Contour Crafting Based 3d Printer

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Abstract- *The major objective of this project was to design and fabricate a 3 – axis gantry framed robot to implement on construction sites for the construction of walls. The 3 axes (X, Y, and Z) will be simultaneously controlled based on the input. This robot will substantially decrease the manual labor in the production line, thus making it more efficient, involving less risk, and less time-consuming. The robot will be controlled through G Codes which were generated using Slicer software. The robot will work in its work envelope, and it would construct the walls of desired dimensions. As the work will be done inside the allocated work envelope of the printer, the chances of risk and accidents will be reduced up to 30-40% and speed will be increased as compared to the conventional method. Implemented solution was based upon the mentioned criteria: Resource, Cost, Time consumption, Safety, Robustness, and Skills required.*

Keywords- 3 Degrees of freedom, 3D printer, Automated Construction Process, Contour Crafting, Gantry, Ramps 1.4, Robotics.

I. INTRODUCTION

1) Gantry Robot:

Contour Crafting can help you save a lot of money on the commercial building.

According to projections, costs will be about a quarter of those of conventional buildings. Contour Crafting promises to reduce waste in the construction industry. Construction projects for Contour Crafting will move at a breakneck speed. Construction projects that ordinarily take six months or longer to complete benefit from the shorter construction duration. Physical strength will be substituted for cognitive power in the building industry, while manual labor expenses will be greatly decreased. Women and the elderly will be able to work in the construction business for the first time.

Construction could evolve into a consumer market, with a house or other structure being planned and built by the family who will live there. Construction will be more accessible to everyone because to lower costs and automated construction. Consider renting a Contour Crafting machine from your local Home Depot. Modern robotics are being used to build custom-designed houses in a matter of hours, thanks to innovative technologies. At this moment, the technology would be most valuable for low- income housing and disaster relief organizations working in areas affected by earthquakes, floods, conflicts, and other natural calamities. Contour crafting forms the house's walls layer by layer, using a quick-setting, concrete-like material until the floors and ceilings are set in place by the crane.

2) Challenge in the existing system:

The construction industry has been slow to adopt automation due to:

a) the unsuitability of existing automated fabrication technologies for large-scale products,
b) traditional design approaches that are not suitable for automation,
c) a significantly lower ratio of production quantity/type of final products when compared to other industries,
d) material limitations that could be used by an automated system,
e) the economic unattractiveness of expensive automated equipment.

Moreover, some serious problems are being continuously reported at construction sites, which are:

- Manual efficiency is low
- Construction sites have a high accident rate.
- Low work quality
- Construction site control is minimal and onerous, and skilled labor is in short supply.

3) Application:

It is the only multilayer fabrication process that is suited for large-scale manufacturing, and it is called Contour Crafting.

Construction of low-income homes and emergency shelters may be able to take advantage of this technology right away. A direct application of the Contour Crafting method is in the creation of extraterrestrial habitats. A second potential application sector for Contour Crafting is the construction of luxury structures with exotic architectural styles that involve intricate curves and other geometry. For the development of Lunar and Martian dwellings, Lunar Contour Crafting looks to be a viable approach to design. The Contour Crafting technology can completely transform the construction industry, shifting it away from the traditional 'beam and post' technique and toward a layer-by-layer method. According to the research, for country-specific case studies, Saudi Arabia is a better fit than China in terms of incorporating contour crafting into cheap housing developments. Construction machinery designed for Contour Crafting may be entirely electric, eliminating the need for exhaust emissions during operation.

Contour Crafting may result in minimal or no material waste as a result of its precise additive production method. " The Contour Crafting process will be capable of finishing the construction of a full house in a matter of hours rather than several months, as is now the case. This increased speed of operation leads to increased efficiency in construction and management, which has a positive influence on the transportation system and the environment. It is a significant step forward in terms of technology. It is more cost-effective, quicker, safer, and simpler than any other approach available today. As a future building approach, it has significant promise. Contour Crating technology allows for the automatic construction of a single house in a single run, each with a potentially different design from the others. By merging the Contour Crafting machine with a support beam picking and positioning arm, as well as adobe structures, it is possible to construct conventional structures. It is possible to construct it without the need for external support pieces by utilizing form characteristics. The approach provides architects with the ability to create structures with functional and novel architectural shapes that are impossible to materialize with the present manual construction method. The use of several materials is permitted in CC, with different materials being used for the exterior surfaces and as fillers between the surfaces. Controlling the quantity of each material and correlating it to various parts of the geometry of the building under construction is possible with computer technology.

