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Control, Design and Analysis of Delta 3D Printer

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Abstract: 3D printers have become the base element in the fourth industrial revolution which will lead the new economic world. The increasing accessibility of 3D printers will help to push boundaries in technology much further, and thus providing a more thriving, prosperous society. With cheaper solutions for parts and eliminating the need for batch supply to make money and profits, 3D printing looks set to change the world today, just as the factory revolution did, in the past. The design of this printer is discussed in detail, and its performance for both hard components and software's were tested and evaluated. Problems faced 3D printers' developers were also discussed, including hardware, software, and production problems. In this study the 3D printer will be designed from local and cheap raw materials. A practical and experimental application to implement a local 3D printer is presented here with cheap hardware and software components. An evaluation and test of the printer performance and efficiency is performed too. It is found that the 3D printers have many problems in implementation and design which need to be solved. The main thing in such solution is to determine the objectives from such printer and choose the appropriate hard and software. Also, it is found that the present 3D printer can works properly with good performance and efficiency and produces low-cost products with good quality by good controlling and good calibration systems.

***Keywords**: 3D printers, Design, Analysis, Implementation, Hardware, Software, Automation, Industry.*

1. Introduction

Three dimensions printers have become a very important tool in new technologies and prototypes production. Many materials and designs are used in such printers. The materials utilized in these homegrown printers can go from plastics, metals, and foodstuffs. The utilizations for these printers are conceivably perpetual. This study aims to explore the assembly and commissioning of a 3D printer, that is the Delta robotic design, its working technologies, and the possibility of taking the concept further. Since the Delta 3D printer is still merely at its prototype stages, the task was given to build and program a version of the Delta 3D printer model. This would mean to recognize the segments and innovation required for building a replicator printer. It would include the coordination of mechanics and gadgets and programming and help towards additional advancement of one's information on innovation in computerization, mechanical technology, and programming improvement.

3D printing or added substance producing (AM) alludes to any of the different cycles for printing a three-dimensional object. Basically, added substance measures are utilized where progressive layers of material are set down under PC control. These items can practically be of any shape or math and are created from a 3D model or other electronic information source. A 3D printer is a sort of mechanical robot. Essentially, all metalworking creation at the time was delivered by projecting, manufacture, stepping, and machining. A lot of mechanization was applied to those advancements, (for example, welding and CNC). The possibility of a device or head traveling through a 3D work envelops changing a mass of crude material into an ideal shape layer by layer related by the vast majority just with measures that eliminated metal (as opposed to including it, for example, CNC processing, and numerous others [1], [8]. Over the most recent few years the term 3D printing has become more known, and the innovation has arrived at a more extensive public. Still a great many people haven't known about the term while the innovation has been in use for quite a long time. Particularly, makers have since quite a while ago utilized these printers in their plan cycle to make models for customary assembling and examination purposes. Utilizing 3D printers for these objects is called fast prototyping. Why utilize 3D printers in this cycle you may ask yourself. Presently, quick 3D printers can procure a huge number of dollars and wind up sparing the organizations ordinarily that measure of cash in the prototyping cycle. For instance, Nike utilizes 3D printers to make multi-shaded models of shoes. They used to burn through a huge number of dollars on a model and sit tight weeks for it. Presently, the expense is just in many dollars,

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and changes can be made in a flash on the PC and the model republished around the same time. Other than fast prototyping, 3D printing is additionally utilized for quick assembling. Fast assembling is another strategy for assembling where organizations are utilizing 3D printers for short run custom assembling. In this method of assembling the printed objects are not models but rather the real end client item. Here, you can expect greater accessibility by altered items [2], [10].

History of 3D printers

The technology for printing physical 3D objects from advanced information was first evolved by Charles Hull in 1984. He named the procedure as Stereo lithography and got a patent for the method in 1986. While Stereo lithography frameworks had gotten mainstream before the finish of 1980s. Other comparable innovations, for example, Fused Deposition Modeling (FDM) and Selective Laser Sintering (SLS) were presented. In 1993, Massachusetts Institute of Technology (MIT) licensed another innovation, named "3-Dimensional Printing strategies", which is like the inkjet innovation utilized in 2D Printers. In1996, three significant items: "Genisys" from Stratasys, "Actua 2100" from 3D Systems and "Z402" from Z Corporation, were presented. In 2005, Z Corp. dispatched an advancement item, named Spectrum Z510, which was the main superior quality color3D Printer in the market. Another breakthrough in 3D Printing occurred in 2006 with the initiation of an open-source study, named Reprap aimed at developing a self-replicating 3D printer [3], [6].

2. Problem Statement

The 3D world has many designers and engineers who work to improve this aspect of modern technology. Therefore, we need to show more about the problems that the designers and developers want to solve. Some of the common obstacles of the 3D printers include:

- Hardware problem: this includes Stepper motor efficiency not adequate to give 3D motion in high resolution, Losses in the torque by converting rotational motion into linear motion by belt to linear bearing, and the extruder operation is manual or automatic.

- Software problem: - The capabilities of the software to take actual shape are limited. - The speed of the processing needs a time to study to learn which software must be chosen.

- Production problem. Include the output of the design or the outcome that can evaluate our work. These problems should be studied to find a solution for them.

Some of these solutions:

- Choose the appropriate stepper motor “torque, step angel, current, connection of wire”.

- Study all the mechanical characteristic of the belt and bearing to obtain the desired motion and efficiency.

- Replace manual controlled extruder by automatic one.

- Analyze all the modifying lists for different programs and choose the best program to our design “speed, resolution, and accuracy” [6].

The product is the most important aim of this study if the product is served efficiently, and high technology is employed and does not suffer from the defects. And this is the feedback to our search and work during nearly one year.

