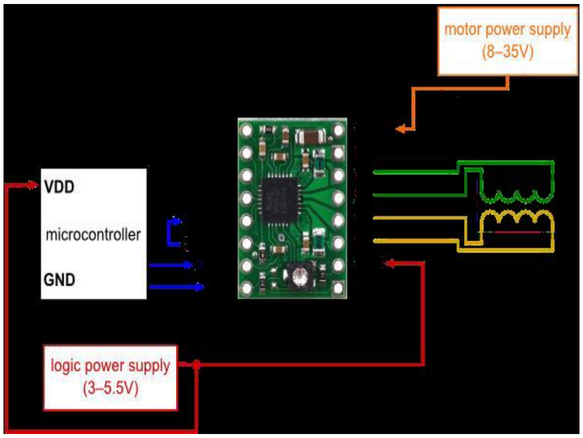

Figure 10. Motor Driver

3.1.4 End Stop Limit Switches

The other essential parts of the 3D printer are the End Stop limit switches.The control of three End-Stops is necessary to determine position of the Coordinate origin. The used End-Stop are a mechanical ones, because they are simpler and more affordable than others (optical Switches). This is an electromechanical device such as image, and it functions as a switch, has two states corresponding to logic HIGH and LOW level (5V and 0V). Figure 11 and Figure 12 show the Limit Switch and its circuitry respectively.

Figure11. Limit Switch

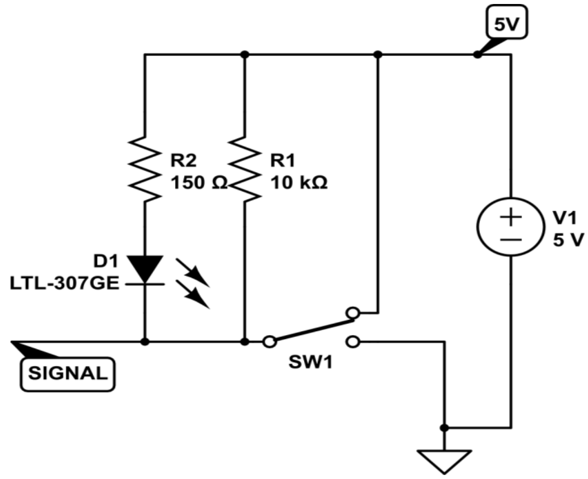

Figure 12. Limit Switch Circiut Diagram

Value	Open	Close
SIGNAL	5 V	0V
I diode	0 A	19.10mA
V diode	0 V	2.135V
I pull-up	0 A	500 µA

Figure 13. limit Switch Values

Figure 13 shows the difference in the results of the values when the switch is open and when closed. If the circuit is open the signal has a high (HIGH) and therefore the LED (zero intensity) is not illuminated, and on the other hand, if the circuit is closed the value it provides is low (LOW) and the led will be illuminated with an intensity close to the nominal.

3.1.5 Arduino Mega (Used in Testing Phase]

The board layout for the 3D printer is based on Arduino. Arduino captures information from the environment through sensors, which allow getting information in order to process, execute or perform the actions that are planned for use.

As shown in Figure 14 the platform has an IDE (Integrated Development Environment) that allows Arduino programming using the programming language C + +. The hardware consists of two main components; a microprocessor Atmel with input readings from sensors such as a temperature and output to run or modify the actuators as motors or led, and USB-Serial converter, which converts a communication protocol to another, thereby facilitating the programming of the microprocessor, and consequently its use.

Figure 14. Arduino Mega

3.1.6 Relay

Figure 15 shows the relay module. This relay module board consists of 1 relay which is connected to a current buffer so, it could be connected directly to a Microcontroller or Arduino. By using this relay it will be easily to control high power devices. The relay is rated for a maximum 250VAC/110VDC

The relay Features:

- 1 Channel I/O
- Digital type
- Indication LED for Relay status

Figure 15. Relay Module

3.1.7 Extruder

The extruder is composed of:

- 1 x 100K Semitic NTC thermistor
- 12v 40W Heater Cartridge
- 1 x 12v 30x30x10mm Fan
- 1 x High temperature fiberglass Wire - for Thermistor (150mm)
- Nozzle
- Hot end

When the filament is in the heating area, a heater block melts the filament, and then the heated filament is forced out to the nozzle at smaller diameter.

