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3D Printer Design

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ABSTRACT

The present project aims at design and manufacture of a 3D Printer with the capability of printing various pieces in arbitrary dimensions and size using the materials and filaments found domestically in a way that the devices make the piece in a reduced period of time and gives an acceptable precision and structure.

Key words: 3D Printer, printer design, industrial pieces, conceptual design, primary and partial

INTRODUCTION

3D printing robots give us various types of pieces with various forms and structures [7, 8]. They provide us with the required prototypes for investigation and analysis of their performance with the least time and cost resources. These printers give us a wide operational scope to the designers and give them the prototype and the sample required products without the need for die making and lathing at the lowest price. A 3D printer can easily print and manufacture anything from a vase, car, house, flower, gear, or anything we need as a prototype like various industrial pieces, jet engine parts, etc. these printers indicate the needs of the production line and may allow customization and production of products based on the needs of the customer. They will make the production line very flexible in the near future in terms of tasks and production. In fact, at present, international companies in high-tech areas have developed samples of metal and laser 3d printers based on the needs of each product.

Conceptual design phases

a. Need assessment
b. Feasibility
c. Requirements analysis, including:
    1. Technical requirements analysis
    2. Managerial requirements analysis
    3. Operational requirements analysis
    4. Procurement and maintenance requirements analysis
d. Choosing TPM or performance assessment index
e. Performance analysis and assignment

Feasibility study of drive unit (stepper motors and drivers)

Here, the aim is to supply the force and moment required to drive the various parts in the printer to obtain the precise spatial positions with the least error and vibration. We use the stepper motors to keep away from the high costs of servomotors as well as the need for controllers and more complex processors. These motors have a digital angle finder and move to the precise location using the PWM signal and its cycle amplitude. Since they move step by step based on signals, there is no need for an RVDT feedback from the position, and this is an open-loop actuator with a theoretical precision of 0.7°, which is relatively suitable for our objectives.

Feasibility study of the supply unit

The supply unit consists of two components: first, the DC adapter and then the shield, which is a connector between the control unit and motor drivers. This unit has an important effect on drivers and power supply by keeping down the noise from the instantaneous withdrawal of power on the processor and by proper assignment and instantaneous management of the load required for the drivers of the stepper motor.

Feasibility study of processor and control command

This unit consists of the processor, user panel connectors, and the connectors between the calibrated sensors and memory. The software is installed on this hardware unit and runs from there. This unit allows effective connection with the shield and responds to the status of the supply unit, and consists of processors, digital decoders for obtaining data, and analogue and digital ports.

Feasibility study of chassis and turret

The chassis is responsible for making the physical connections possible for all parts of the printer and keeping the parts together. It determined the operational dimensions of the printer. The chassis and the turret undergo more significant vibrations compared to other parts considering that they host the motors and injection components. Also, they are mainly responsible for damping these vibrations. So, they require higher strength, weight, and durability against vibrations. Viable options to be used in this unit: 1. Aluminum, 2. Polymers such as polyamide or polyethylene, and 3. Plexiglass.

Considering the proper costs and weight, the robot is confirmed by the identification unit to be feasibly manufactured.

Feasibility study of the conveyor and piece floor adjustment unit

This unit is part of the mechanical chassis and performs a 1-degree-of-freedom movement on the 3D printer. It is moved by the stepper motor and uses a switch at the end of the stroke to indicate its primary position in the processor. Since the weight of the piece being manufactured is completely born by this unit, the system moves on a shaft and very smooth bearings so that it may move and take the required positions with the least force. For this unit, the shaft and bearings are used for movement, belt pulley or gear rail for transport, and the plexy or aluminum for the piece floor. With the proper design of the floor and the appropriate position of the switch, maximum manufacturing precision could be achieved.

Feasibility study of the injection unit

This unit is responsible for injecting at a proper rate and delivering the raw melt to the end effector. It consists of a stepper motor to transfer the filament at the rate required by the processor unit, a heater with the RTC thermometer to maintain optimal conditions, and adjustment of the injection temperature in the tip, which not only maintains the high temperature but also leads to increased injection quality from the tip and deposition on the piece. The filament transfer can be performed using a pulley or a gear. For better temperature control, a fan can be used to cool the chassis around the heater. This unit will be placed at the tip of the arm, and due to the considerable weight, it is possible to use stepper motors with less precision and smaller size mounted on an aluminum injection chassis to reduce the weight and save costs.

Feasibility study of arm transmission unit

The transmission mechanism involves an arm with two prismatic degrees of freedom, the first of which, consisting of the z-axis and the transmission at arm’s height, may be performed using the ball screw and the stepper motor drive. The balance may be maintained by using shafts and bearings moving along the z-axis. The second part is the transmission of the arm itself, which moves axially and makes possible the end effector transmission using both belt pulleys and gears. This dual mechanism sets the device free along the Y and Z axes and provides transmission in two spatial dimensions above the workpiece. Considering the suspension state of the injection mechanism as well as the transmission of the Y-axis in space, as well as the fact that the whole pressure of the system is on the ball screw, this is a very sensitive part that should withstand the most static pressures and bending. Therefore, using the proper diameter of the ball screw as well as the softness of the shafts and bearings, a high strength may be achieved in the arm by reducing the vibrations of the expected accuracy. This is one of the most challenging parts in terms of design and structural complexity, on which three servomotors, injection chassis, and END ENFFECTOR injection transmission arm are placed, and it has two prismatic degrees of freedom.

Feasibility study of the control unit

The responsibility of the control unit is controlling the motors, data reception from the sensors, making communications between different parts of the robot, as well as receiving and sending data to and from the robot. One of the important points about this part is using a controller with low software complexity and cost. The three most common controllers in robotic projects are AVR, ARM, and ARDUINO series processors. In addition, this unit may take advantage of a variety of controllers such as PID, etc. Therefore, by correct adjustment, the maximum conformance of the command and the inherent properties and frequency of the structure could be achieved to reduce the vibration in the system and increase accuracy. The controllers in the ready-made Lego kits could also be applied. In terms of the control unit, robot manufacture is feasible.

Feasibility study of detection and calibration unit

This printer unit is used at the beginning of the work to obtain the initial position of the desk and the arm relative to each other with the use of a set of switches, and then, based on the print map data, the printer moves to the workpiece position.

Reviewing the tasks and through the experience of the group members, it would be possible to perform the detection process at an appropriate speed.

Summary of the feasibility study

Taking into account the feasibility study of various units of this mechanical system, it can be concluded that this mechatronic device has the potential to meet the needs of the employer, that is, making a 3D printing machine. In addition, this machine can feasibly be manufactured, and different parts can be used for different requirements and different units. This is discussed in detail later.

Requirements

Managerial requirements

The project should not exceed a certain time limit. The final cost should be in check. The robot should complete the tests a sufficient number of times. It should have a good level of performance. The activities of the team members should be controlled and performed according to plan.

Functional and technical requirements

The functional requirements of the system are as follows:

1. The printer should have the capability to manufacture a piece with minimum dimensions of 10x10x20 cm.
2. The printer should have the capability of long-term continuous operation, i.e., min. 4 hours.
3. The printer should have the capability of injecting filaments available in the market, such as ABS and PLA, with a minimum thickness of 1 mm.
4. The printer should be able to create a print resolution of at least 100µ.
5. The printer should have the capability of printing and injecting at a minimum speed of 3.6m/h.

Maintenance and support requirements

There are three levels of maintenance and support, as follows:

1. Simple level: If the parts, nuts, and joints are loosened, the user should be provided with the basic tools. Also, after the job was done, the injection residuals should be cleaned from the workbench.
2. Intermediate level: Broken parts that are repairable. Failure of part of the printer due to minor mistakes by the dealer.
3. Advanced level: Replacement of main components such as sensors or processors, loss of components that require the intervention of the manufacturer.

