Design and implementation of 3D printer with automatic bed leveling based on Arduino

Nuradeen Khalifa Fethalla [1*], Abdelrazak A. Elbunan [2] , Abdulrahman Meelad Fanner [3,]
[1,3] Electrical and computer engineering Department, Faculty of Engineering, Elmergib University, Alkhoms, Libya
[2] Computer Science Department, Higher Institute of Science and Technology, Mesallata, Libya
, *Corresponding author: nkfethalla@elmergib.edu.ly

تصميم و تنفيذ طابعة ثلاثية الابعاد ذات سطح تسوية طباعة أوتوماتيكي باستخدام لوحة أردوينو

نورالدين خليفه فتح الله [1*]، عبدالرزاق عبدالسلام البونان [2]، عبدالرحمن ميلاد فنير [3]
[3،1] قسم الهندسة الكهربائية والحاسوب، كلية الهندسة، جامعة المرقب، الخمس، ليبيا
[2] قسم علوم الحاسب الالي، المعهد العالي للعلوم والتقنية، مسلاته، ليبيا

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Abstract:
In this paper, the structure design and working principle of the automatic 3D printer are introduced, and the 3D prototype model is designed according to hardware system design and software system design. The objective of this paper is to attain an automatic 3D printer prototype with relatively simple design. With the existing problems of the ordinary 3D printer, such as low printing speed, low accuracy, and high prices, automatic 3D printing has made a major impact on many fields of manufacturing industries. The most advantageous of using additive manufacturing process is the ability to work without much human intervention. The automatic bed leveling process is achieved using the bed surface observation. The designed prototype improves the efficiency of 3D printer through reducing the waste of the material amount that is used for mass production. The electromechanical integrated development environment has built for Arduino mega 2560 board, and the graphical user interface code has generated with the help of Pronterface software. The final device can achieve a suitable performance for the manufacturing of 3D parts and is ready for the applications of research and manufacturing.

Keywords: 3D printer; Arduino; Bed leveling; Microcontroller**.**

الملخص:
في هذه الورقة، تم تقديم هيكلية تصميم ومبدأ العمل للطابعة التلقائية ثلاثية الأبعاد المصممة، وتم تصميم نموذج مبدئي ثلاثي الأبعاد وفقًا لتصميم نظام الأجهزة وتصميم نظام البرمجيات. الهدف من هذه الورقة هو الحصول على نموذج مبدئي لطابعة ثلاثية الأبعاد تلقائية بتصميم بسيط نسبيًا. مع المشاكل الحالية للطابعة ثلاثية الأبعاد العادية، مثل سرعة الطباعة المنخفضة، والدقة المنخفضة، وارتفاع الأسعار، كان للطباعة ثلاثية الأبعاد التلقائية تأثير كبير على العديد من مجالات الصناعات الإنتاجية. إن الميزة الأكثر فائدة لاستخدام عملية التصنيع المضافة هي القدرة على العمل دون تدخل بشري كبير. تم تحقيق عملية التسوية السريرية تلقائيًا باستخدام مراقبة السطح السريري. يعمل النموذج المبدئي المصمم على تحسين كفاءة الطابعة ثلاثية الأبعاد من خلال تقليل هدر كمية المواد المستخدمة في الإنتاج الضخم. تم إنشاء بيئة التطوير المتكاملة الكهروميكانيكية للوحة *Arduino mega 2560*، وتم إنشاء شفرة واجهة المستخدم الرسومية بمساعدة برنامج *Pronterface*. يمكن للجهاز النهائي تحقيق أداء مناسب لتصنيع الأجزاء ثلاثية الأبعاد وهو جاهزًا لتطبيقات البحث والتصنيع.

الكلمات المفتاحية: طابعة ثلاثية الابعاد، أردوينو ، سطح التسوية، المتحكم الدقيق.

Introduction

A 3D printer is an innovative technology that has revolutionized the fields of manufacturing and design. It creates three-dimensional objects by layering thin materials, such as plastic, metals, or fibers, based on a digital 3D model. One important feature in modern 3D printers is auto bed leveling. Auto bed leveling is a mechanism incorporated into some 3D printers to ensure the print bed is perfectly leveled before each print job. The print bed is the platform where the object being printed is placed. Achieving a level print bed is crucial for successful 3D printing, as it ensures that the initial layer adheres properly and that subsequent layers are accurately deposited.
In traditional 3D printers, manual bed leveling is required, which involves adjusting the bed's position and leveling screws manually. However, auto bed leveling simplifies this process by utilizing sensors or probes to measure the distance between the print nozzle and the bed at various points. The printer's firmware then calculates any deviations and automatically adjusts the bed's position to compensate for unevenness. The benefits of auto bed leveling are significant. It saves time and effort by eliminating the need for manual adjustments before each print. It also improves print quality by ensuring consistent layer adhesion and preventing issues like warping or nozzle clogging. Additionally, auto bed leveling allows users to work with a wider range of materials and achieve better

overall print accuracy. While auto bed leveling is a valuable feature, it's important to note that different 3D printers may use different methods for implementing it. Some printers utilize inductive or capacitive sensors, while others employ mechanical switches or optical sensors. The choice of auto bed leveling mechanism may depend on factors such as printer design, cost, and user preference.