This process takes place at the extruder, which has the following areas as shown in figure 16:

- Heating area: The material fuses on the nozzle part which is (part 5) heated and where the extruded material melts.
- Temperature control zone (part7) where is situated a temperature sensor.
- Cooling area: It allows the extruder not to obstruct or block the nozzle.

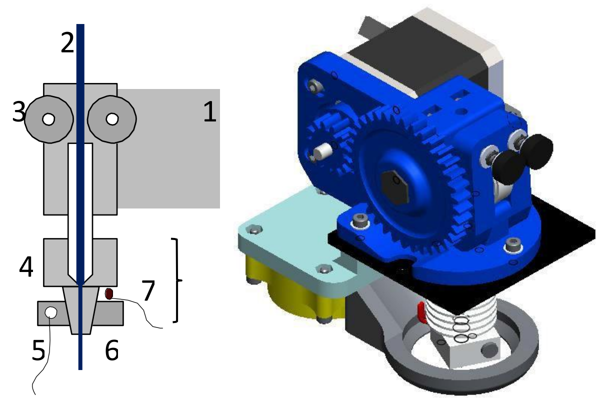

Figure 16. Extruder

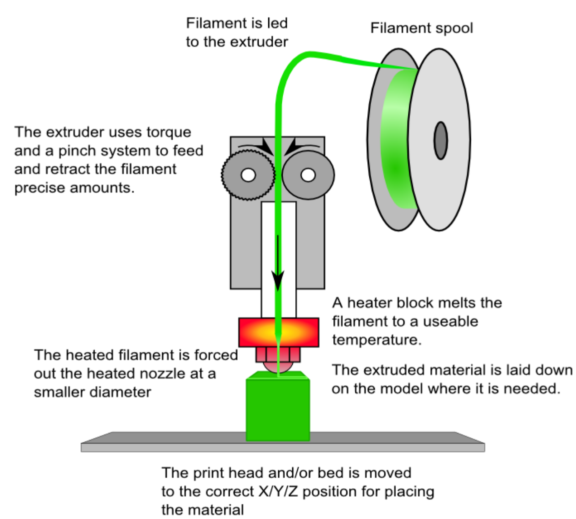

Figure17. Extrusion Process

These electronic components are essential for printing process. Each one has a function:

- The thermistor is a transducer that enables the measurement of temperature of the extruder. With this piece, it is possible to control the heating process.

- The heater cartridge is used to transform electricity into calorific energy to perform the extrusion process.
- The fan allows cooling a part of the extruder and to avoid the obstruction. Figure 17 shows the extrusion process

3.1.8 Thermistor

The thermistors are sensors , their operations are based on the variation of the resistance of semiconductor.

There are two types of thermistors:

- The NTC (Negative Temperature Coefficient) thermistors are nonlinear resistor in which the resistance decreases according to the temperature.
- The thermistors PTC (Positive Temperature Coefficient) resistors are increasing their resistance versus temperature.

There is a relationship between the resistance of the temperature and ambient catching.

$$R_R = R_o e^{\beta\left(\frac{1}{T_s} - \frac{1}{T_0}\right)}$$

Where:

- R_R is the resistance in ohms at the absolute temperature of the environment.
- R_0 is the resistance at the reference temperature T_0.
- β is the constant that appears in a moderate temperature range and depends on the material.