Technical and Performance Measurement Criteria (TPM)

Table 1. Technical and performance measurement criteria of the 3D printer

Electronic and control subsystem	Supply unit	12V AC adapter with minimum 20 amps dc and shield capable of managing and distributing 700 watts of power between drivers and long-term operation (more than four h)
	Processor and control command unit	• Noise resistant • Communication with the user panel, sensors, and shield • Possibility of processing data and command in real-time to control drivers as accurately as possible • Sending and receiving digital and analog commands and signals
	Drive unit (stepper motors and drives)	• Motors should be powerful enough to move the arm and desk of the printer. • Motors should be able to maintain a precision of at least 5 microns or half a degree • Motors and drivers should be controlled and processed by the controller
Mechanical subsystem	Chassis and turret unit	• High strength and vibration tolerance • Vibration damping capability
	Workbench floor transmission and adjustment unit	• Smooth transmissibility of the workbench with the weight of the whole piece and the least inertia at a weight of at least 500 grams • Keeping the workbench level under vibrations during the printing operation • Resistance to twisting and vibration • Minimum accuracy 10 microns in transmission

	Injection mechanism unit	• The capability of change injection rate • Possibility of injecting PLA, ABS filaments with a minimum diameter of 1 mm • Possibility of smooth and accurate in-situ injection of the melt
	Arm transmission mechanism unit	• Two prismatic degrees of freedom along the X and Y axes of the printer • At least 1 kg weight transmission along with the height • Vibration resistant • Accuracy of 10 microns in transmission
	Command and control panel	• The capability of installing the lcd2400 user panel shield • Correct placement of Arduino and processor • Accurate shield placement and proper connection to the power supply and power transmission cables to the stepper motor • Proper cooling of digital drivers and processors
Software subsystem	Control	• An operating system capable of receiving commands, and user interface • Possibility to set different types of controls and use common processors • Personalization of command with the physical and natural properties of the printer structure • Possibility of texture analysis and providing a print map for data received from the user • Possibility of connecting to gcode maker software and submission of online reports to the computer
	Detection and Calibration	• The initial and precise position of the workbench and the arms should be aligned at the beginning
	User interface	• Possibility of receiving commands separately from the user's PC • Possibility of providing coordinates and temperature and performance status during printing • Possibility of searching among commands • Possibility of using reset and stop commands • Possibility of displaying errors
	Gcode generation software	• Possibility of downloading parts simulation files from CAD • Possibility of creating an online link with the printer and online monitoring of the operation • Possibility of sending commands and separate injection temperature control • Possibility of representing the design errors • Possibility of defining the details of the texture and injection diameter

Primary and basic design

Table 2 shows the functional allocation in the partial product design.

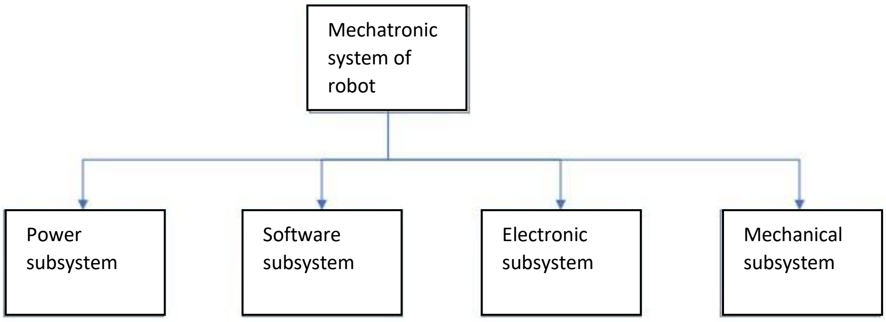
Table 2: Functional allocation at the second level

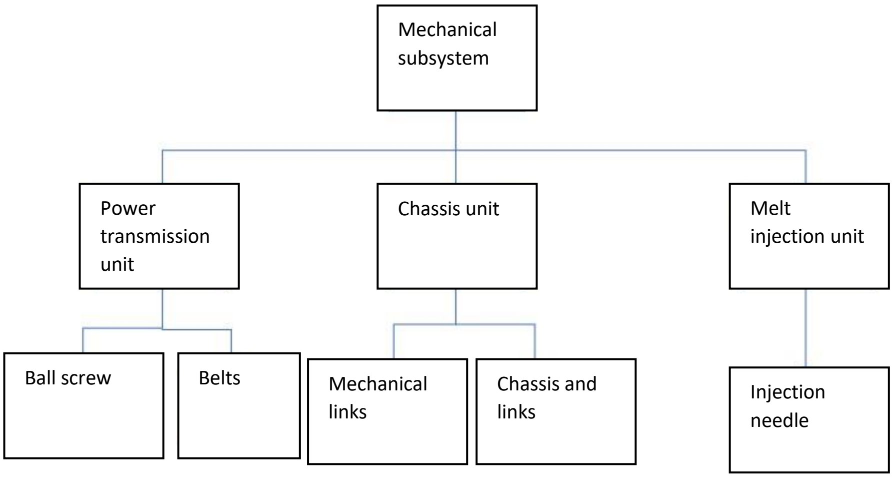
Function code	Function description	Function assignment	Input	Output
1.1	Removing parts and checking for defects	-	Machine kit	Manufactured machine and its accessories
1.2	Re-inspecting the machine and ensuring proper assemblage	-	Manufactured machine	Maintenance in case any defects
1.3	Inspecting electronic connections	Electronic	Machine's electronic connections	Maintenance in case any defects
1.4	Turning on laptop and machine's control system	Computer	Laptop	Laptop
1.5	Inspecting motor and drive connection	Electronic	Machine drives and motors	Maintenance in case any defects
1.6	Inspecting shafts and motors of the machine	Power	Shafts and motors of the machine	Maintenance in case any defects
1.7	Inspecting power transmission system of the robot, especially connecting cables	Electronic	Electronic parts and connecting cables	Maintenance in case any defects
1.8	Inspecting correct functioning of	Mechanical	Mechanical parts, including belts and links	Maintenance in case any defects
1.9	Melt injector installation	Mechanical	Melt injection mechanism	Maintenance in case any defects
1.10	Inspecting sensor	Electronic	Sensor	Maintenance in case any defects
1.11	Inspecting online connection between computer and printer	Computer	Laptop and Arduino	Data communication between Laptop and Arduino
1.12	Running the program	Computer	Laptop software	Maintenance in case any defects
2.1	Uploading the intended map into the central system	Computer	Map to be printer	Map scanning in computer
2.2	Testing, calibration, and preparation of the printer	Mechanical, electronic	Sensors and injection mechanisms of the machine	Sensors and mechanisms ready for injection
2.3	Pushing machine's power ON knob	Electronic	Machine	Machine ready to start printing
3.1	Obtaining final settings from end user	Computer	Unser interface	Final settings
3.2	Processing of roadmap of printing the workpiece	Computer	Final scanned map	Map processing for printing
3.3	Command for positioning arm and workbench at the reference point based	Mechanical, electronic, computer, and power	Input command from the central system	Positioning the arm at the reference point