In 3D printing, primarily additive processes are used where successive layers of material are laid down under computer control. These objects can practically be of any shape or calculation and are created from a 3D model or other electronic information source. There are numerous kinds of advances utilized in added substance producing. One of the most significant of them is a fused deposition modeling (FDM). FDM starts with a product cycle which measures a STL document (sound system lithography record design), numerically cutting and situating the model for the manufactured cycle. Whenever required, uphold structures might be created. The machine may administer various materials to accomplish various objectives. For instance, one may go through a material to assemble the model and utilize another as a dissolvable help structure, or one could utilize different shades of a similar sort of thermoplastic on a similar model. The model or part is delivered by expelling little dabs of thermoplastic material to frame layers as the material solidifies following expulsion from the spout. A plastic fiber or metal wire is loosened up from a curl and supplies material to an expulsion spout which can kill the stream. There is regularly a worm-drive that drives the fiber into the spout at a controlled rate. The spout is warmed to soften the material. The thermoplastics are warmed past their glass progress temperature and are then stored by an expulsion head. The spout can be moved in both flat and vertical bearings by a mathematically controlled system. The spout follows a device way constrained by a computer aided manufacturing (CAM) programming bundle, and the part is developed from the last, each layer in turn. Stepper engines or Servo engines are ordinarily utilized to move the expulsion head. The instrument utilized is regularly a X-Y-Z rectilinear plan albeit other mechanical plans, for example, delta robot have been utilized. Albeit, a printing innovation FDM, is truly adaptable and equipped for managing little shades by the help from lower layers. FDM, by and large, has a few limitations on the incline of the shade, and can't deliver unsupported stalactites. Horde materials are accessible, for example, ABS, PLA, polycarbonate, polyamides, polystyrene, and lignin, among numerous others, with various compromises among quality and temperature properties [5].

Proposed System

- Description

There are basically two types of 3D printers used in the manufacturing process:

1. Cartesian

Cartesian 3D printers have a square or rectangle base structure where X, Y and Z axes of control are linear and are at right angles to each other as shown in Figure (1). These axes come in the form of sliding joints, belts or screws that manipulate individual axes in correspondence with a square grid. Because the simple geometry of its motion, the printer's mechanisms and software can be more simple than other printer designs [11].

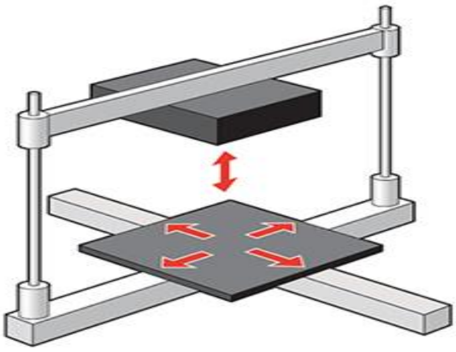

Fig. 1 Cartesian model.

2. Delta

A Delta 3D printer is a unique design that uses three arms to control the movement of the extruder, which is located in the center as shown in Figure (2). Because the arms are fixed to one another, the extruder always remains parallel to the bed, but still has a wide range of freedom of articulation. The arms translate in wide 120-degree arcs across the build platform creating 3D cross sections calculated using trigonometry. These features enable Delta printers to have built areas that are both tall and large, making it very space efficient, eye-catching and they can also be quite fast because of its efficient use of parts, and its low cost. Unfortunately, because of the complex geometries involved in calculating its tool path, the software must be very complicated [12]. In this study the Delta 3D printer model will be used.

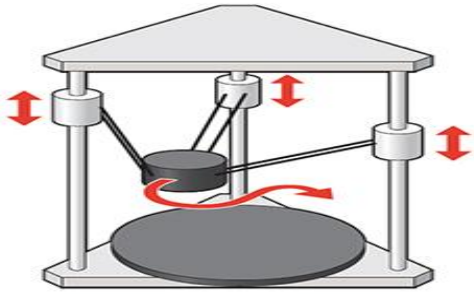

Fig. 2 Delta model.

The concept of Delta 3D printer comes from the parallel robots (Delta robots). The Delta robot is a parallel robot, i.e. it consists of numerous kinematic chains associating the base with the end-effector. The robot can likewise be viewed as a spatial speculation of a four-bar linkage as appeared in Figure (3). The key idea of the Delta robot is the utilization of parallelograms which confine the development of the end stage to unadulterated interpretation, for example just development in the X, Y or Z heading with no revolution . The robot's base is mounted over the workspace and all the actuators are situated on it. From the base, three center jointed arms expand. The closures of these arms are associated with a little three-sided stage. Activation of the info connections will move the three-sided stage along the X, Y or Z heading. Incitation should be possible with direct or rotational actuators, with or without decreases. Accordingly, the moving pieces of the Delta robot have a little latency. This takes into account exceptionally rapid and high increasing speeds. Having all the arms associated together to the end-effector builds the robot firmness, yet diminishes its working volume [13].

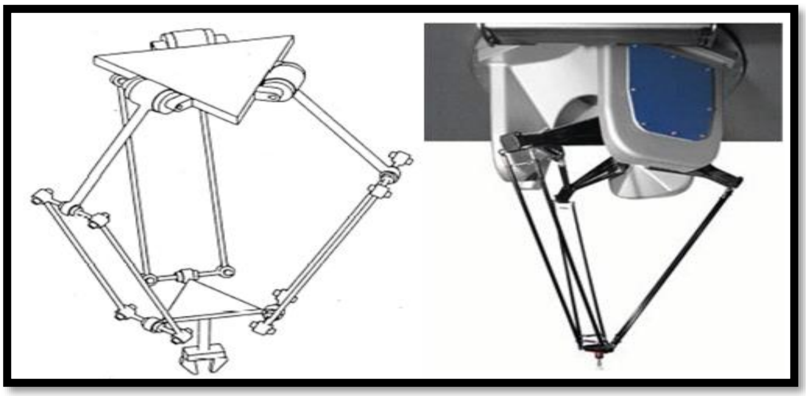

Fig. 3 Delta mechanism.