The process of 3D printing is an additive manufacturing where a layer-by-layer products are built to fabricate three dimensional solid objects directly from computer-aided-design (CAD) [1]. Conversely, 3-D printing utilizes CAD software and additive manufacturing technologies to create objects by fusing different materials with a laser [2]. Additive manufacturing has attracted significant attention in both the academic and industrial sectors. This interest has led to innovative research and development in products, processes, and machinery, prompting a reevaluation of manufacturing logistics and structures [3]. At present, 3D technology is utilized across numerous industries, including medicine, aviation, and food. [4-7]. Nowadays, 3D printing technology is widely used for mass production (customization) and to produce a variety of open-source designs in different fields; aerospace industry, agriculture, automative industry, and health care [8]. Various techniques can be applied to 3D print food materials, including selective laser sintering, hot air cooking, liquid bonding, and extrusion [9]. The function of the extrusion mechanism is to transfer the material to the spray head, with the stepping motor serving as the power component of the extrusion mechanism [10]. 3D printing technology is truly innovative and has become a versatile platform. It offers new opportunities and inspires many possibilities for companies aiming to enhance manufacturing efficiency. Materials that can currently be printed using 3D printing technology include conventional thermoplastics, ceramics, graphene-based materials, and metals [11]. There are several drawbacks to adopting 3D printing technology in the manufacturing industry. For example, its use may decrease the demand for manufacturing labour, which could significantly impact the economies of countries that depend heavily on a large number of low-skill jobs [12]. In 3D printing, bed leveling is essential for model creation since an uneven print bed might result in unforeseen problems with the first layer. which results in poor adhesion of the printed model. If the nozzle is too close to the bed, it may get blocked. getting accurate information on The bed level with a sensor is also difficult. Additionally, bed leveling accounts for 12 to 26% of the failures in machines and 3D-printed components. [13, 14].

3D printing can significantly contribute to cloud-based manufacturing, where a service-oriented network allows users to configure, choose, and utilize customized product resources and services [15]. There is already a 3D community that shares ideas and designs, which can be easily downloaded via an internet link and sent to 3D printers.

In general, 3D printers are utilized for two main purposes: rapid prototyping (developing prototypes for traditional manufacturing and research) and rapid manufacturing (producing products for short-run custom manufacturing).

In summary, 3D printing technology has recently emerged as a versatile and powerful tool in the advanced manufacturing industry. It has gained widespread use in many countries, particularly within the manufacturing sector. The purpose of this work is to present the design and fabrication of 3D printing combined with auto bed leveling technologies, their applications, and the materials used for 3D printing in the manufacturing industry.

The primary subject of this study was an automatic bed leveling system that employs a load cell as a touch probe to allow real-time 3D printer path tracing. The open-source Marlin microcontroller firmware is used in conjunction with the method on an open hardware FDM (Fused Deposition Modeling) 3D printer. The bed adjustment makes up for discrepancies in the bed's flatness between layers. The proposed technique reduces the time required for manual bed calibration and makes the printers more accessible to users who are not familiar with manual bed probing. This paper contributes by offering:A step-by-step guide to designing a fully integrated 3D printing system with auto bed leveling suitable for educational projects.

The rest of the paper is arranged as follows: the methodology is presented in the next section followed by the functional description and design analysis section. Then, build process section, assembly, electronic control circuit of 3D printer section, software section, implementation and results section, and conclusion are presented respectively.

Methodology

An uneven bed surface can lead to manufacturing defects or warping of the layer as it heats. This issue can be mitigated by tilting the bed plane during printing and compensating for inconsistencies in real-time. Initially, the bed is probed to detect flatness errors. The nozzle is moved to several predefined points on the bed surface, typically four or nine. The gap between the bed and the nozzle is adjusted by placing a sheet of paper the size of the bed between them and fine-tuning the Z-axis (vertical) using the touchscreen (Human Machine Interface) until the paper is firmly gripped. The Z-axis position is recorded at each calibration point, and the process is repeated at subsequent points The operator's memory stores the outcome as a mesh of two-dimensional points on the bed (i. e. , x, y) together with their corresponding Z locations. Using bilinear interpolation on the saved mesh, Z offset compensation at any point (x, y) on the bed is computed during printing. As a result, the printing plane is more uniform, which improves bed adhesion and the overall print quality. But the process of leveling the mesh bed using probes is laborious and necessitates the operator's participation. A leveled bed can be obtained using a manual bed levelling within minutes. However, automatic bed leveling not only saves time and reduces the likelihood of human error but also provides precise calibration for all coordinates.

A. 3D Printing Manufacturing Process

3D model is the foundation for 3D printing and can be designed using software like AutoCAD, with the file saved in formats such as STL or SLA. To ensure the successful completion of a 3D printing job, it is important to verify that the model's size falls within the printer's maximum print range. If the model exceeds this range, its size must be adjusted. For rapid prototyping, the object is sliced into layers before printing. Once slicing is complete, the slicing software converts information about the object's shape, size, and other details into G-code instructions that the 3D printer can interpret to complete the printing task as illustrated in Figure 1.

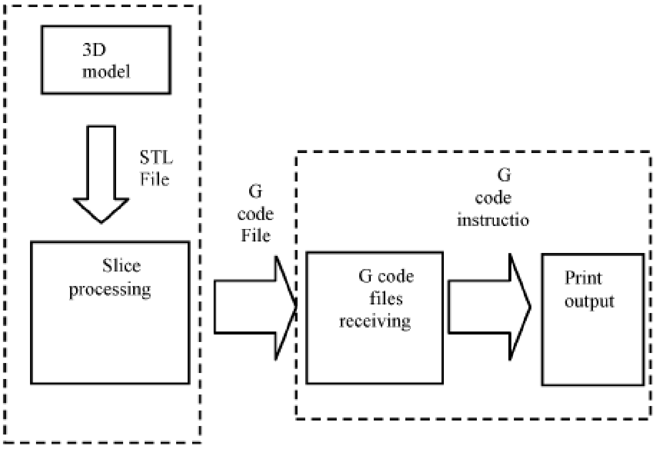

Figure 1: 3D print data processing.