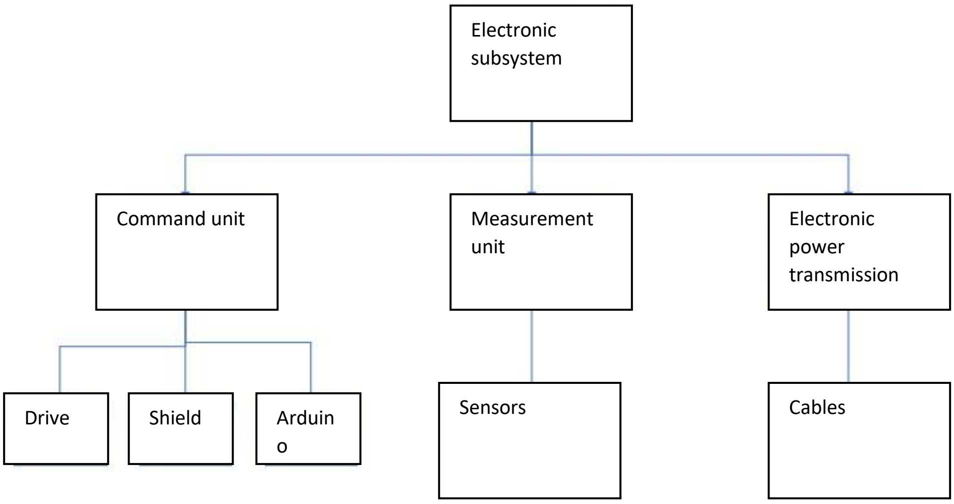
	on the user map			
3.4	Start of injection and movement of arm and workbench based on printing coordinates and roadmap	Mechanical, electronic, computer, and power	Input command from the central system	Map projected on the surface
3.5	Return to the reference point after injection	Mechanical, electronic, computer, and power	Input command from the central system	Positioning the arm at the reference point
4.1	Pushing machine's power ON knob	Electronic	Machine	Powered-off machine
4.2	Turning off the drive and operators	Electronic and mechanical	Drivers and actuators	Powered-off drivers and actuators
4.3	Turning off Arduino and sensors	Electronic	Arduino and sensors	Powered-off drivers and actuators
4.4	Collecting accessories and cleaning the area	-	Machine and accessories	Retracted kit of the machine
5.1	Mechanic troubleshooting	Mechanical	Inspecting mechanical parts	Maintenance in case any defects
5.2	Electronic troubleshooting	Electronic	Inspecting electronic parts	Maintenance in case any defects
5.3		Computer	Inspecting computer and software	Maintenance in case any defects
5.4	Power troubleshooting	Power	Inspecting motors	Maintenance in case any defects
5.5	Troubleshooting and maintenance	Mechanical, electronic, computer, and power	Defective robot	Healthy robot

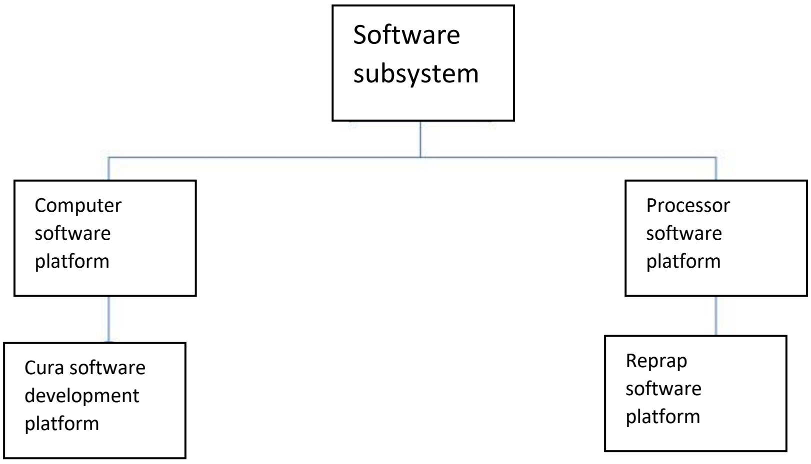
Tree diagram of subsystems at the partial design level

Fig. 1 shows the subsystems of the printer in a graph




Mechanical subsystem
Power transmission unit
Chassis unit
Melt injection unit
Ball screw
Belts
Mechanical links
Chassis and links
Injection needle


Electronic subsystem
Command unit
Measurement unit
Electronic power transmission
Drive
Shield
Arduin o
Sensors
Cables


Software subsystem
Computer software platform
Processor software platform
Cura software development platform
Reprap software platform

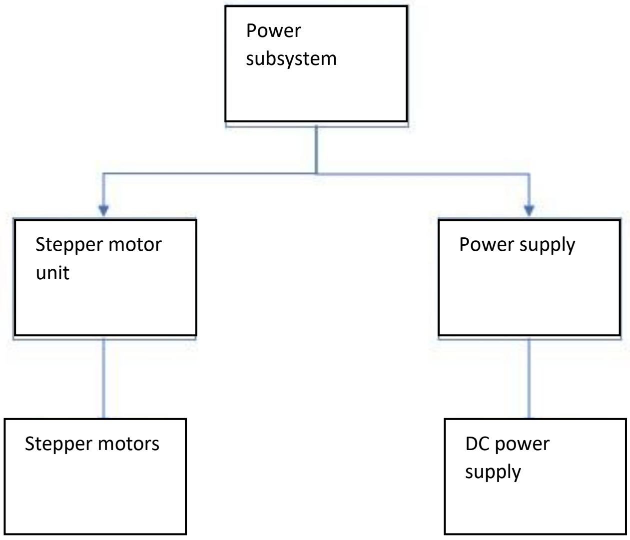


Figure 1. Division of the system into subsystems

Partial allocation of requirements

Operational and technical requirements of the mechanical unit

M-t1: Bearing of the forces (or pressures) in different parts of the structure made from plexy with a thickness of 6 mm

M-t2: No deformation in the structure

M-t3: Tolerance of the melting heat in the lower part when injected by plexy

M-t4: Tolerance of forces in ball screw

M-t5: Tolerance of forces in bearings

M-t6: Straightforward rotation of pulleys along with filaments

M-t7: Tolerance of vibrations and engine shocks by the plexy structure

M-t8: Tolerance of forces and ease of movement in belts

M-t9: No need for a 3D printer for printing parts of the printer

M-t10: Tolerance of forces using suitable screws and gaskets

M-t11: Lightness and simplicity of the mechanism

Operational and technical requirements of the electronic unit

E-t1: Proper processing of data sent from various modules such as thermometers and position switches as well as data sent from the user interface and computer software by the processor

E-t2: Sending/receiving analog and digital data and supporting suitable bandwidth to send video data to the user interface and to send data to computer software using an online method

E-t3: Requirement for a clean, noise-free communication platform with drivers and sensors

E-t4: Proper resistance of the data transmission network to ambient noise and vibrations of components during operation

E-t5: Support and adaptability of communication network with the analog flow of motor drivers

Operational and technical requirements of the power unit

P-t1: Provision of adequate power and amper for the simultaneous running of all components

P-t2: Full loading power supply in high consumption mode for all parts, including stepper motors and heaters

P-t3: Provision of electrical power in full loading mode for long-term performance, i.e., higher than 24 hours

Operational and technical requirements of the software unit

S-t1: Selection of an adequate software platform in the PC to receive and process CAD data and their conversion into GCODEs and the possibility of real-time communication with the Arduino processor platform

S-t2: Design of a programming platform based on the type of input data of sensors and motor feedback and receiving data from the user panel and computer software

S-t3: Appropriate Arduino programming structure for high-speed operation compatible with data processing for the real-time performance in software decision making

S-t4: Proper storage and preparation for processing in the command and control unit

S-t5: Selecting appropriate software platform aiming to adjust the texture density and route

S-t6: Adjustability of injection speed and temperature in computer software

S-t7: Capability of determining the type of filament in the platform and injection based on the material used

S-t8: Arduino programming capability to display injection position coordinates and errors in the user interface

S-t9: Capability of integration anding send commands to various stepper motors and related drivers and support for PID controllers in the Arduino programming platform

Support and maintenance requirements

Mechanical unit support and maintenance requirements

M-s1: Inspecting the correct placement of the feed filament in the injection unit

M-s2: Proper heating of the injection unit

M-s3: Inspection and tightening the bolts and nuts

M-s4: Aligning the chassis with the workbench

Support and maintenance requirements of electronic unit

E-s1: Capability of supporting and replacing machine's consumables such as cables, sockets, etc.