-Block diagram of 3D printer mechanism implementation

Figure 4 shows the block diagram of the steps of Delta mechanism implementation

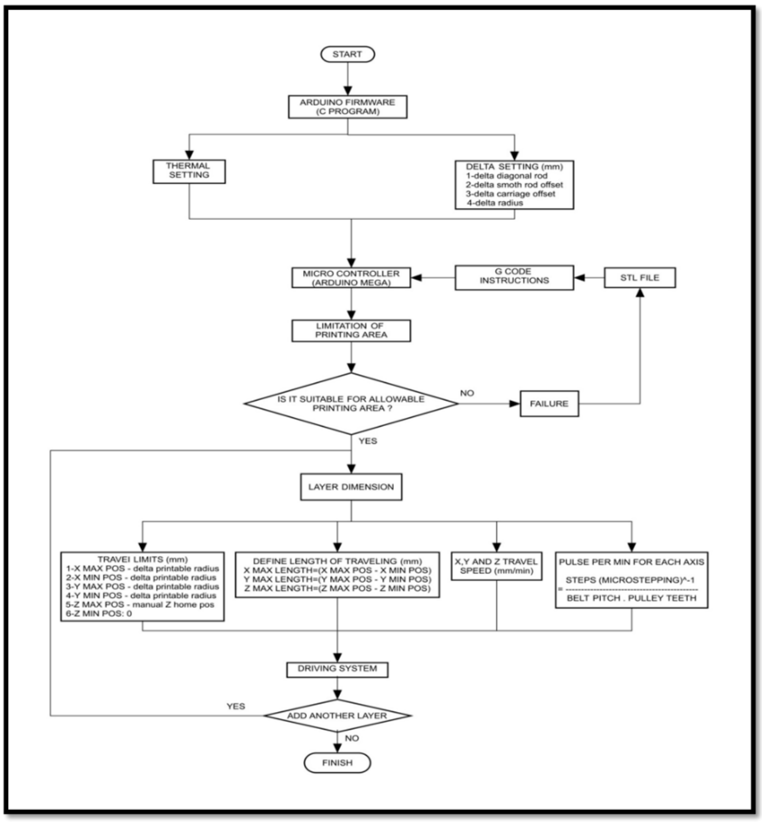

Fig. 4 Block diagram of Local 3D printer mechanism implementation

3. Results and Discussion

Delta 3D printer shape basically based on two symmetrical hexagonal MDF shapes; one for the base as shown in Figure (5),and another for the top as shown in Fig(6). The positions of the pillars can be seen on the small edges of the hexagonal. These pillars connect the base and the top with M8 steel rod, the steel rods will provide rigidity to the frame. Cutting the three edges of a MDF equilateral triangle with the same dimension at each edge and drilling two 8 mm holes at each edge as shown in Figure (5)[8].

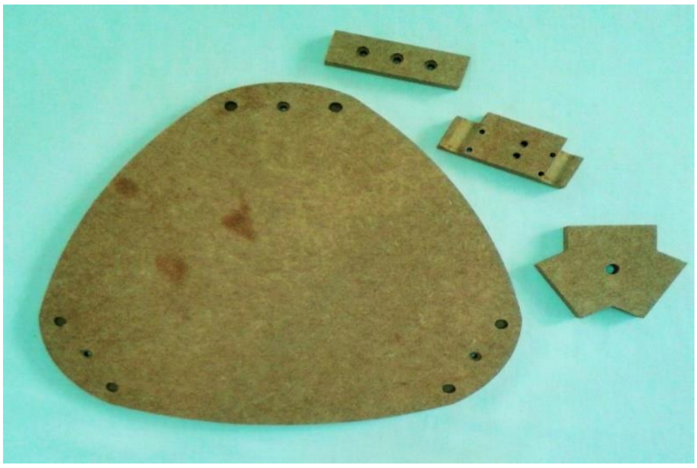

Fig. 5 Base of Delta printer.

As shown in Figure (6), the top shape is not a one piece to provide suitable locations to the other components to be in the right place. For example, the stepper motor located between each two pillars is to represent X, Y and Z axes.

Fig. 6 Top assembly of Delta printer.

As shown in Figure (7), we see all MDF Delta printer parts.

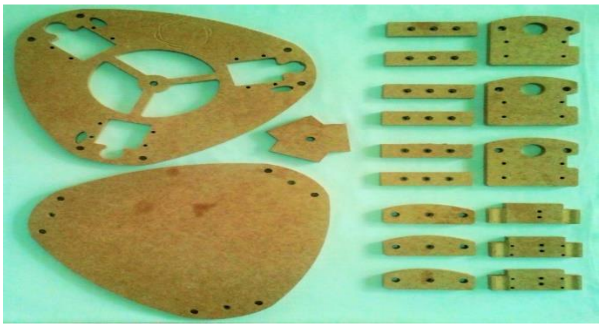

Fig. 7 Delta printer shapes.

The top view of Delta printer has the same dimension of the base and designed to be appropriate with the other components (stepper motor, end-stops, timing belt and the extruder) and to be more sophisticated as shown in Figures (8, 9 and 10).