Figure 18 shows the relation between the thermistor resiststance versus temperature

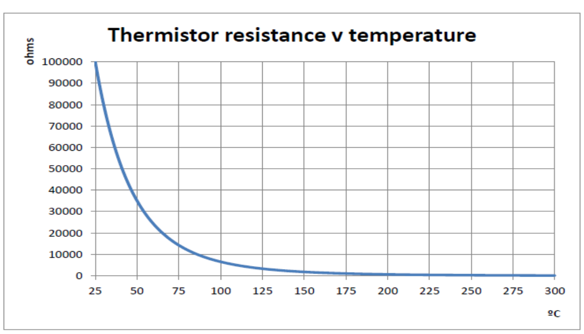

Figure 18. Resistance Versus Temperature

3.2 Printer Motion

Printer movements are those that carry out printing process. For performing this process, the movements of the printer are produced by Cartesian coordinates. This coordinates have three axes (X, Y and Z), which perform the movements necessary for the 3-dimensional object. These movements are generated by stepper motors, which in turn, are controlled by a microcontroller that sends electrical signals to the motors. Figure 19 shows the motion axes

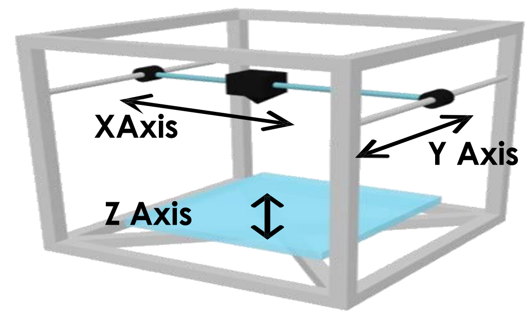

Figure19. Motion Axes

3.2.1 Belts

Belts move things. The X and Y motors have sprockets that drive the belts. Figure 20 shows the belt used in the proposed system

Figure 20. Belt

3.2.2 Lead Screws

These are usually used on the printer's Z-axis. They rotate, thus forcing nuts to move up and down as shown in figure 21.

Figure 21. Lead screw

3.3 Other Components

There are other components like connection jumpers, power supply, Heat shrink, Printed Circuit board (PCB), and Aluminum plate as shown in figure 22.

Figure 22. Other components

3.4 Software Description

3.4.1 Microcontroller Firmware (Marlin)

The firmware was used for organizing the communication between the Microcontroller and the components of the machine.

The firmware should be customized with the final specs of the machine so, the Arduino Mega board can lead the process efficiently. .It delivers outstanding print quality while keeping full control of the process.

3.4.2 Cura Software

As shown in figure 23, Cura is a Software program that prepares files for printing by converting any model into G-CODE, and also allows controlling the operation of 3D printer.

STL (Stereo Lithography) is a file format native to the stereo lithography CAD software created by 3D Systems. While usually the whole GCode generation process is called 'slicing', the Slicer in the Cura Engine is the piece of code that generates layers. Each layer contains closed 2D polygons. These polygons are generated in 2 steps process. First all triangles are cut into lines per layer, for each layer a "line segment" is added to that layer. Next all these line-segments are connected to each other to make Polygons.

Figure 23.Cura Software

As every printer has a different setup, print area, build plate and nozzle size, the Cura slicing software needs to know these hardware details in a printer profile. Once it has the required details, so it will be easy to specify the settings like layer height and thickness. Cura will calculate the path the print head needs to take in order to print the model and produce a list of instructions for the printer. These instructions are saved in that G-Code file.

The G-Code can then be saved to SD card or either be sent to the printer over wireless or through direct cable. Figure 24 shows the Cura setting.