B. Block diagram of 3D printer system

The concept design began with creating the block diagram shown in Fig. 2. The system includes a personal computer connected to control system where the microcontroller sends the necessary pulses to the drivers to control the speed and direction of the axis motors. Feedback signals from the thermistor are utilized to regulate the heat generated by the hot end.

Functional Description and Design Analysis

This 3D printer was fabricated using a variety of materials and processes. Most of the components employed in this endeavor were ordered from external sources. A detailed study was conducted on all components of the 3D printer to understand the working mechanism of each part and how they are interconnected. To ensure the printer operates with high efficiency and precision, a square-frame was chosen among the three common frame archetypes [16]. The frame was constructed using rigid and stable materials, maintaining dimensional accuracy during the printing process. This robust structure helps the printer withstand vibrations and rapid movements without compromising print quality, ensuring reliable performance and reducing the likelihood of malfunctions or errors during operation. Fig.3 illustrates the square 3D printer design.

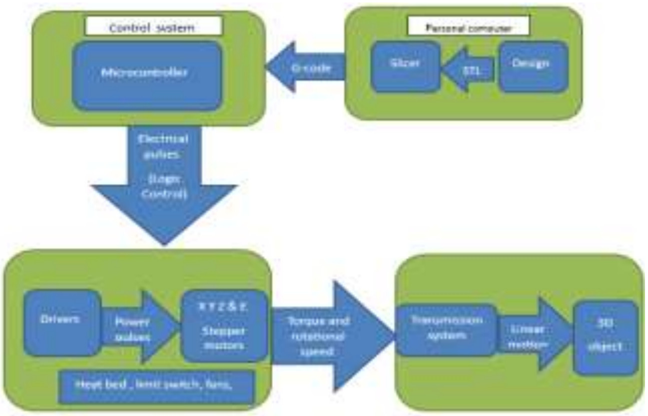

Fig. 2: Block diagram of 3D printer system.

There are multiple extruder types that can handle the function of filament movement and processing for 3D printer. A Bowden extruder is considered in this research. The main function of the extruder is to take the motor and the extruder components and move them from X-Y carriage to the frame can be handled. In order to extrude the plastic filament in the liquid form and deposit it on a printing platform, successive layers will be adding. This type of extruder with combination of Nozzle wall of 0.4mm hole can permits more precise filament extruding without jamming and extruder hole diameter 0.4mm [16]. Fig. 4 shows the extruder and its motor used in the designed 3D printer.

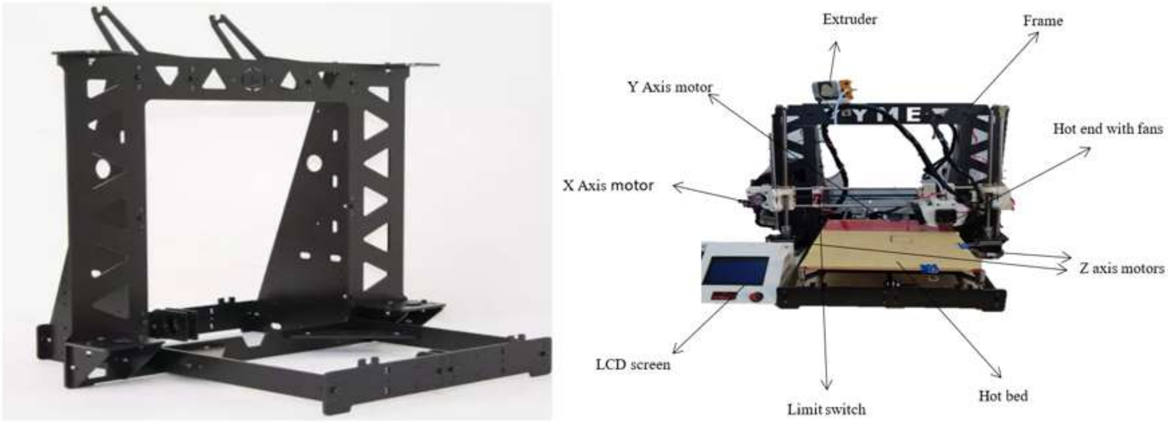

Fig. 3: The Frame of designed custom 3D printer and its components.

The heat beds are essential components for printing specific materials such as Acrylonitrile butadiene styrene (ABS). Using the heated beds, forming the thermal gradients within the printed material can be prevented.

This printer utilizes an Arduino Mega 2650 combined with a RAMPS shield to manage the printing process. The RAMPS shield incorporates five Pololu stepper drivers to operate the X, Y, and Z axes, as well as two extruder motors. By using the open-source Marlin firmware on the controller, future students can improve the new machine. More code can be added to boost the machine's features, like auto bed leveling, extra lights, and fan connections. The Arduino controls all the rapid prototyping machine's functions.

Heated build plates are crucial for printing materials like ABS. They help prevent uneven heating within the printed object, which can cause warping and deformation, negatively impacting the final part. Figure 5 shows an example of a heated build plate.