4) Need of the project:

Current construction systems hold a lot of problems which include increased time consumption, and a larger workforce which in turn leads to several accidents and in many cases prove to be fatal. For more than three decades, the contour crafting application has been widely employed in a wide range of industrial, pharmaceutical, medical, and aviation applications, among others. Recently, large-scale 3-D printers have been created that are capable of printing full-scale construction projects, such as walls, homes, bridges, and multi-story structures, on a single piece of material. The Additive Manufacturing (AM) technique, which involves the installation of successive layers of building materials with the assistance of robotic arms, is responsible for the successful 3-D printing of projects (3-D printers). Contour crafting is the term used to describe this multilayer structure that is controlled by computer modeling software. The paper will discuss the development of contour crafting over time, its current application in construction, the advantages of contour crafting applications in construction, and the main obstacles that have prevented contour crafting from becoming more widely used in the local construction market. The present research efforts to incorporate Building Information Modeling (BIM) with contour crafting construction are also highlighted in this publication, which is also available in English. The application of contour crafting in construction increases job site efficiency and project sustainability, according to current research findings, as a consequence of the reduction of material waste on building sites. Finally, enhanced automation in construction is achieved via the use of the contour crafting approach, which results in improved job site safety as well as an overall improvement in the quality of building projects as a result of increased automation in construction.

Architects may use the method to develop structures with functional and unusual architectural geometry that would be impossible to actualize with the present manual construction approach.

Multiple Materials: CC allows for the use of a variety of materials for the exterior surfaces as well as fillers between the surfaces. Additionally, various materials that chemically react with one another may be supplied via the CC nozzle system and combined in the nozzle barrel right before deposition using this technique.

Controlling the quantity of each material and correlating it to various parts of the geometry of the building under construction is possible with computer technology.

Structures containing different substances in variable concentrations in various places will be conceivable as a result of this development.

Utility Conduits: utility conduits can be included in the walls of a building structure in the exact location and configuration specified by the CAD data. Examples of CC sections that have been filled with concrete,

Painted Surfaces: The quality of the surface finish in CC is determined by the surface finish achieved with the trowel, and it is not affected by the size of the nozzle orifice. It is therefore possible to combine and extrude through the CC nozzle a variety of additives like sand, gravel, reinforcing fiber, and other appropriate materials that are readily available in the local area. Regardless of the materials used. Construction of typical buildings employing CC is always the same. The surface quality of CC is such that it does not need any further surface preparation before painting surfaces. An automated painting system can be implemented into the CC system.

II. DESIGN AND FABRICATION

1) Model of the proposed solution:

To check the feasibility of the project, the basic model was designed on the SOLIDWORKS software fig 2.1, 2.2. The online model of the prototype gave a proper insight into how the model would look and work. Moreover, the materials which were to be used were made clear with the online model. Different materials were proposed to check which material will suit the prototype and will provide structural integrity to the whole model.

FRAME:

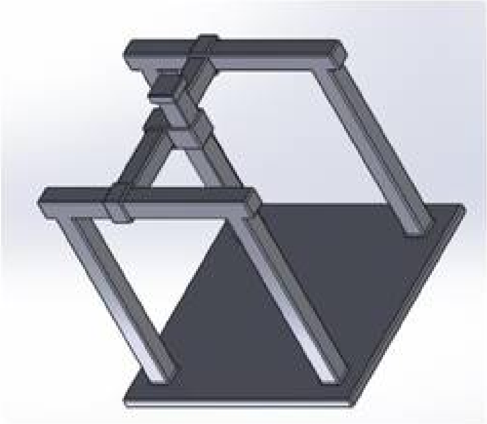


Fig 2.1: Frame of Gantry Robot

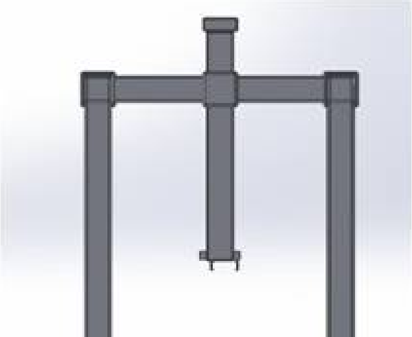


Fig 2.2: Frame of Gantry Robot

2) Online simulation of the proposed system:

To get the correct idea of how the Z-axis would work in both positive and negative directions, an online simulation was done using C-prog software as shown in fig 2.3, 2.4. It gave an insight into how the 3rd axis would work on the plane.

In the initial stages, the test run was done on the motor. This run was successfully executed using the Arduino Mega and Ramps 1.4 board as shown in fig 3.8.

Fig 2.4: Simulation of Gantry in C-prog

3) Components Used:

In the initial stages, the test run was done on the motor. This run was successfully executed using the Arduino Mega and Ramps 1.4 board as shown in fig 2.5.