E-s2: Inspection and ensuring the proper connection of actuator and sensor modules to the CPU unit

E-s3: Ensuring proper connection of the CPU core to the control board

E-s4: Using a technical team for support in case of defects

Support and maintenance requirements of the power unit

P-s1: Using a proper power supply that fully supports the need for power during operations

P-s2: Using an infrastructure for re-powering in the shortest time

P-s3: Proper ventilation during long operations and full loading power supply

Support and maintenance requirements of software unit

U-s1: Obtaining a file with the CAD format appropriate for analysis

U-s2: Online communication and detection of a computer with Arduino and sending/receiving data online from Arduino

U-s3: Using a technical team for troubleshooting

U-s4: Checking the feedback sent from the injection tip and temperature controller in the user panel and computer software

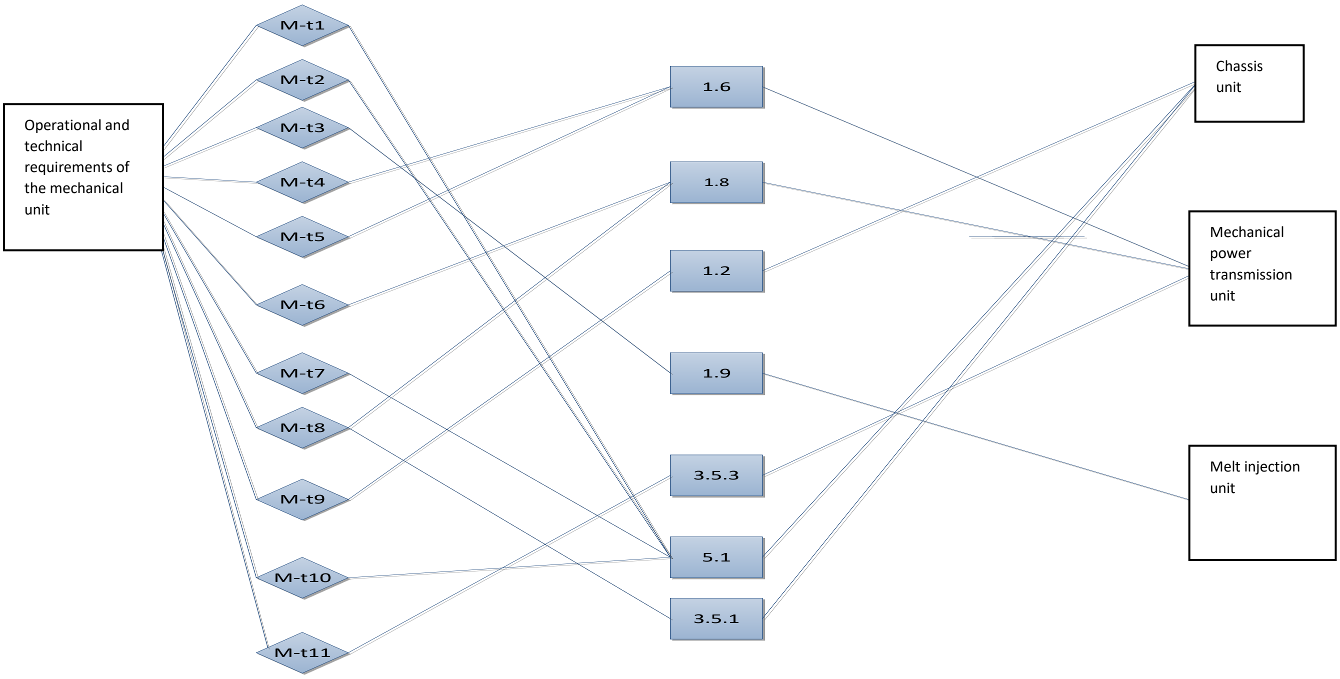


Figure 7. A functional packet of operational and technical requirements of the mechanical unit

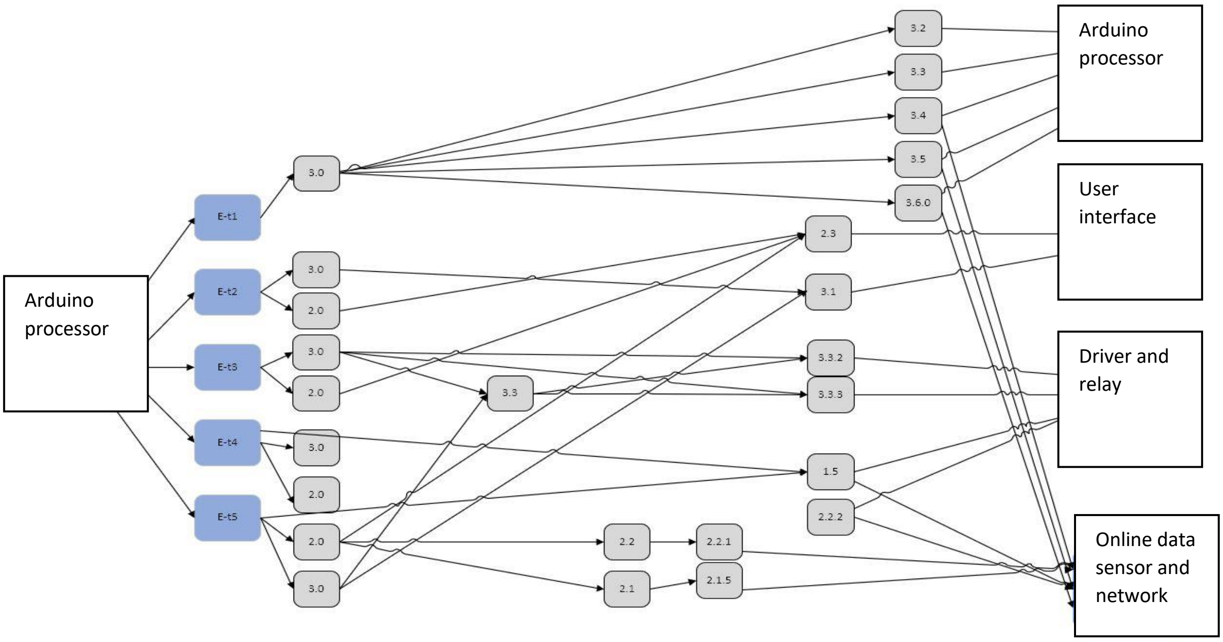


Figure 8. A functional packet of operational and technical requirements of the electronic unit

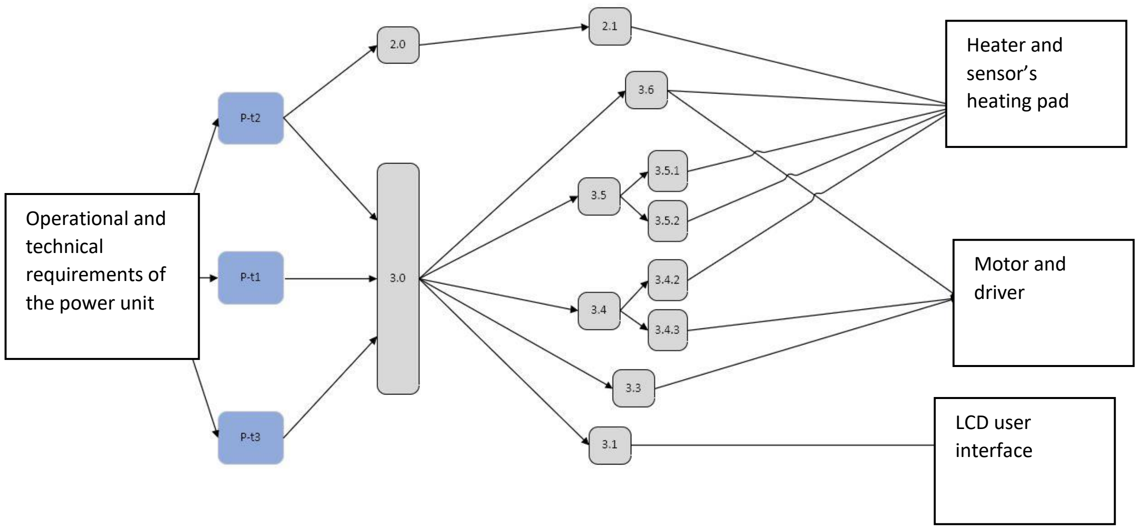


Figure 9. Functional packet of operational and technical requirements of the power unit