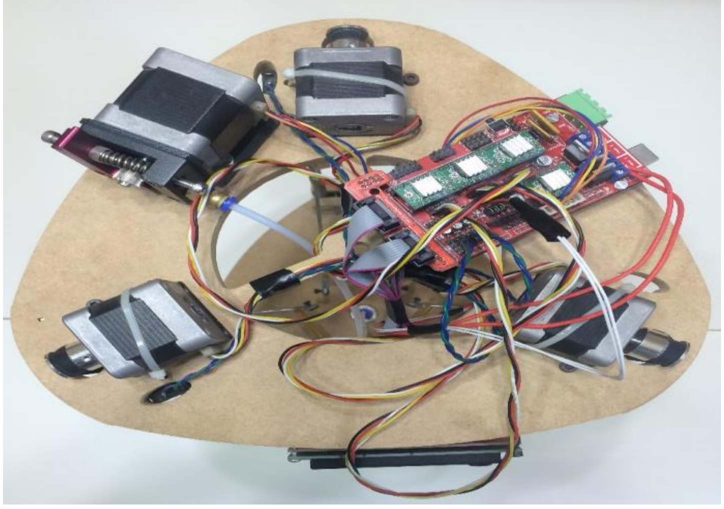

Fig. 8 Top assembly

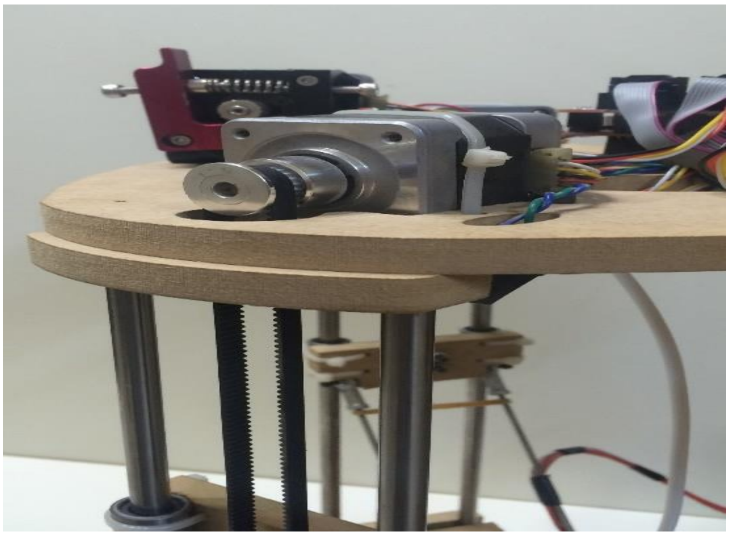

Fig. 9 Stepper motor in top assembly.

Note that the small piece of MDF is just below the top assembly to hold the stepper motors and keep it tied to the belt. In the supported piece of MDF there is a space to locate the limit switch (End-stop) and fix it by sticky double face as shown in Figure (10).

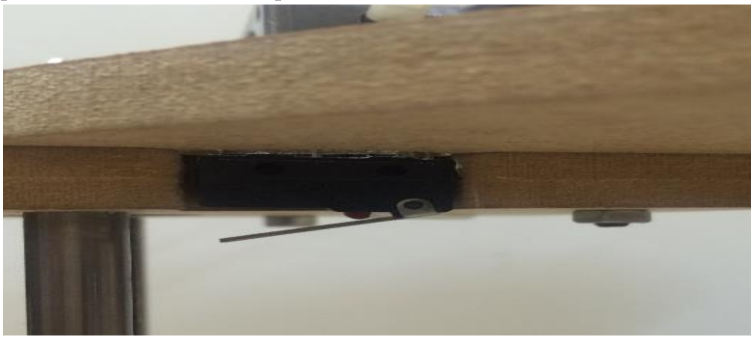

Fig. 10 End-stop position.

Connecting the base and top with six 8mm steel rods two at each edge as shown in Figure.(11).

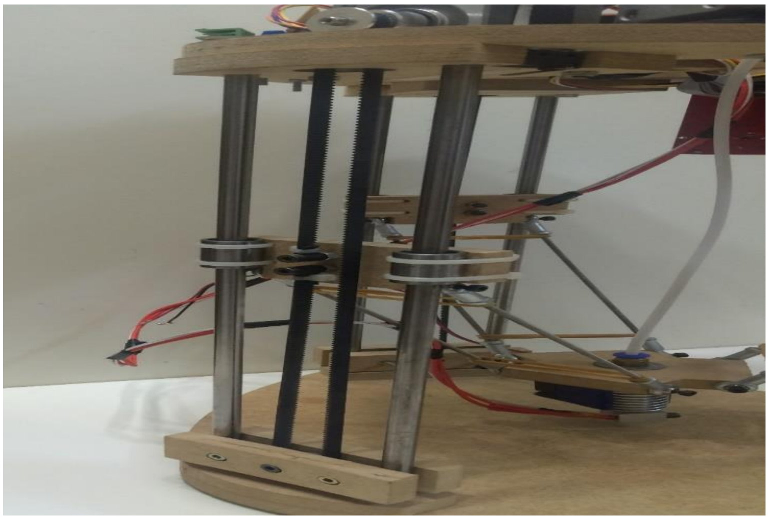

Fig. 11 Delta printer pillar.

Using a LM8UU linear bearing at each rod attached to the slider that is connected with a timing belt to convert the rotational movement caused by the stepper motor as shown in Figure (12).

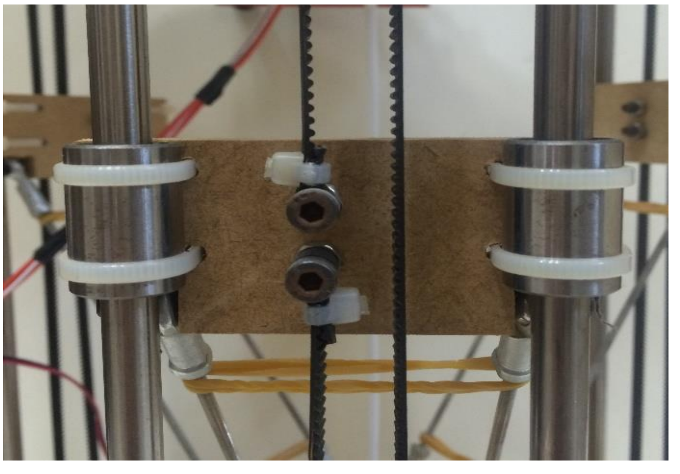

Fig. 12 Two linear bearings at each pillar.

As shown in the figure above, these two bearings attached to a piece of MDF make this combination acts like a slider. Note that it's called a carriage because it carries the diagonal rods of the Delta mechanism which is connected to universal joints that carry the effector as shown in Figure (13).