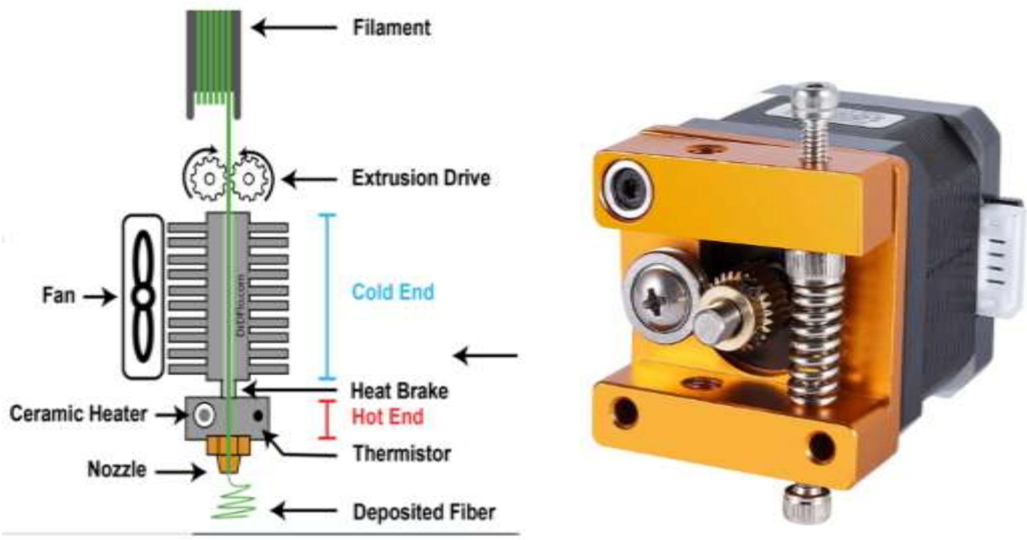

Fig. 4: The extruder and its motor

Fig. 5: Heated Build Plate.

Build Process

The 3D printer was initially designed using Solidworks, a Computer-Aided Design software, to demonstrate the compatibility of components, the size of the printer, the logistics of construction, and to provide the builders with a reference point. The FreeCAD files served as a blueprint for the printer's construction, as depicted in Fig. 6. The first step in the construction process was to cut the 1.5m V-slot stock on a horizontal band saw. The complete assembly required 18 distinct V-slot extrusions of 6 different lengths. The frame was fabricated using V-slot aluminum, RP components from the Makerbot Replicator 2, and an array of fasteners. Additional fastening points were incorporated into the frame to accommodate the diverse mounts for the Y and Z-axes. The construction process commenced with the development of a sturdy base to serve as the foundation for the printer's assembly. Afterward, the upper portion of the frame was assembled and positioned on top of the base. The lower bracket connects and stabilizes the platform, while the upper bracket fastens the top part of the frame to the platform Four rapid fabricated mounting brackets are used to connect the A-frame to the upper supports, holding the top part of the structure in place. During assembly, it was important to insert T-slot nuts into the frame at points where other components would later be mounted, since they cannot be added or removed without taking the structure apart. These T-slot nuts were necessary for attaching all brackets to the V-Slot.

Fig. 6: FreeCAD model of the designed 3D printer frame.

The Z-axis motor supports, Y-idler, Y-belt drive motor, were all mounted on the frame after it was constructed. Rapid prototyping (RP) methods were also used to create and construct the idler and motor mounts. Using 2mm pitch Z-axis screws, the frame for the Z carriage was then built, put together, and placed inside the framework. The vertical supports were aligned by moving the Z carriage up and down while they were loosely placed. The

vertical supports were then tightened to prevent movement after they had been properly aligned. After that, the Z-axis screws were put into the RP ends of the Z-axis carriage and fastened to the Z-axis motors. The V-slot wheel mounts were inserted into the supports and secured in order to maintain the stability of the Z-axis carriage. A ¼-inch acrylic sheet with predrilled holes for V-slot wheels and eccentric spacers that may be used to regulate their tension makes up the Y-axis carriage. The acrylic sheet also has mounting holes for the spring suspended heated build plate. The last element of the axis assembly is the X-axis plate, which has four V-slot wheels that are positioned in slots to provide the right tension on the aluminum extrusions of the Z-axis carriage. Zip ties are used to route and secure the X-axis and Y-axis belts to prevent them from slipping.
Following that, the extruders and the plate to which they were attached were put together. By utilizing herringbone gears to lower the drive from the NEMA 17 stepper motor, the extruders increase torque and filament control. To create the smallest diameter filament feeders, the gears activate hobbed bolts. The filament is pressed against the hobbing on the bolts by spring-loaded 688 bearings that act as idlers and are situated against the bolt. The filament is driven through the hot ends by the stepper motors. The manufacturer's website provides instructions for installing each hot end into its matching extruder. The entire dual extruder assembly is attached to the plate using two extruders and four springs to allow for hot end leveling on the x carriage. Fig. 7 shows the installed dual extruder tips.