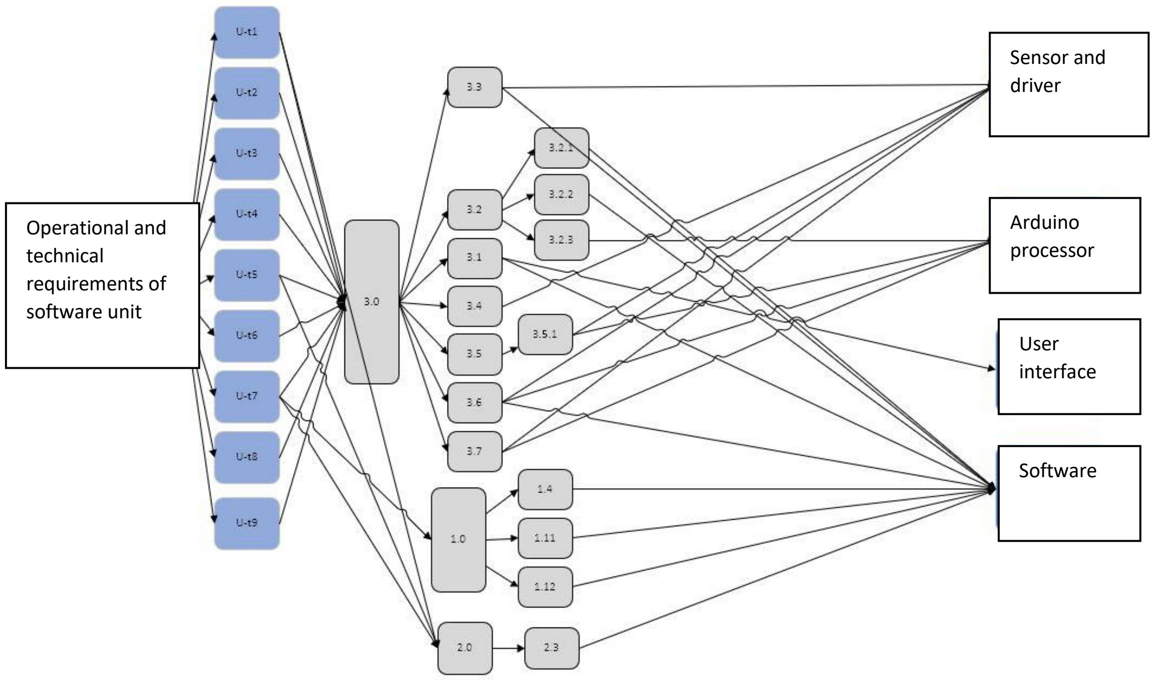


Figure 10. Functional packet of operational and technical requirements of the software unit

Correspondence studies

Table 3. TPM of 3D printer body module

TECHNICAL PERFORMANCE MEASURE	Quantitative Requirement	Relative Importance
Dimensions (Inch)	6*6*6	**15**
Pressure tolerance (kg)	5(minimum)	**25**
deformation	1µ	**25**
Vibration tolerance	10	**10**
Reliability (%)	99.9	**25**
		100

Parameters	value
Dimensions	**[6*6*6 8*8*8]**
Pressure tolerance (kg)	**[5 10]**
Deformation (µ)	**[1 4]**

The vibration tolerance in the chassis should be about 10 Hz. This vibration transfers from the stepper motors to the chassis and is partially controlled by metal couplings.

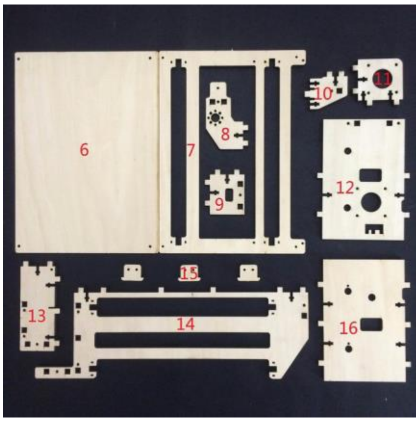


Figure 2. View of chassis

Table 4. TPM of Power transmission module

TECHNICAL PERFORMANCE MEASURE	Quantitative Requirement	Relative Importance
Precision required in ball screw	Min. 10 µ	**20**
Precision required in belts	Min. 10 µ	**20**
Weight tolerated by ball screw	Min. 6 kg	**30**
Pressure tolerated by belts	Min. 3N	
Reliability (%)	99	**30**
		100

Parameters	value
Motion precision required in ball screw (µ)	**[0 10]**
Motion precision required in belts (µ)	**[0 10]**

The ball screws have to be able to bear the weight of the overhead parts, including the filaments and the motor. In addition, along with supporting the pressures and provision of a suitable space in terms of dimensions, the bearings in the upper part of the turret and under the board and the ascending part of the injection mechanism should also allow low motion wear. The ball screw is used instead of the belt in the z-direction, taking into account the low-pressure tolerance of the belt. The pressure borne by the belts is related to the beginning of the motion, where the belt moves the relevant platform, weighing about 5 kg, with an acceleration of about 0.5 m/s.

Figure 3. View of power transmission system

Table 5. TPMs of melt injection module (extruder)

TECHNICAL PERFORMANCE MEASURE	Quantitative Requirement	Relative Importance
Injection rate	Min. 3.6 m/s	**20**
Heater power	40 W	**25**
Filament material	PLA,ABS	**30**
Reliability (%)	98	**25**
		100

Parameters	value
Injection rate (m/s)	**[3.6 4]**
Heater Power (Watts)	**[40 50]**

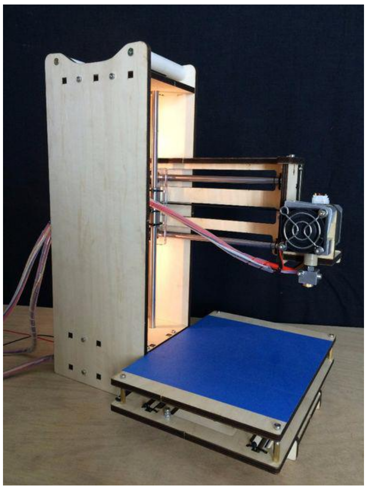


Figure 4. View of melt injection system

Synthesis, analysis, and evaluation

First, the map used in the project is evaluated

In the manufacture of the 3D printer, some parts are used as standard, and, as follows, they have similar values for the domestic printers:

1. Shaft diameter (8 mm)
2. Linear bearings
3. 20-tooth belt pulley

4. Flexible coupling
5. Bolts used
6. Extruder (MK8)

In this project design (Fig.1), two rods were used to fix and align the above chassis so that the deformation of this part, which holds the filament and the extruder, reaches its minimum and it maintains a 10µ precision. A 6mm Plexiglas plate has been used to increase the strength, bear the vibrations and align the machine. In order to move along the X and Y axes, a belt has been used. One of the belts which move the upper part is fastened with a 90° angle against the body. The other one, which moves the workpiece, is fastened, as shown in Fig. 5, due to the non-availability of proper space. Also, the ball screw has been selected based on its precision and weight tolerance, as mentioned before. In order to dampen the vibrations, the motors are placed on an elastic frame so that lower vibrations are transferred to the body, and the required precision is maintained. In terms of the costs of the chassis materials, it should be noted that the wood is 30% cheaper than aluminum and Plexiglas.