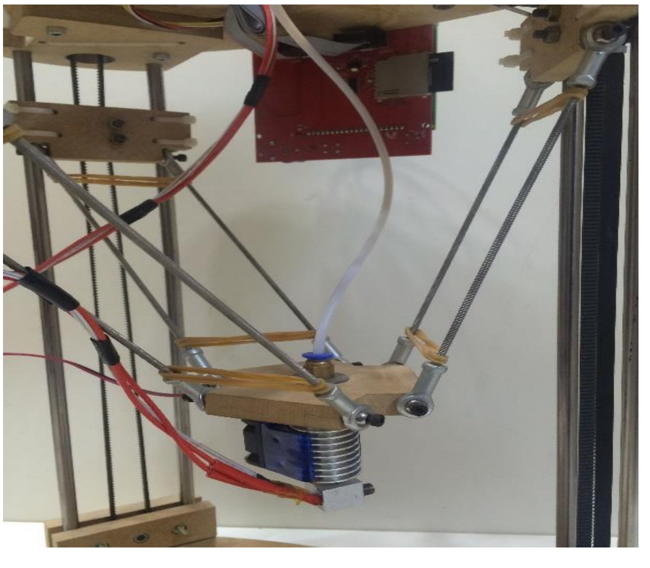

Fig. 13 the carriage connected to the universal joint.

As shown in the figure (13), the universal joints move the effector in all directions of the printing area. This is done by using two balls and sockets at each diagonal rod; one for carriage and another for effector. Place the extruder at the top of the printer as shown in Figure (14) and be sure that the extruder is placed well to keep it balance.

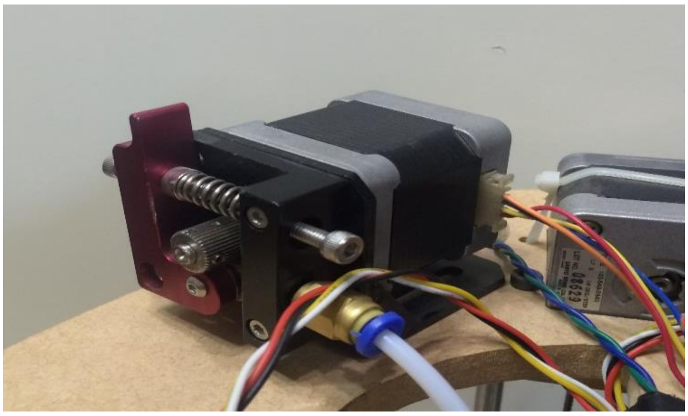

Fig. 14 the extruder

-Electrical parts:

Install the RAMPS 1.4 shield into the Arduino Mega (as shown in Figure 15)

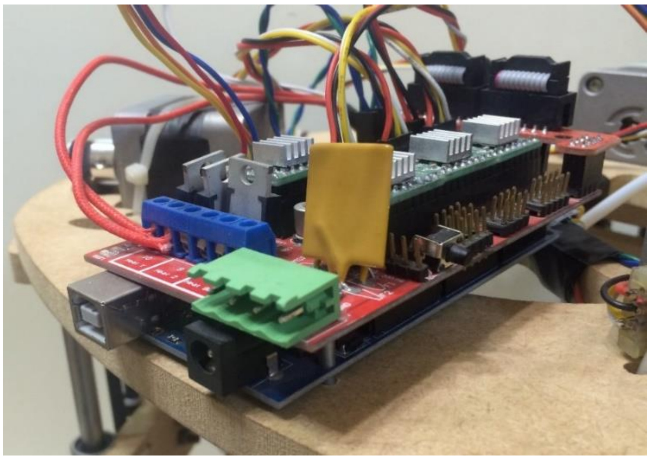

Fig. 15 RAMPS 1.4 shield on the Arduino Mega.

Install the stepper drivers at each motor port (X, Y, Z and Extruder) and connect the wires of the four steppers as labeled on the RAMPS 1.4 shield as shown in Figure (16).

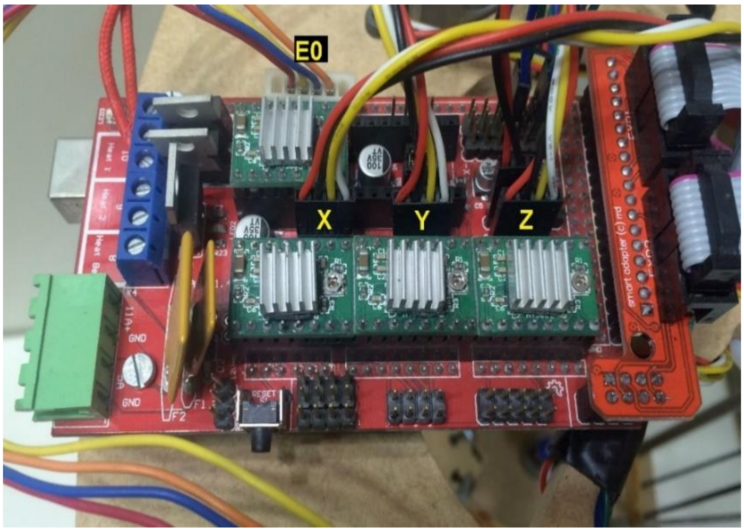

Fig. 16 Stepper drivers and wiring.

Connect the end-stops wires at the RAMPS 1.4 shield as shown in Figure (17). Install the temperature sensor of the hot-end (100k NTC thermistor) at the RAMPS1.4. Note that there are three ports of temperature sensors on RAMPS 1.4 shield so the type and the port number are defined in Arduino firmware and the installed sensor on RAMPS should be selected according to the type and port defined on the firmware.