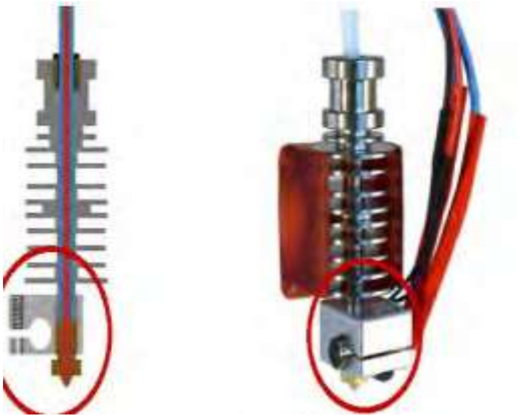

Fig. 7: Hot End Extruders

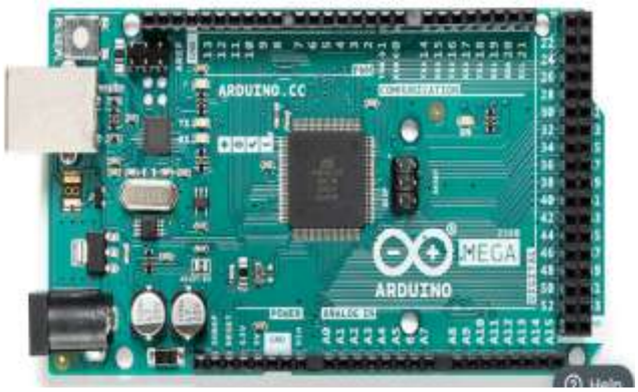

Fig. 8: Arduino Mega Board

The next step is to install the Arduino board, as depicted in Fig. 8, and initiate the wiring process. Each stepper motor has a corresponding port for connection. The heaters for the hot end and the relay input for the heated bed must be properly secured to avert short circuits and faulty connections. Similarly, the thermistors on both the hot end and bed must be plugged into their respective ports. The final component of the wiring was the 12V rail of the ATX power supply to power the entire RAMPS board. Adjustable mounting of the endstops on each frame axis is necessary. Endstops enable the printer to determine the origin in the 3D space. Meticulous care is essential when wiring the endstops to ensure their proper functionality.

Assembly:

The development process involves the assembly of the 3D printer hardware, followed by the installation and connection of the software to the constructed components. The initial design was performed to satisfy the required mechanical properties. A comprehensive investigation was conducted on all components of the 3D printer to understand the operational mechanism of each part and their interconnections. To guarantee the printer operates with high efficiency and precision, its frame was constructed using rigid and stable materials, preserving dimensional accuracy during the printing process. This sturdy structure enables the printer to withstand vibrations and rapid movements without compromising print quality, ensuring reliable performance and minimizing the likelihood of malfunctions or errors during operation. In this research, the assembly stages of the 3D printer were carried out as depicted in Fig. 9.

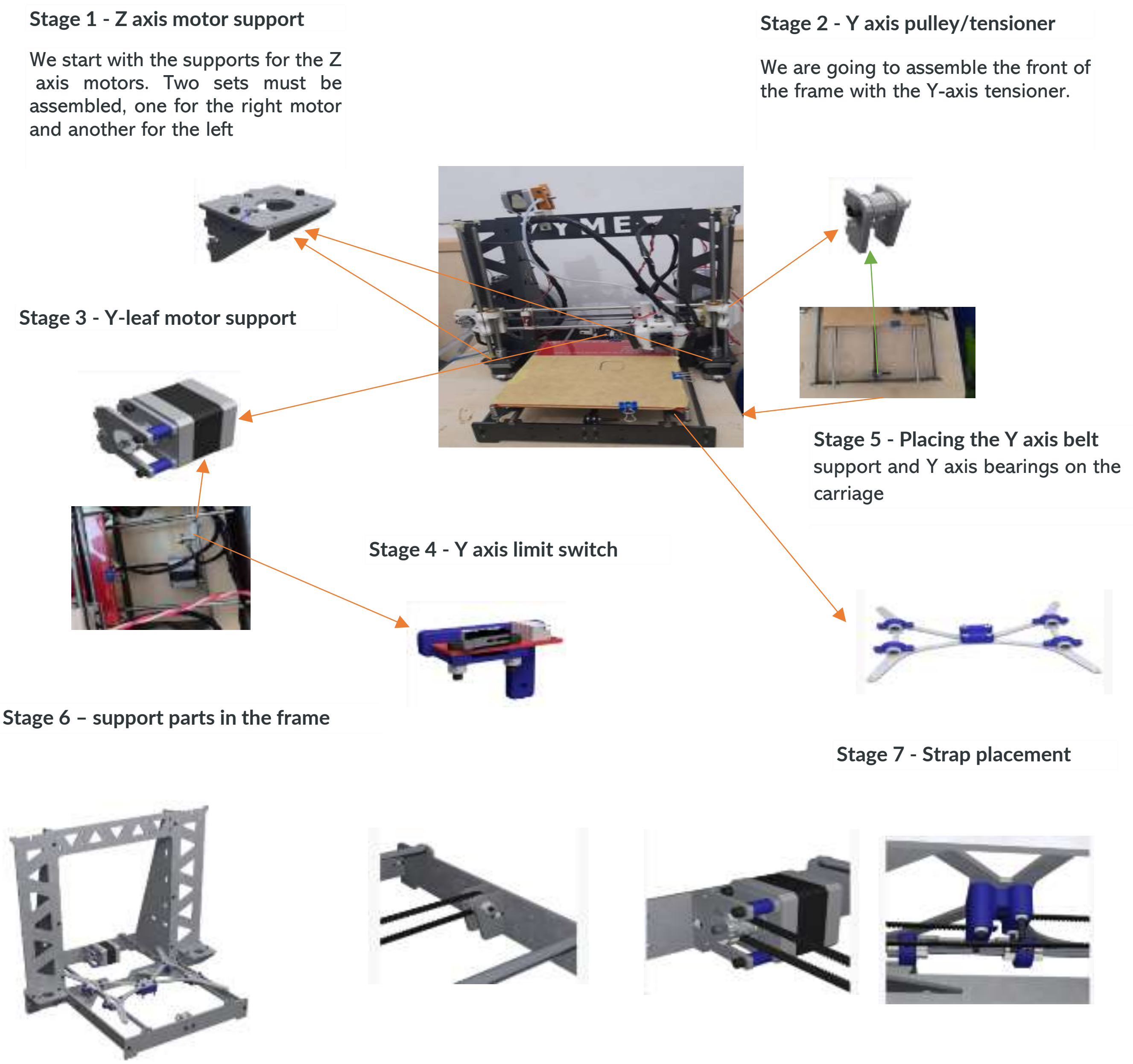

Fig. 9: (a) Assembly stages of the designed 3D printer

Electronic Control Circuit of 3D printer:

During the 3D printing process, each model requires a G-code. The 3D design is sliced into layers, and for printing each layer's points, specific temperatures and speeds must be set. These operations can be managed by various popular electronic hardware. Fig. 10 shows the electronic parts of the 3D printer. In this research, the electronic circuit of 3D printer contains the following electronics parts; (i) the Arduino AT MEGA 2560, one of the most commonly used models, is utilized. The connection between the equipment and the Arduino 2560 is facilitated by a RAMPS 1.6 shield. The primary controller for the control system utilizes the Arduino MEGA 2560 due to its capability of running open-source software. Additionally, the input power required is minimal, enabling the DC adapter to adequately power the Arduino Mega. Furthermore, this controller is cost-effective. (ii) the DRV8825 stepper motor driver module features micro-stepping capabilities. Its pinout is analogous to the A4988 driver, while providing enhanced performance. Both driver modules are compatible with the RAMPS shield utilized in 3D printers and CNC machines. (iii) AC/DC power supply for the motherboard that cannot be connected directly to an AC outlet. It requires a low DC voltage, either 12V or 24V depending on the board and 3D printer components. (iv) LCD screen: It works as a monitor and manual controller for your 3d printer. (v) Ceramic Heater: the heating component within a 3D printer is a crucial element that warms the printer's build platform or extruder.

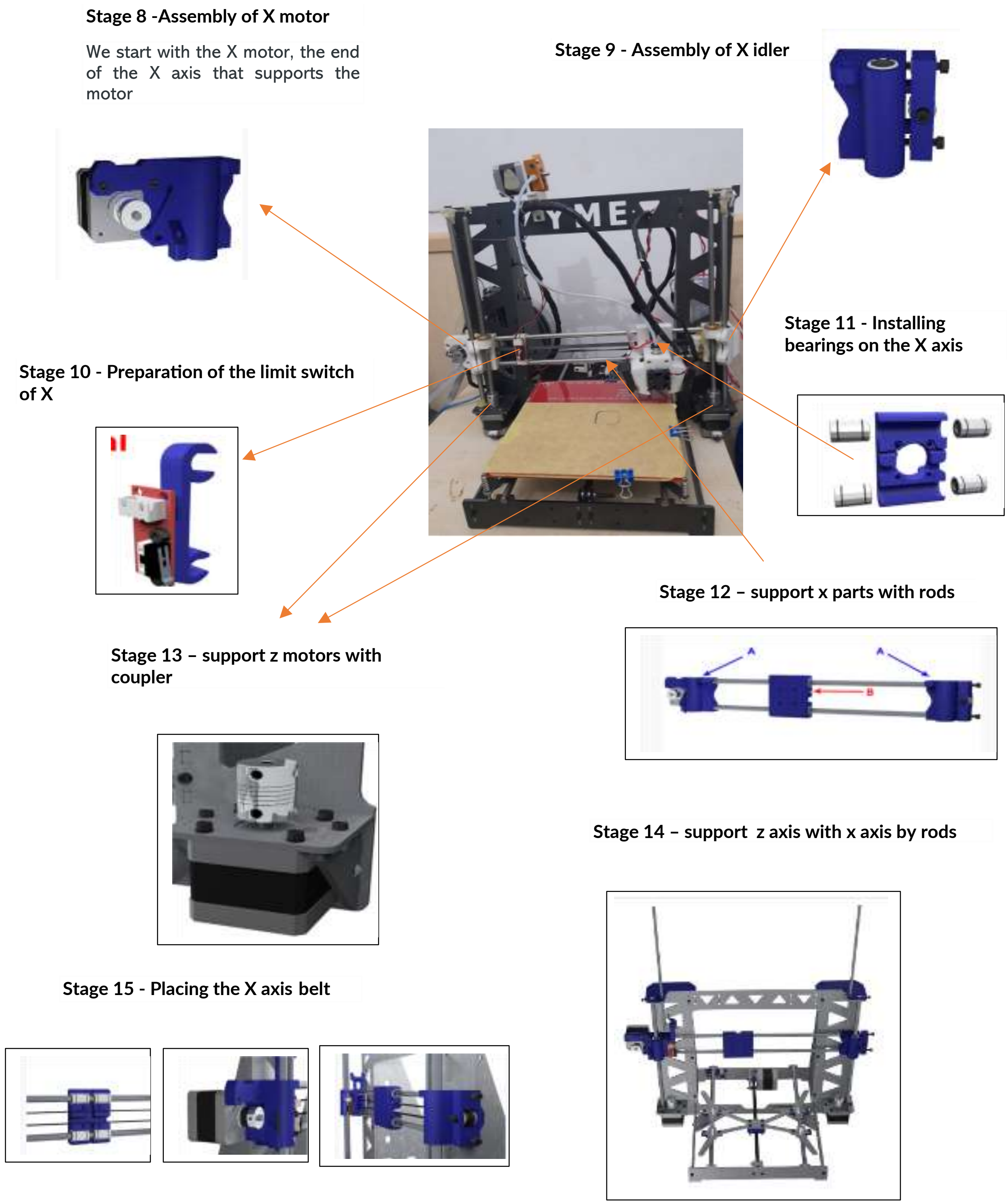

Fig. 9: (b) Cont. Assembly stages of the designed 3D printer.

nozzle. A 2V 40W Heater Cartridge Ceramic hot end heating tube with uniform distribution of heat for 3D printer was used. (vi) 3D touch: it is an auto leveling sensor for 3D Printers that can precisely measure the tilt of your print surface. It can greatly improve the printing precision of your 3D printer. (vii) thermistor: it is a type of resistor whose resistance exhibits a pronounced dependence on temperature, more so than in standard resistors.