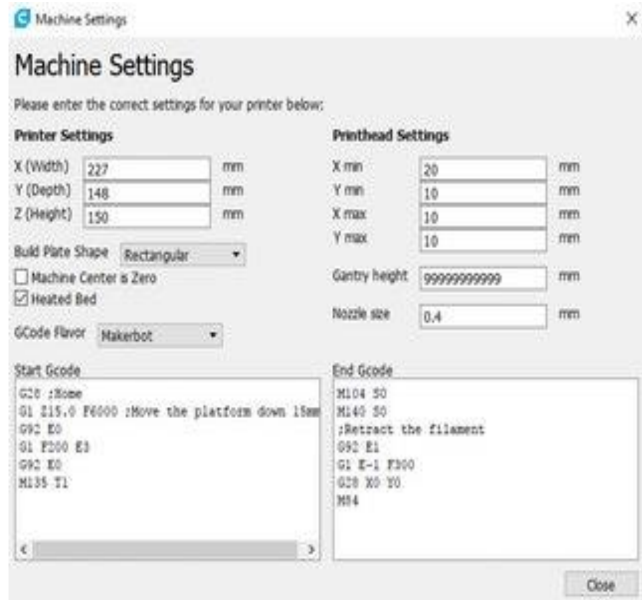

Figure 24. Cura setting

3.4.3 Hosting Server

The computer where website files are stored assigns a Domain Name server address (DNS) so, it can be reached on the Internet by typing in the domain name as it plays the role of the static IP Address in an indirect way .Upon that the communication will be established with the host name which directs the data in bi directional way to the IP latched to the Raspberry pi as it is connected to a router by enabling the port forwarding feature. In computer networking, port forwarding or port mapping is an application of Network Address Translation (NAT) that redirects a communication request from one address and port number combination to another while the packets are traversing a network gateway, such as a router or firewall. Figure 25 shows the static and dynamic ip addressing.

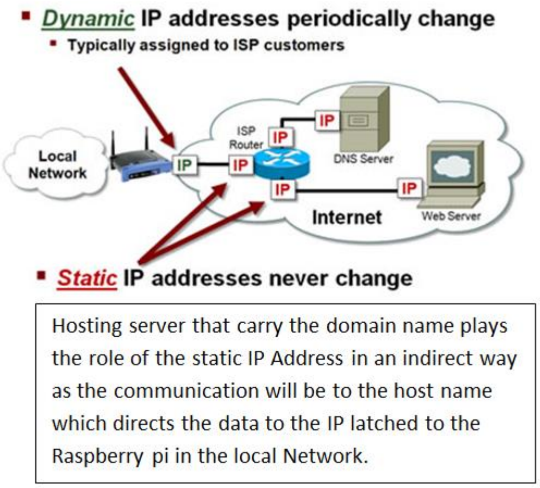

Figure 25. Static and dynamic IP

After making the web PHP code and saving the received data , it will be publicized on a local host server (free hosting sites) which will complete the URL needed to communicate with the proposed system .The host will be integrated with octopi software to have a complete control and monitoring over the 3D printer remotely. Figure 26 shows a snapshot for the server domain page.

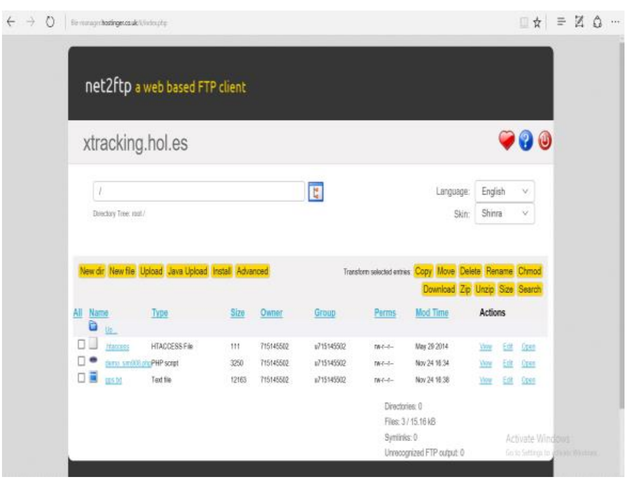

Figure 26 .Server Domain Page

A hostname is used instead of the IP address whenever we need to connect to a service at any location. Hostnames take the form of hostname.domain.com. This means they are the same as names used in URLs to surf the web.