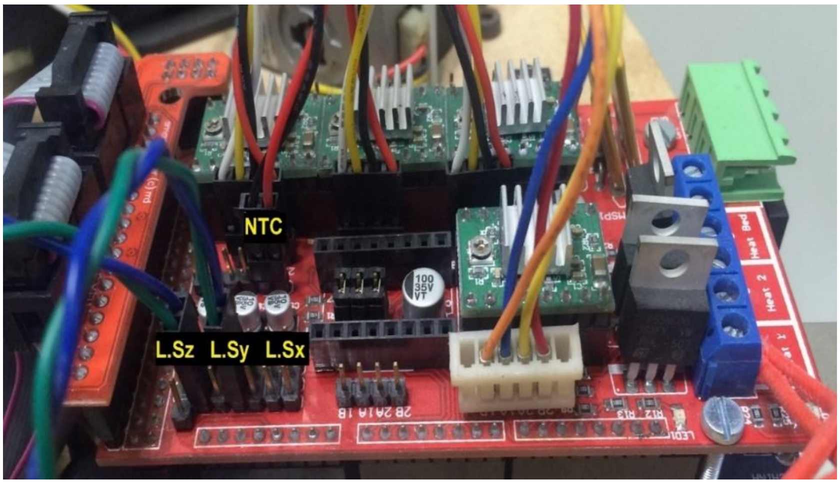

Fig. 17 End -stops wiring at RAMPS 1.4.

Prepare the 12V power connector on RAMPS. The power supply should have 12V and a minimum of 5A. After all, the final view of Delta printer should be like as shown in the figure (18).

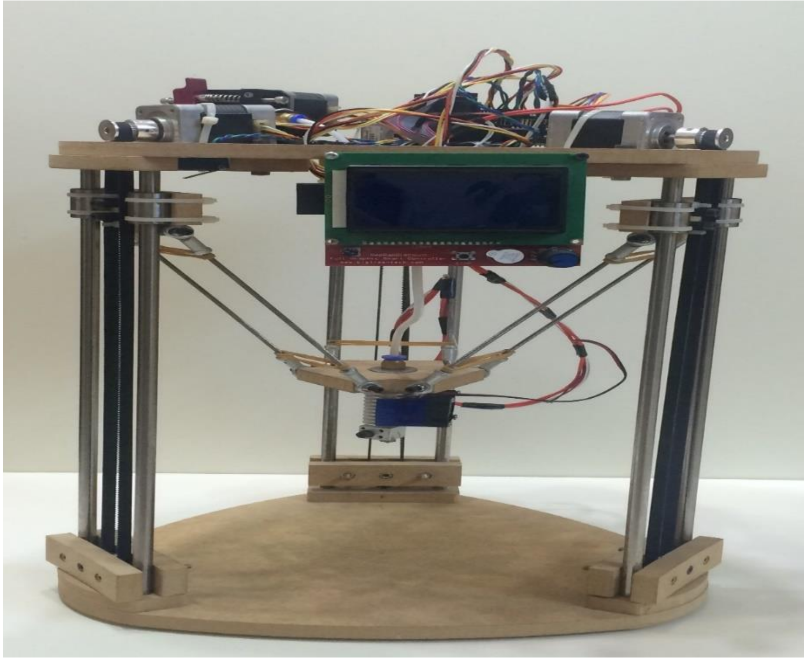

Fig. 18 final product of Delta printer.

The firmware is responsible for making the printer move according to the G-code commands. The firmware will be able to calculate the distances, and each axis is allowed to move in order to reach the desired position. It is installed on the Arduino mega microcontroller, which processes the G-code instructions coming from the Repetier Host and permits the effector to move from one point to another. It also restricts the effector from crashing into the other printer parts, if used correctly. The firmware used in Reprap machines includes Sprinter, Marlin and Teacup firmware. In the case of the Delta printer, Arduino will be used to upload the 'Repetier' firmware. The configuration file in the Repetier Software can be amended to suit the measurements of the specific printer. It is possible to change the settings, such as, the lengths of the arms, the height of the printer, the feed rate, stepper motor steps per mm, etc. After selecting the correct COM port and the correct board data (RAMPS 1.4) (as shown in Figure 19), then it is possible to upload the firmware to the Arduino chip. After downloading all the software and uploading the firmware for the controller, it is necessary to set parameters such as the correct baud-rate (as shown in Figure 20).

```
Repetier | Commands.cpp | Commands.h | Communication.cpp | Communication.h | Configuration.h | Eeprom.cpp | Eeprom.h
// MEGA/RAMPS up to 1.2       = 3
// RAMPS 1.3/RAMPS 1.4        = 33
// Azteeg X3                  = 34
// Azteeg X3 Pro              = 35
// Ultimaker Shield 1.5.7     = 37
// Gen6                       = 5
// Gen6 deluxe                = 51
// Sanguinololu up to 1.1     = 6
// Sanguinololu 1.2 and above = 62
// Melzi board                = 63  // Define REPRAPPRO_HUXLEY if you have one for correct HEATER_1_PIN assignment!
// Azteeg X1                  = 65
// Gen7 1.1 till 1.3.x        = 7
// Gen7 1.4.1 and later       = 71
// Sethi 3D_1                 = 72
// Teensylu (at90usb)         = 8 // requires Teensyduino
// Printrboard (at90usb)      = 9 // requires Teensyduino
// Foltyn 3D Master           = 12
// MegaTronics 1.0            = 70
// Megatronics 2.0            = 701
// Megatronics 3.0            = 703 // Thermistors predefined not thermocouples
// Minitronics 1.0            = 702
// RUMBA                      = 80  // Get it from reprapdiscount
// FELIXprinters              = 101
// Rambo                      = 301
// PiBot for Repetier V1.0-1.3= 314
// PiBot for Repetier V1.4    = 315
// Sanguish Beta              = 501
// Unique One rev. A          = 88
// User layout defined in userpins.h = 999

#define MOTHERBOARD 33
```

Fig. 19: Define the board type in Repetier firmware.

Note that RAMPS 1.3 is the same chip of RAMPS 1.4 that used in this study.

```
//#define BAUDRATE 76800
#define BAUDRATE 115200
//#define BAUDRATE 250000
```

Fig. 20 Baud-rate for Arduino.

In a Delta robot, it is required to split curves into several lines, or segments due to the rotational axes in the design. The Delta segments per second 100 which means that a curve will be split into 100 segments, per mm as shown below.