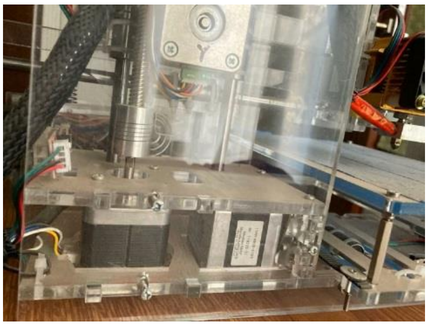


Figure 5. Model 1

In Model 1, we have:

Body	Power transmission system	Injection
Plexiglas with a thickness of 6mm in all parts of the printer	Use of belts in the X and Y axes	Possible to use ABS, PLA filament materials
Using an extra 2mm for maintaining alignment	Using 2 ball screws in the Z-axis for better stability and maintaining alignment, and keeping away from deformation	Application of MK8 extruder
Fixing is performed by making square cuts and creating holes inside the body and integrating them together with bolts	Other items are common to all domestic 3D printers	

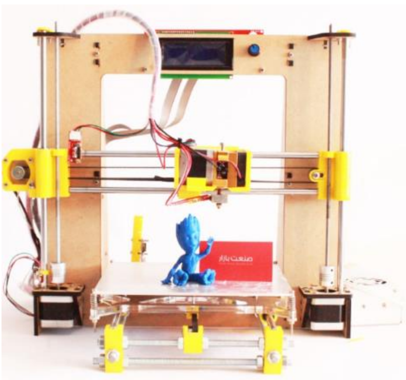


Figure 6. Model 2

In Model 2, we have:

Body	Power transmission system	Injection
Laser-cut wood (MDF) is used, and several parts are made of Plexiglas with a thickness of 6 mm	Use of belts in the X and Y axes	Possible to use ABS, PLA filament materials
Using an extra 2mm for maintaining alignment	Use of ball screws in the Z-axis	Application of MK8 extruder
	Other items are common to all domestic 3D printers	

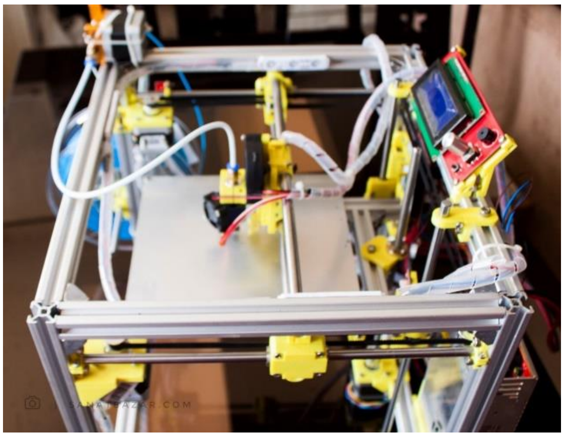


Figure 7. Model 3

In Model 3, we have:

Body	Power transmission system	Injection
Aluminum body	Use of belts in the X and Y axes	Possible to use ABS, PLA filament materials
Using an extra 2mm for maintaining alignment	Using 2 ball screws in the Z-axis	Application of MK8 extruder
	Other items are common to all domestic 3D printers	

Analysis of arrangements

Power transmission module: In this module, all parts are common to all three models. The only point is that in this, a filament with a diameter of 1.75 mm should be injected at a rate of a maximum of 1m/s.

Table 6. The final result of the mechanical unit

TECHNICAL PERFORMANCE MEASURE	Model1	Model2	Model3
Body	99	94.25	**98.9**
Power transmission	99.25	95.2	**95.2**
Extruder	100	100	**100**
Mean	99.41	96.48	**98.03**

Therefore, Model 1 was selected. It should also be noted that there is a slight difference between Models 1 and 3, but in the end, Model 1 is more suitable considering that it meets the requirements and has a lower cost.

Electronic unit

Due to their electromechanical nature, high considerations should be taken in the design and selection of components of 3D printers in terms of data communication, power, instrumentation, and weight. For example, communications and processing, which are performed by the processor and controller, are directly affecting the selection and operation of the appropriate software platform and even completely change the programming and functional logic. The power unit and the motor are chosen based on cost, weight, and precision. They may, in turn, have a tremendous impact on the choice of power supply and drivers. Therefore, in terms of designing and selecting the electronic platform, there are different 3D printers, each of which includes its own software packet, electronics, and power supply, and sometimes they use languages other than c and ide.

Requirements:

1. Suitable for Cartesian printers with three degrees of freedom
2. Support for a wide range of Nema stepper motor precision instruments, having the potential to support the ability to move half a step
3. Capability of repairing, replacing, installing, and adapting to different drivers of the A-XXXX family for stepper motors
4. Com32 online communication support with computer software and user interface
5. Continuous operation for at least 7 hours
6. Ability to handle at least one extruder
7. Maintaining quality at different printing speeds and the possibility of printing at a speed of more than 4 mm per second
8. Supporting monitor and sd card in the user interface
9. The finished cost of the board and driver is less than 1 million Tomans
10. Board resistance against electrical noise from the driver and also against under-voltage and under-amp phenomena during operation due to the power supply unit
11. Ability to store minimal programs with 50 MB of internal storage
12. Support and compatibility with common market platforms such as marlin, mendel, etc.
13. Having the minimum performance in DIY project

Table 7. Requirements of the electronic unit

Requirement No	Description	Score	Arduino mega/ reprap shield	ANET3D 1.7	GTM32
1	1=existing 2=nonexistent	1	1	1	1
2	2 means supporting more than one driver families	4	4	1	3
3		4	4	0	0
4		2	2	2	2
5		4	2	3	4
6		3	2	2	3
7		6	2	2	6
8		2	2	1	2
9		10	10	4	2
10		3	2	3	3
11		1	1	1	1
12	Score based on the number of supported platforms	4	4	2	3
13		4	2	2	4
14					
Total		48	38	24	34

According to Table 7, the Arduino mega/reprap shield seems to be the most logical alternative as the electrical infrastructure.

Software unit

It consists of command codes and control methods on the printer processor and computer software. This unit is responsible for receiving and processing raw files based on cad, conversion to Gcode based on user preferences, exchanging data and online communication with the printer processor platform, receiving and analysis of GCode control and position commands, and finally, sending commands to the electronic unit, drivers, relays and user interface.

The in-processor programming is known as frameware. It converts software data into control commands to be understood by the hardware. On the other hand, in the 3D printing industry, there are many computer programs that perform convert cad into gcode. What determines our needs here is the online data exchanges of the computer throughout the operation, with the program running inside the printer processor. Therefore, the selection of computer software is largely a function of the programmed platform in the central processor (frameware). This software platform inside the processor should be compatible with the dimensions, performance specifications of the printer and the processor so that the printing process is performed with the maximum speed and best quality and requires reasonable processing power. The following is a table of requirements for selecting and adapting the appropriate application platform based on the first platform selected in the electronics section because not every frameware is suitable for every board, and not every board can run every firmware. Regarding the analyzing software, CURA had the best communication and operational performance with the desired electronic processor and the selected application platform taking into account the existence of a wide range of software and the high compatibility with the entire printer software platform, according to the discretion and experience of the user interface, and based on the performance of printer components during operation.