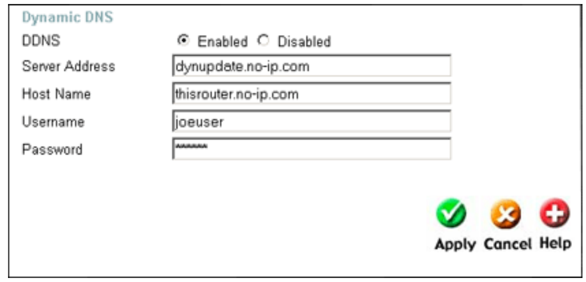

Figure 27. DDNS Setting

To run a web server, it is necessary to connect to the server using a web browser, add (http://hostname.domain.com) in the address bar. Figure 27 shows a snapshot for the Dynamic Domain Name Server (DDNS) setting.

To configure the host name the following steps should be taken:

• First fill in the Hostname box with a name of your choice.

• Choose the Host Type. The default choice, DNS Host A, is usually the correct one.. If your ISP blocks Port 80 for example, and you're trying to run a web server or other service on port 80, then you can choose Port 80 Redirect (at that point you'll be asked to specify the port to use for the redirection). If you're not running a web server, then do not choose this option as it will likely prevent you from connecting properly. Figure 28 shows a snapshot for the Host name configuration.

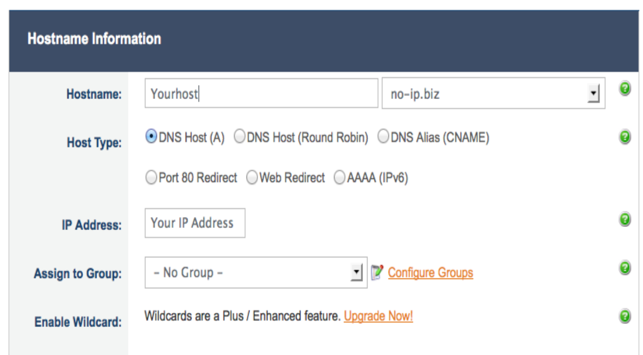

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Figure 28. Host name configuration

3.4.4 Octopi

Octopi Software as shown in figure 29 is Full remote control and monitoring software .It Controls and monitors every aspect of the 3D printer. It is also responsible for the following functions:

- Access the embedded webcam used to feed and watch remotely.
- Gets constant feedback regarding the current progress of the print job?

- Take a look at the integrated GCODE visualizer to see a rendition of the GCODE that is currently printing.
- Keep an eye on the temperatures of your hot ends and print bed and adapt them on the fly.
- Move the print head along all axes, extrude, retract or just define your own custom controls.
- Start, stop or just pause the current print job.
- Unzip the image and install the contained .img file to an SD card like any other Raspberry Pi image.
- Configure the WiFi connection

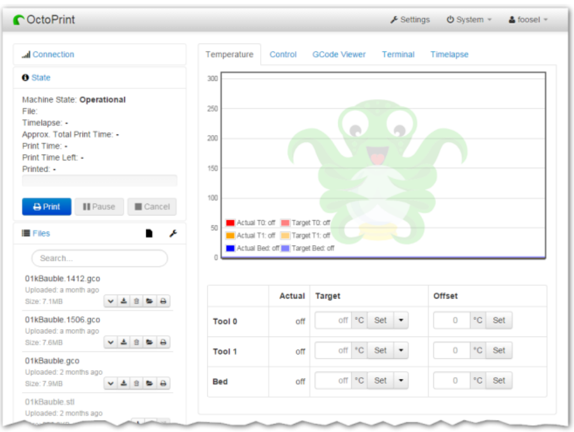

Figure 29. Snapshot for Octopi Software Home Page

4. System Flow Chart

Figure 30 shows the generic flow chart for the newly proposed 3D printer model. The flow chart in Figure 31 indicates the steps of the printing process. At starting the system will check the status of the sensor to show up the zero points for axis, and then it will prepare for printing by heating both the bed and the nozzle. After that the printer is ready for printing and performing the uploaded G-Code to finalize the 3D object.