#define DELTA_SEGMENTS_PER_SECOND 100

The Repetier firmware needs to know the lengths of the arms, and the offset of the middle of the printer bed to the carriage, the offset of the u-joints to the end-effector, and the offset of the u-joints to the carriage (as shown in Figure 21) in order to make the calculations (as shown in Figure 22).

```
Repetier | Commands.cpp | Commands.h | Communication.cpp | Communication.h | Configuration.h | Eeprom.cp

/** Max. radius the printer should be able to reach. */
#define DELTA_MAX_RADIUS 80


/** \brief Horizontal offset of the universal joints on the end effector (moving platform).
*/
#define END_EFFECTOR_HORIZONTAL_OFFSET 35

/** \brief Horizontal offset of the universal joints on the vertical carriages.
*/
#define CARRIAGE_HORIZONTAL_OFFSET 33

/** \brief Printer radius in mm, measured from the center of the print area to the vertical smooth rod.
*/
#define PRINTER_RADIUS 166.9
```

Fig. 21 Definition of lengths and offsets.

```
// Effective horizontal distance bridged by diagonal push rods.
#define DELTA_RADIUS (DELTA_SMOOTH_ROD_OFFSET-DELTA_EFFECTOR_OFFSET-DELTA_CARRIAGE_OFFSET)
```

```
// Effective X/Y positions of the three vertical towers.
#define SIN_60 0.8660254037844386
#define COS_60 0.5
#define DELTA_TOWER1_X -SIN_60*DELTA_RADIUS // front left tower
#define DELTA_TOWER1_Y -COS_60*DELTA_RADIUS
#define DELTA_TOWER2_X SIN_60*DELTA_RADIUS // front right tower
#define DELTA_TOWER2_Y -COS_60*DELTA_RADIUS
#define DELTA_TOWER3_X 0.5 // back middle tower
#define DELTA_TOWER3_Y DELTA_RADIUS
```

Fig. 22 Delta equations implemented into the firmware code.

Another important configuration is end-stops setting that affect the performance of the Delta printer; code is set in place to ensure that the arms aren't twisted or pulled, or crash into their own pillars, and stop when they hit the end-stops or the bottom of the printer.

-Calibration:

It is important to calibrate the printer in order to ensure that the motors increment is at the correct rate, and cause the arms to move the correct distances each time they move. If you skip this step, it is probable that any printed parts by the unit will be lop-sided or skewed.

-Definition of the correct number of steps per mm

The following equation is used to calculate the number of steps per mm [6, 10, and 13].

$$NO.of\ steps\ per\ mm = \frac{S\ .\ MS^{-1}}{P\ .\ N} \quad (1)$$

Where: S: number of steps per revolution, MS: Micro-stepping, P: pitch of the belts N: number of pulley teeth.

For example with Delta 3D printer in this study:

$$NO.of\ steps\ per\ mm = \frac{200\ .\ (\frac{1}{16})^{-1}}{2.03\ .\ 16}$$

$$= 98.5\ steps/mm$$

By inserting these values into firmware code the movement of stepper motors is calibrated (as shown in figure 23).

```
#define XAXIS_STEPS_PER_MM 80
/** \brief Number of steps for a 1mm
For xy gantry use 2*belt moved!
Overridden if EEPROM activated.*/
#define YAXIS_STEPS_PER_MM 80
/** \brief Number of steps for a 1mm
#define ZAXIS_STEPS_PER_MM 80
#endif
```

Figure 23 Default axis steps per mm.

Note that the first three values for X, Y and Z respectively and the last number in default axis steps per mm for the extruder.

These are default values, and are not always correct due to other parameters, in the code or to do with the jumper pins and micro-stepping capabilities of the stepper drivers, etc. In any case, on testing the development of the arms of the robot, you can compute the genuine separation voyaged. In the event that it isn't a similar sum as the ideal separation voyaged, isolate the ideal incentive by the genuine worth, and increase by the default esteem. For the extruder, for instance, it was discovered that advising the extruder to take care of the fiber 1mm, it really took care of 2 mm. This can be corrected by calculating. [6, 10, 13].

$$\frac{Default\ feed\ of\ the\ filament}{Actual\ feed\ of\ the\ filament} * Default\ extruder\ speed \quad (2)$$

$$\frac{1\ mm}{2\ mm} . 100 = 50\ steps\ per\ mm$$

Host Software

The host software allows communication to the printer electronics before and during the print jobs. It allows the user to upload a"STL" file and convert it to G-code to control the printer. Repetier-Host (shown in figure 6.8) is a simple GUI (Graphical User Interface) software that permits the user to input G-code instructions to the controller. Cura or Slic3 (appeared in figures 24 and 25) are one of the Repetier alternatives that will take input 3D drawings (.stl records) and will mathematically breakdown the document into layers which are then changed over into a progression of ways where the device head should move. This data is sent to the regulator by means of the firmware which will control the development of the printer.