Requirements:

1. Adaptation of the upstream application platform of the Arduino board with the frameware
2. Compatibility with printer hardware components
3. Compatibility and easy correction of computer compiler and TEXT EDITOR
4. Suitable size to run on EEPROM processor
5. Programming structure commensurate with processor speed and real-time control response in command modification
6. Availability of appropriate control settings for each motor and heater operator
7. Supporting eight and 32-bit processors
8. High speed in gcode file processing
9. Supporting microcontrollers based on ARM and ATMEL/ATMEGA
10. Supporting half and a quarter step in the stepper motor settings
11. Supporting multi-material printing capability
12. Availability of technical community and appropriate instructions for fixing problems in functional settings
13. Supporting the web-based network configurations and control
14. Supporting the STL-file receiving and processing
15. Compliance of GUI with the Slicer software
16. Supporting RAMPS
17. Running operations using the sd card

Table 8. Requirements of the software unit

Requirement No.	Requirement factor	Score	RepRap	Prusa	Klipper	marlin
1	3	5	5	3	0	5
2	2	5	5	5	3	5
3	3	5	5	2	0	5
4	2	5	4	3	1	3
5	2	5	4	3	5	5
6	3	5	5	2	5	5
7	1	5	5	2	2	5

8	1	5	4	3	5	4
9	2	5	5	5	0	5
10	2	5	4	1	5	4
11	1	5	5	3	5	5
12	3	5	5	0	2	4
13	1	5	4	0	5	2
14	3	5	5	5	5	5
15	1	5	5	3	4	5
16	2	5	5	3	0	5
17	1	5	5	0	0	3
Total		85	80	42	47	75

Based on the studies and Table 8, it could be concluded that the RepRap is the most compatible platform with this project.

The RepRap platform has been specially designed for systems with multiple board controls and is the first system to support 32-bit architecture. The system is updatable and supports sd cards. There is also a wide range of libraries and sites for online support and modification and reconfiguration of the system. In general, operational support is at hand in the technical community. This is one of the few software that is compatible with Atmel AVR-based controllers and is easily adaptable to the Arduino compiler.

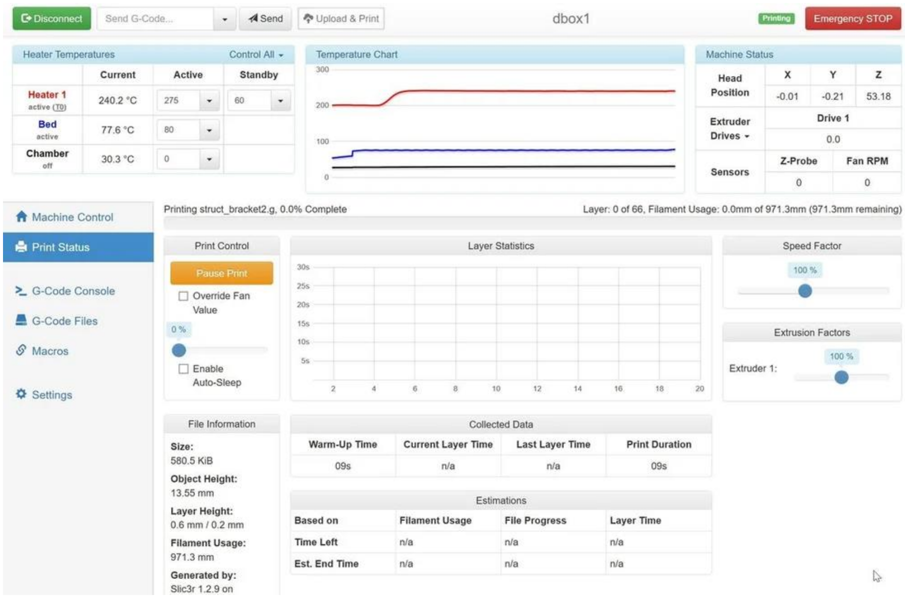


Figure 40-2: GUI of the reprap platform

Power unit

The power unit includes the power supply and the stepper motors.

Requirements and requirements

1. Stepper motors support half-step motion.
2. Stepper motors produce a torque of 40 Nm. It is defined as safe torque based on the weight and inertia of the mechanical structure.
3. The dimensions of stepper motors should not exceed a certain range.
4. The power to the stepper motors should be provided by the power supply.

Based on these requirements, 40-45 N stepper motors of the nama17 family are required for the 3D printer. The nama17 is the standard for all industrial 3D printers, and all boards and applications are designed to support this family. A 12-volt, 20-amp DC source should also be used for the power supply, as each stepper motor draws a current of 2 amps from the source. Considering that we have only one choice in this section, different requirements and models have been ignored.

Complexity analysis

In designing and manufacturing a product, complexity is analyzed in terms of production complexity, organizational complexity, process complexity, and sales complexity. In order to optimize the design process, structural complexity must be classified and displayed. Two common methods to represent complexity are to use graphs as well as matrices. Structural complexity depends on a variety of factors, such as the diversity of the elements and the quantity of each element. Other factors could also affect complexity, including the type and intensity of communication. Fig. 1.1 shows the main subsystems of the 3D printer, which include the illustrated units.

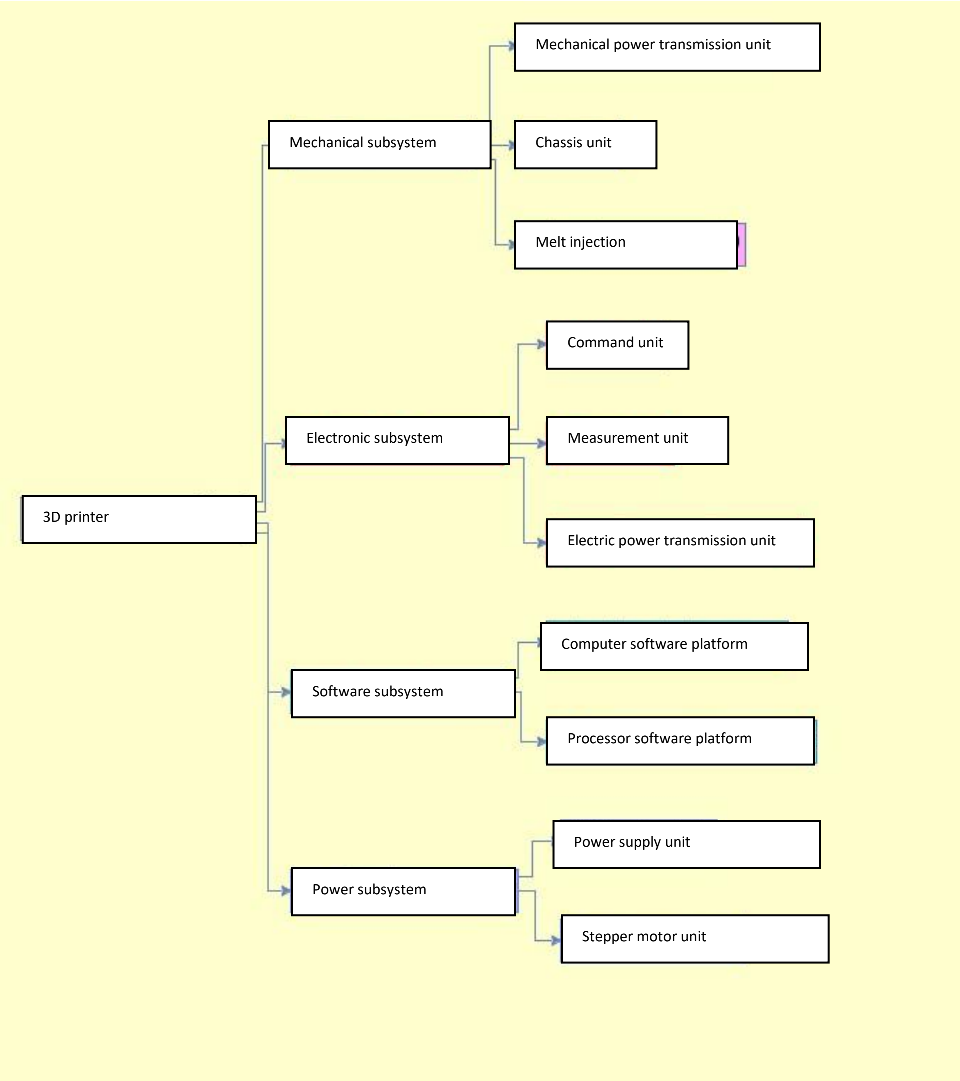


Figure 8. Subsystems and units of the 3D printer

Graphs of communications of units of subsystems

System communication matrices

Figure 10 indicates the SCM matrix for the whole system. The matrices on the main diameter are the same as the dependency matrices.