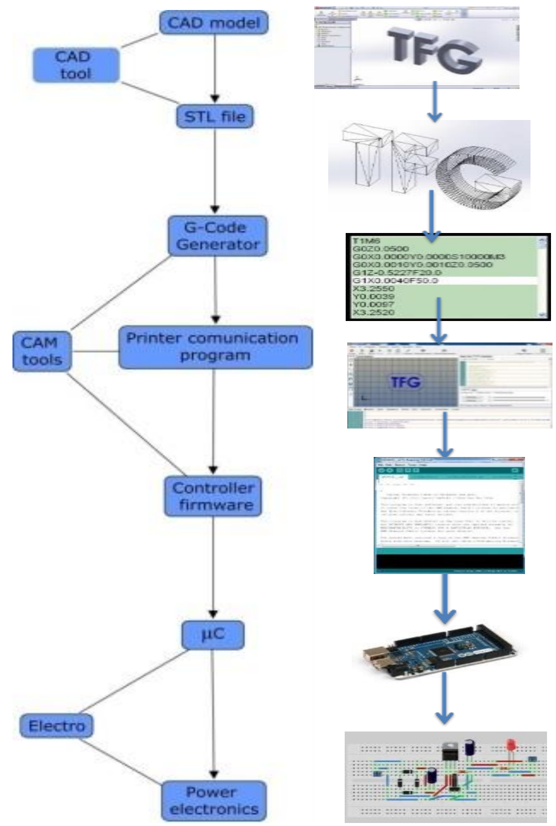

Figure 30. Generic System Flow Chart

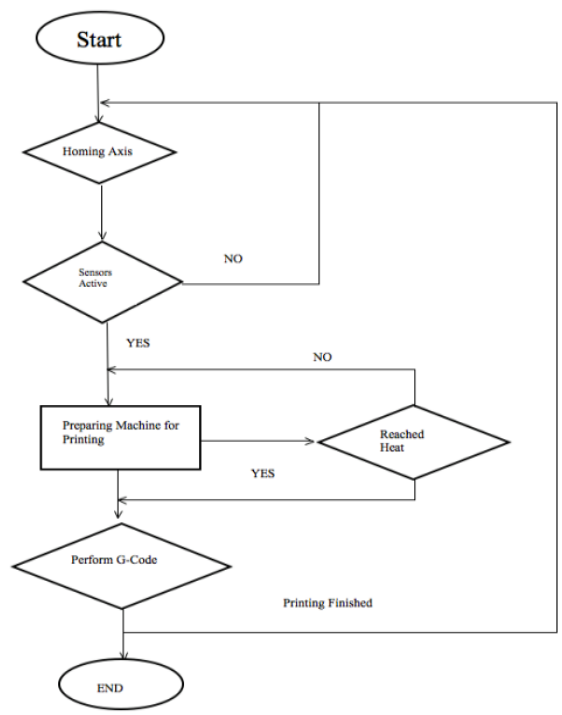

Figure 31. Printing Process

5. System Testing and Results

After performing the testing steps of the basic function of the 3D printer and adapting errors and problems, a stable design had been reached.

Many test scenarios had been performed till the final stage of the printing is reached. The printing is based on remotely using octopi software installed on the raspberry pi connected to the MKS board to act as a server computer linked to the hosting server to enable remote connectivity through internet. Figure 32 shows the snapshot for real printing process of the proposed model

Figure 32. Printing process of the proposed Model

Figure 33 shows snapshots for Octopi Temperature control and monitoring and figure 34 shows the snapshots for the printing and remote monitoring.