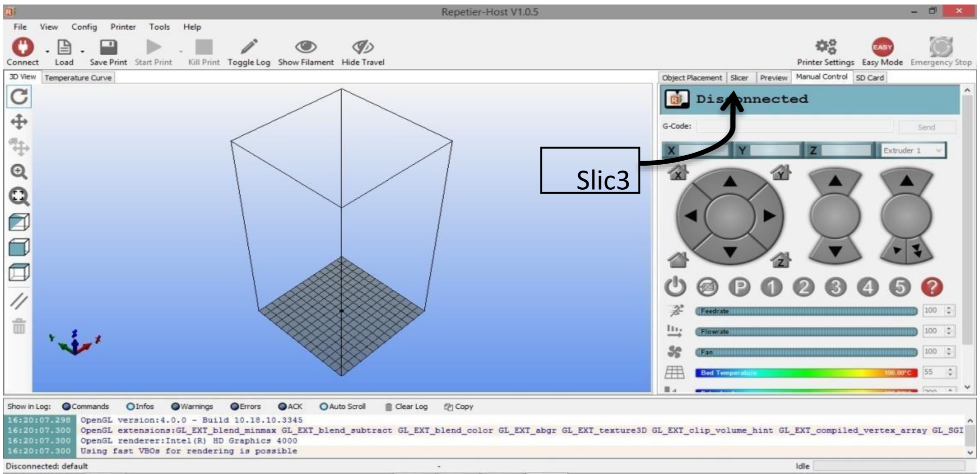

Fig. 24 Repetier Host

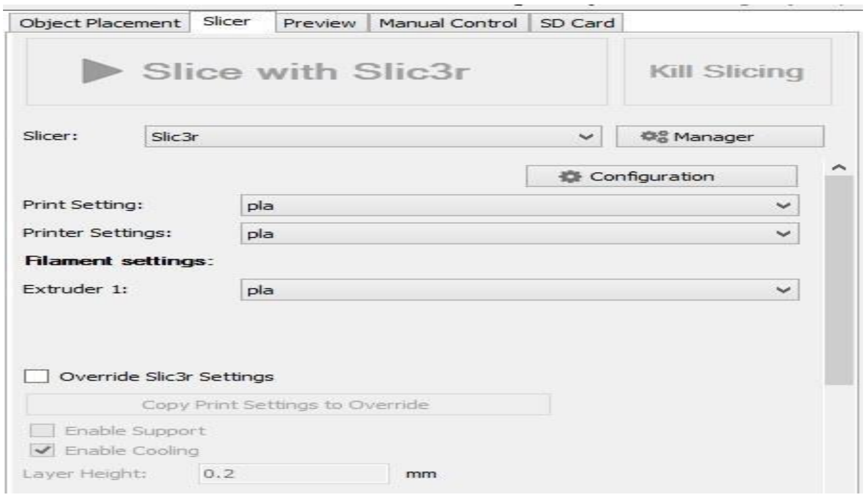

Fig. 25 Slic3r in Repetier Host

Final Performance Of Delta Printer

-Problems Encountered

There are a lot of problems occurred at the final product of Delta 3D printer. Note that almost all the problems are mechanical because of the inaccurate machining process that used in 3D printer. This chapter will introduce these problems.

-Motor and Driver Testing

A 12 V, 10 A connected to the Ramps terminals in order to feed the four stepper motors (X, Y, Z and the extruder motor). Each motor has a driver control whose motion in this study is the stepper motor driver without heat sink. This caused increase in driver temperature caused by the current. This temperature may damage the IC on the driver during work. To avoid this problem a small fan is used just above the RAMPS board to make ventilation instead of the heat sinks. Another problem in stepper motors is holding time of the stepper. The holding time is the time that the stepper can lift the load without letting it fall under its weight. Note that the holding time of a stepper is proportional to its holding torque and the weight attached to the stepper. In this study, it was found the Nema14 stepper is not the proper stepper for the load and the holding time is too short. This problem leads to position failure when waiting the extruder to heat up. To avoid this problem, it's recommended to use Nema17 stepper motor instead of Nema14. This allows higher holding torque and longer holding time.

-Calibration problems

After calibrating the Delta printer volume height if the G-code command G X0 Y0 Z0 used the hot-end should come to rest at the center of the print bed, about .1mm above the surface and the hot-end should keep the same level when moving to the printer edges. But delta printers have an additional variable of flatness. It was found when trying to move to the edges of the printer, the hot-end does not move at the same level of the center , and there is convex as (as shown in Figure 26).

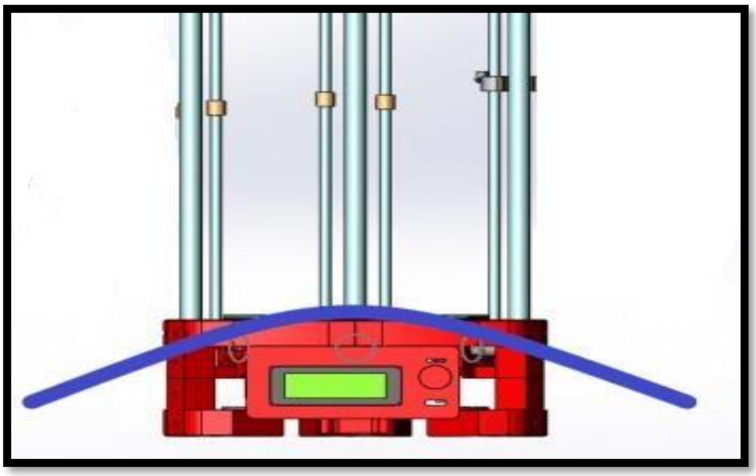

Fig. 26 Convex in Delta surface.

The flatness of the Delta printer is reliant on the Delta radius which is the sum of several variables as shown below.

$$DELTA\ RADIUS = DELTA\ SMOOTH\ ROD\ OFFSET - DELTA\ EFFECTOR\ OFFSET - DELTA\ CARRIAGE\ OFFSET \quad (3)$$

To correct the flatness of the surface, the Delta radius should be adjusted by changing these variables until the flatness problem is solved.

-Homing after printing problem

After completion of a desired printing operation, the hot end should go to the home position of the printer. It was found that the printer will not go to the home position but moving into undesired motion which might cause damage on the arm rods.

4. Conclusion

3D printers are boundlessly turning into an aspect of things to come. It is an energizing idea and one that will absolutely help push the limits on terms of innovation. The rundown of possible applications for 3D printing gadgets is interminable. What's more, in Mechatronic designing, it is a decent beginning ground for picking up involvement with coordinating mechanical, electronic, control and programming designing. Upon completion of the study many problems were encountered, and it is through this and the practical aspect of the study that ample knowledge has been gained. The increasing accessibility of 3D printers will help to push boundaries in technology much further, and thus providing a more thriving, prosperous society. With cheaper solutions for parts and eliminating the need for batch supply to make profits. It is found that the printer works in good manner but still needs some technical adjustments and calibrations. Fortunately, the printer can be used in printing some products with low costs and good quality and precision comparing with brand printers.

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