Thermistors are commonly utilized as temperature sensing elements in printer extruders and heated beds. In the majority of RepRap systems, a thermistor is employed to measure the temperature of the hot end. (viii) end switch: A limit switch is an electromechanical device activated by the movement of a machine component or the presence of an object. They serve a crucial role in control systems, providing safety interlock functions, and enabling the enumeration of objects traversing a specific point.

This electronic circuit controls all necessary printer functions, including motor movement, cold plate cooling, heating elements, and more. Figure 5 illustrates the system's electronic components.

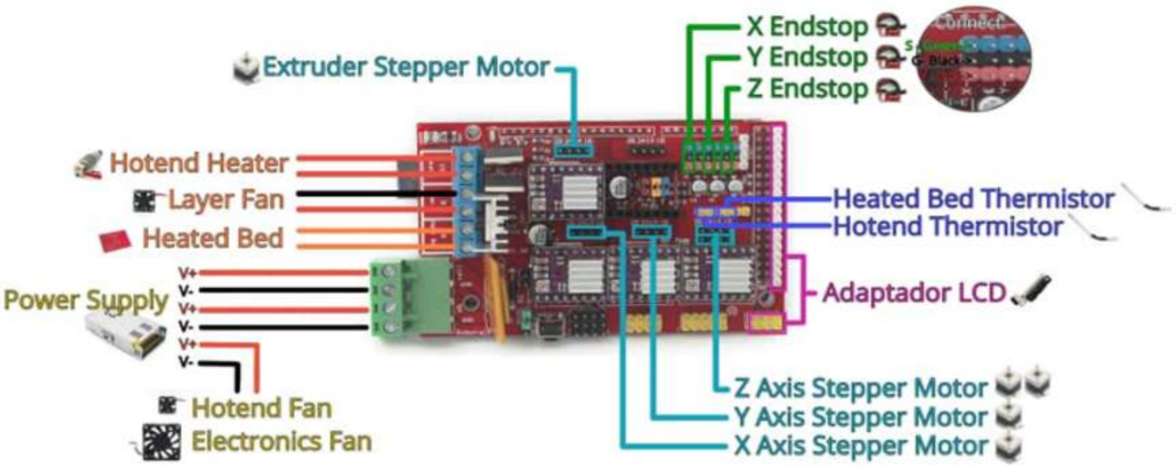

Fig. 10: Control Circuit of the designed 3D printer

Software:

After generating the G-Code and interpreting the commands using the firmware as it was illustrated in the methodology section, the firmware and G-Code are then uploaded to the microcontroller. The microcontroller issues the necessary signals to the motor drivers to regulate the speed and orientation of the axis motors. The heat generated by the hot end is controlled by using feedback signals from the from thermistor.

In 3D printing, the user-interface software represents a crucial component that demands meticulous selection. This host software is tasked with multiple responsibilities, including the creation of three-dimensional models, the segmentation of objects, and the conversion of stereo lithography (STL) files into G-Code format. There are numerous software applications available for designing 3D models and converting STL files into G-code. Ultimaker CURA is one of the used softwares that executes the slicing operation on 3D models as shown in Fig. 11. In other words, it converts the 3D printing file into the G-code format [17]. Pronterface [18] was chosen for its interface to convert files to G-code format. Furthermore, it enables direct communication with the firmware, eliminating the requirement for additional software. Pronterface, as depicted in Fig 12, is a graphical user interface software that incorporates a built-in application called a slicer. The slicer is primarily responsible for converting STL files into G-code and slicing the 3D model. The slicer interface consists of four principal tabs: the plater, where 3D models are sliced and converted to G-code; the print settings, which contain the parameters controlling the printing method; the filament settings, where filament information can be configured; and the printer settings, which encompass the parameters related to the printer itself.

Implementation and results

The integrated bed probe sensor system enables automated leveling of the build platform surface within the 3D printing machine and associated controller firmware. The methodologies utilized to derive the reported findings, as well as their substantive implications, are elaborated upon in the following sections. The 3D printer executes the additive manufacturing process from the G-code 3D design that has been created utilizing filament material as the construction medium.

The printer's initial calibration involves determining the calibration factor using developed firmware and the load cell reading.