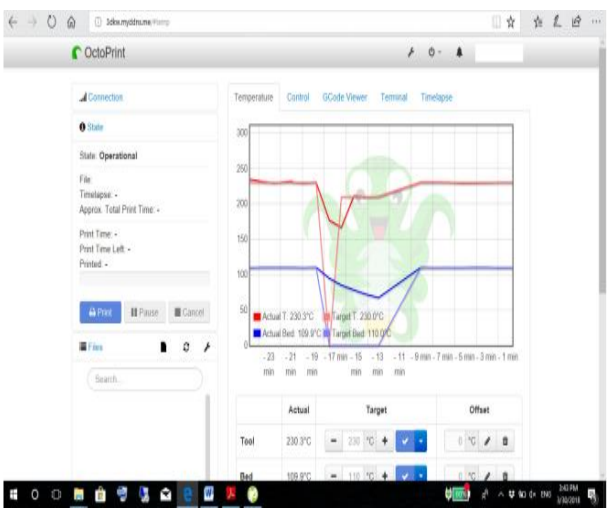

Figure 33. Octopi Temperature control and monitoring

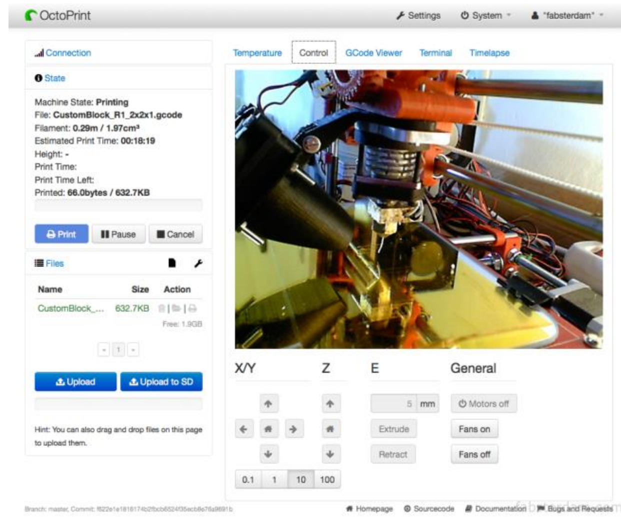

Figure 34 .Printing and remote Monitoring

6. Cost analyses

Table 1 shows the economic study for the newly proposed system .The table shows the itemized cost with total cost of 900$ per system.

Table 1: Cost Analysis

ITEM	COST ($)
RaspberryPi	70
1 - 15mm Aluminum plate	14
Filament Extruder Feeder	6
Nema 17 Motors and Driver Gear	90
Kapton Tape	9
Hot end	2
Relay 10A	7
Extruder	36
rubber heatbed	36
End-Stop Switches	2*3
Camera	31
Linear Ball Bearing Support 10mm	3
Ballscrew with Fitted Anti Backlash Ballnut	39
Motor coupling Bore Size: 8mm to 6mm	3
Precision ground round shaft with support (10 mm) rod hard chrome	6
4M Timing Belt	6
Pulley	5
Wires, cables, tubs, connectors, plugs	17
Fans	5
12V power supply 15A	7
motor drivers	8
turbo blower	2
tensions "packet"	1

memory cards	25
MKS Board	101
Flexible cable	8
Wood and cutting	168
Glass sheet	50
Corners and plastic stands	20
Arduino	8
Ramps	10
Lcd Screen	34
TOTAL	900

7. Conclusion and Future Work

There are many different 3D printing techniques. The best known techniques are: Selective Laser Sintering (SLS), Stereo Lithography (SLA), and Fused Deposition Modeling (FDM). The SLS technique is based on repeatedly dosing a layer of powder on a powder bed and the product is created by putting the laser on a selection of the powder bed. SLA is based on curing resin using a UV-laser, creating a product layer after layer. FDM is the most popular contemporary technology to create products. The FDM technique is based on the extrusion. By means of a print head, a molten layer of plastic is deposited on the print bed, which then adheres. Once the first layer has been drawn, the print bed drops and a new layer is built on the previous layer.

This process is repeated several times, ultimately resulting in a 3D printed model. The reasons behind choosing FDM is the lower cost and the user friendliness of this technique. Compared to other techniques, FDM is much cheaper. The powder that is used in SLS and the liquid for SLA are very costly for example. In contrast, for the material that is used in FDM technology, the filament costs are much lower. For this reason FDM technology is more attractive to many companies. Because the range of filaments is extensive, companies can switch materials easily and economically. Companies can also choose to simultaneously print a multitude of materials. This makes printing of complex models is possible Also, printing with multitude of colors is possible. Future plan will be based on converting this prototype model into a pilot project ready to be promoted in the real market.

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