	Mechanical subsystem – mechanical power transmission unit	Mechanical subsystem – chassis unit	Mechanical subsystem – melt injection unit	Electronic subsystem –command unit	Electronic subsystem –measurement unit	Electronic subsystem –power transmission unit	Software subsystem –computer software platform	Software subsystem –processor software platform	Power subsystem –power supply unit	Power subsystem –stepper motor unit
Mechanical subsystem-mechanical power transmission unit		800E	000E			0004				800E
Mechanical subsystem- chassis unit	800E		800E		0026	0004			0004	000C
Mechanical subsystem-melt injection unit	000C	840C			3026	2004			2002	8024
Electronic subsystem-command unit		8024	2002		2002	2006	03C2	1BA8	2824	3102
Electronic subsystem- measurement unit		8004	8024	2202		3004		23C2	2000	
Electronic subsystem- Electronic power transmission unit		0004	0004	2004	2004		2002	2002	2006	2004
Software subsystem-computer software platform				03C2				03C2		
Software subsystem-processor software platform				23C0	03C0	0080	01C2			
Power subsystem – power supply unit		0424	2002	2826	2000	2004				2002
Power subsystem –stepper motor unit	800E	802E	802E	3002		2000		0002	3002	

Figure 9. SCM matrix at the component level

Notably, considering the complexity of communications between units, sometimes, the numbers are higher than ten and are displayed in certain letters.

Structural features

Table 9. Structural features

Node ID	Node	Active Sum	Passive Sum	Activity	Passivity	Criticality
0	Mechanical subsystem-mechanical power transmission unit	4	3	1.3333334	0.75	12
1	Mechanical subsystem- chassis unit	6	7	0.85714287	1.1666666	42
2	Mechanical subsystem-melt injection unit	6	7	0.85714287	1.1666666	42
3	Electronic subsystem-command unit	8	6	1.6666664	0.75	48
4	Electronic subsystem-measurement unit	6	6	1	1	36
5	Electronic subsystem-Electronic power transmission unit	8	8	1	1	64
6	Software subsystem-computer software platform	2	3	0.6666667	1.5	6

7	Software subsystem-processor software platform	4	5	0.8	1.25	20
8	Power subsystem – power supply unit	6	6	1	1	36
9	Power subsystem –stepper motor unit	7	6	1.1666666	0.85714287	42

The following results are obtained from Table 9:

Active Sum:

The third column of the table shows the active sum of each node. In this column, the command and electric transmission nodes adopt the highest value, followed by the stepper motor unit node. This means that these nodes have the greatest impact on others, and modification of these parts may change many other parts. Therefore, these nodes are very important in the design, and they should be focused upon. Also, in this table, the lowest active sum is related to the computer software; that is, this node has a lower impact on others. Of course, it should be noted that even this low degree of activity is effective in the modification of other components.

Passive sum:

In fact, it is the opposite of activity. The highest passivity is related to the electrical power transmission node, which is most influenced by other units, and as a result, in case of any change in any of the parts, this node will suffer the most damage. Changes in each node affect this node more than others, and it should be inspected first.

Activity

The activity of a node is defined as the ratio of active sum to passive sum, which depends on the low and high behavior of passive and active nodes. As shown in the fifth column of Table 1-3, the highest activity is related to mechanical power transmission and command nodes; that is, these nodes have a higher activity than others. It should be noted that this larger activity does not mean that these nodes have a large effect on others or that they are highly sensitive. This value shows the behavior of the node itself.

Passivity

The passivity of a node is defined as passive sum to active sum ratio, and in contrast to activity, it indicates the passive behavior of a node relative to its active behavior. As can be observed in the sixth column of Table 1-3, the highest value of positivity is related to the computer software platform; that is, this node behaves more passively than others.

Criticality:

The seventh column of the table shows the criticality of the nodes. Criticality is the product of the activity and passivity, and in fact, it indicates the sensitivity of a node in the whole system. Nodes that have a high criticality rate should be under more focus in the design because these are more likely to affect or be affected by other nodes. In this table, the electric power transmission unit has the highest criticality rate.

Characteristics of nodes

In this system, no node is the final destination of the path. No node is separate from the other nodes. In general, the software does not recognize any of the nodes as the starting or ending transmission, and no one is isolated.

Loops

Maximum loop length is that related to power subsystem → Stepper motors unit→ software subsystem → processor software platform→ electronic subsystem → electrical power transmission unit→ electronic subsystem → command unit→ mechanical subsystem → molten injection unit→ mechanical subsystem → Mechanical power transmission unit → mechanical subsystem →chassis unit→ electronic subsystem → measurement unit→ power subsystem → power supply unit→ power subsystem → stepper motors unit with ten links. Also, the shortest loop length is related to the electronic subsystem → electric power transmission unit→ electronic subsystem → measurement unit→ electronic subsystem → electric power transmission unit → with three links.

Path analysis

The largest length of a straight path is 11 links, and the smallest one is two links.

Conclusion

Taking into account the feasibility studies of all units of this mechanical system, we may conclude that this mechatronic machine is capable of meeting the need of the clients for a 3D printing machine. Also, the machine designed in this study could be used at an industrial scale. It can also be concluded from the results that this machine is possible to be manufactured could be produced at an industrial scale.

References

[1] https://www.instructables.com/Building-a-3D-Printer-Under-200/

[2] https://all3dp.com/2/3d-printer-firmware-which-to-choose-and-how-to-change-it/

[3] https://m.all3dp.com/2/3d-printer-stepper-motor-what-to-consider-and-which-to-choose-2/.

[4] https://www.sanatbazar.com/tech/manufacturing/item/254-%D9%85%D8%B9%D8%B1%D9%81%DB%8C-10-%DA%A9%DB%8C%D8%AA-%D9%BE%D8%B1%DB%8C%D9%86%D8%AA%D8%B1-%D8%B3%D9%87-%D8%A8%D8%B9%D8%AF%DB%8C-%D8%A8%D8%B1%D8%A7%DB%8C-%D8%B3%D8%A7%D8%AE%D8%AA.

[5] https://www.sanatbazar.com/tech/manufacturing/item/179-%D8%A2%D9%85%D9%88%D8%B2%D8%B4-%D8%B3%D8%A7%D8%AE%D8%AA-%D9%BE%D8%B1%DB%8C%D9%86%D8%AA%D8%B1-%D8%B3%D9%87-%D8%A8%D8%B9%D8%AF%DB%8C-%D8%A8%D8%A7-%DA%A9%D9%85%D8%AA%D8%B1%DB%8C%D9%86-%D9%87%D8%B2%DB%8C%D9%86%D9%87

[6] https://www.aniwaa.com/product/3d-printers/noura-m100p/

[7] Kryukova, E. M., Khetagurova, V. S., Ilyin, V. A., Chizhikova, V. V., & Kosoplechev, A. V. (2021). Forming students' environmental culture: modern educational approaches and technologies. Journal of Advanced Pharmacy Education & Research, 11(2), 113-118

[8] Kubanov, S. I., Savina, S. V., Nuzhnaya, C. V., Mishvelov, A. E., Tsoroeva, M. B., Litvinov, M. S., ... & Povetkin, S. N. (2019). Development of 3d bioprinting technology using modified natural and synthetic hydrogels for engineering construction of organs. International Journal of Pharmaceutical and Phytopharmacological Research, 9(5), 37-42.