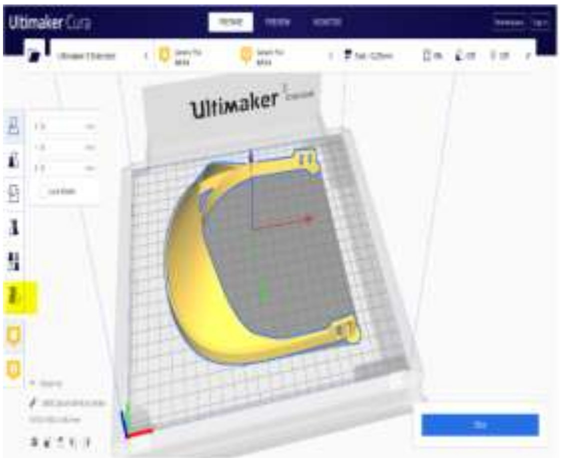

Fig. 11: Ultimaker CURA interface overview

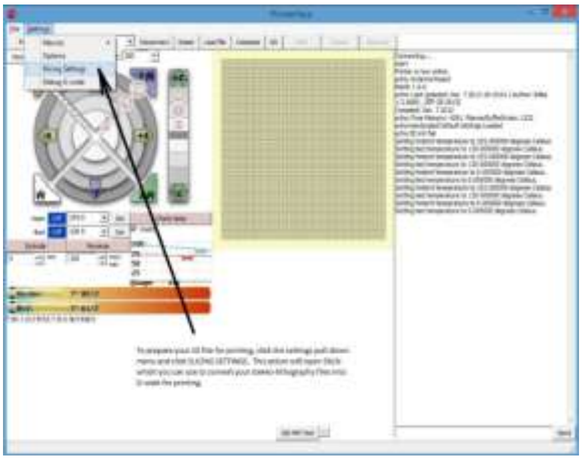

Fig. 12: Pronterface interface

The Arduino IDE is used to compile the code, which is then flashed onto the microcontroller, and the 3D printer machine is subsequently evaluated. The firmware's functionality is verified by adjusting the bed level and nozzle using the knob. If the knob is loosened, the bed will contact the nozzle, as indicated by the illumination of an LED. Tightening the knob moves the bed away from the nozzle, and the LED light turns off to signify this change. Initially, to verify and calibrate the positioning of the device, two-dimensional figures were printed using a 60% boat sample. After some adjustments, the desired results were achieved. Following the planar shapes, several 3D parts were printed. Initially, due to the low viscosity of the used material, the printer was unable to print accurately over the previous layers, and the boat could not maintain its shape after extrusion. Consequently, hydrocolloid additives were employed to increase the viscosity. Mechanical parts, sliced for 3D printing, are produced from PLA using the Pontefract interface software., as depicted in Fig. 13.

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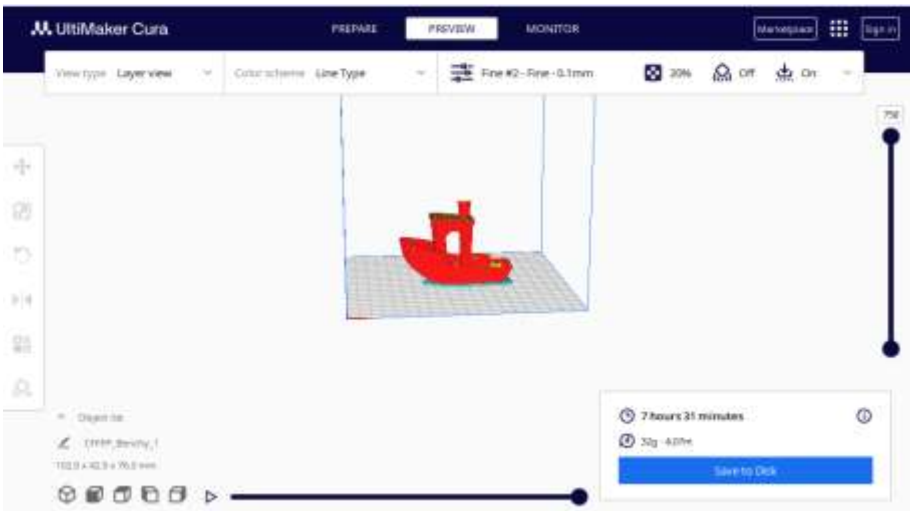

Fig. 13: Slicing using cura

Auto bed leveling simplifies the process of changing the build surface, eliminating the need to recalibrate the printer. It ensures high precision printing even with uneven heating or a warped build plate. Integrated sensors maintain the print head's parallel movement to the bed, removing the need for manual adjustments of bed leveling or Z-height. In 3D printing, only the required amount of material is used, significantly minimizing waste. Traditional methods such as CNC cutting and injection molding often generate large amounts of scrap, since they involve removing material from solid blocks. In contrast, additive manufacturing produces components in bulk according to user specifications while consuming only the material needed for each part—no more, no less. Furthermore, materials from 3D prints can be easily recycled, making the process both cost-effective and environmentally friendly.

Fig. 14 presents the printing results with boat of varying viscosities. For basic geometries, such as the depicted Z-shape, a precision of 0.2 mm was achieved.

After the 3D printing process, the chocolate lacked sufficient strength to maintain its form during removal from the build plate. Measurements indicated that it had not cooled adequately. To address this, the printer screen temperature was lowered using cooling elements. The final printed parts, as shown in the figure, demonstrated satisfactory results.

Fig. 14: 3D objects using ordinary boat.

Conclusion

In this study, the design and development of an auto bed leveling 3D printer were presented. A custom 3D printer was constructed, and the extrusion system was designed according to the specific properties and requirements of the boat. The electronic components, including motors, drivers, cooling units, and sensors, were also described. Printer performance was evaluated through multiple tests, during which certain elements such as rails and motors were modified to enhance functionality. Trials with standard boat were conducted to produce 3D objects, and hydrocolloid additives were later introduced to improve print quality by adjusting chocolate characteristics. Ultimately, the printer successfully produced satisfactory 3D parts and will serve as a platform for future research on chocolate additives and the fabrication of more precise geometries. For future research, some features can be added to the designed 3D printer platform to enhance its functionality such as Increased Print Speed, Dual Extruders, Auto-shutdown Mechanism, Larger Print Area, Multicolor Printing, and In-Print Error Detection.

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