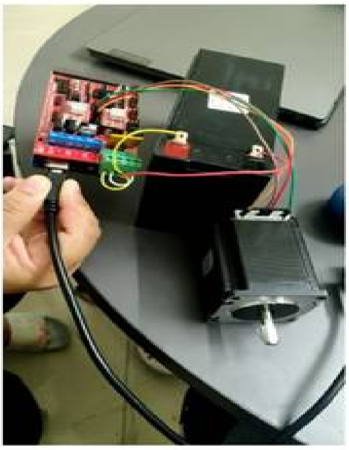


Fig 2.5: Test 1 with single motor

For the future stage, the test run was done with 3 stepper motors, one for each axis i.e., x, y, z as shown in fig 2.6. To make the motors run synchronously a sample CAD drawing of a cube was made as shown in fig 2.5 and then it was converted to G-codes using Slicer software. All the M-codes (Hot end codes) were deleted and uploaded on

PronterFace software to upload code on Ramps board via Arduino Mega. And made all the motors run synchronously.

Fig 2.5: Sample CAD cube which was used to test motor run in synchronous movement

Fig 2.6: Test 2 With 3 motors

4) Fabrication:

To start with the fabrication, components and materials were purchased, namely, Guide Rails, Mild Steel Columns, Mild Steel beams, L-shaped clamps to join columns with the guide rails, and a 100x100 mm square base for the column to stand on it, and miscellaneous material.

Fig 2.7: Guide Rails

After purchasing the components, a custom L-shaped clamp was fabricated to connect the Y-axis guide rail to two X-axis guide rails. And one to connect the Z-axis guide rail to the Y-axis guide rail. Subsequently, a few screws had to be cut for the desired length to attach it to the L-shaped clamp and guide rails which were about 10mm long.

The design idea was completed, and the second stage was to assemble all the components. Firstly, the mild steel columns and X-axis guide rails were attached with the L-shaped clamps which were purchased.

Each column required 2 clamps one on either side (fig 2.8).

Fig 2.8 Completed Parallel X-axis

With the completion of the second stage, individual guide rails were able to withstand their load as a mild steel road provided structural integrity to the structure that was half-made.

However, as the whole prototype is non- stationary, the main aim was to make it strengthened so that it can withstand the load with all the 3-axis moving simultaneously.

With 2 guides standing horizontally, it marked the X-axis. The next part was to place the smaller guide rail horizontally on the top of 2 guides which would act as the Y-axis. The Y-axis was connected using the custom-made L clamps (fig 2.9), which were fabricated according to the already drilled holes of the guide rails. Custom-made L clamps were fabricated using aluminum which was of high thickness to withstand the load of the heave guide rail resting on top of X-axis rails.

On the side of the guide rails, stepper motors were attached which helped to power each axis. As the guide rails use the mechanism of thread and screw, the shaft of the motor was inserted into the universal coupling. The stepper motor was supported using spacers which gave it proper support along with the room for movement of the shaft. After the Y-axis was placed on the X-axis, next was Z-axis which was to be hung (fig 2.10) from the center of the Y-axis. Z-axis is one of the most significant components of the prototype as it would be suspended with only one side supported and the rest was to move according to the movement of the other axes. Moreover, the end effector used for printing would also be attached to the Z- axis. The movement of the Z-axis would be in a vertical position, aiming for both positive and negative axes. The upward and downward direction satisfies the layer-by- layer process of the CC-based printer.

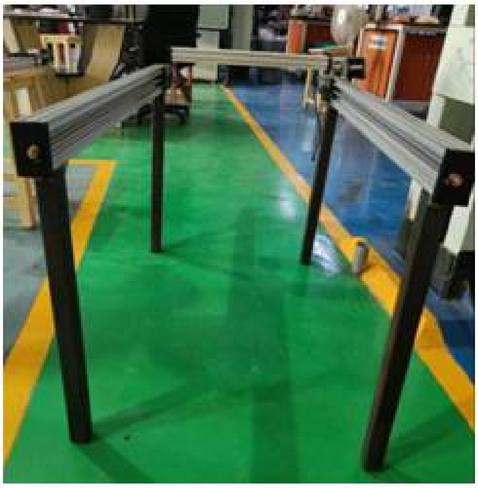


Fig 2.9: Completed attaching Y-axis

Fig 2.10: Completed Z-axis attachment

All the 3 motors were placed on the sides of the rails to ensure smooth and resistance less motion of all the axes. As all the 3 axes will be non-stationary, just the four steel pillars would not be enough to hold the moving weight of the prototype. To rectify this issue, four steel rods were purchased. Two of 860mmx565mm dimensions and for the shorter legs, two rods of 960mmx660mm dimensions were custom cut. Along with these supporting beams, four square-shaped steel supporters of 100mmx100mm dimensions were brought.

Initially, the idea was to attach all three components simultaneously to each other. However, later it was modified keeping in mind the feasibility of the attachments.

To achieve these attachments, as the material used was mild steel throughout the bottom of the model, arc welding to done to provide the additional strength required to hold the model still during the operational timing of the project. The long columns were attached directly to the square supporters which were placed at the bottom of the longer pillars.

Fig 2.11 Final Frame

The shorter beams were placed at a certain height from the bottom attachments. The primary aim to provide height to these short supporters was to weld them directly to the longer beams so that they would be steady during the operation of the model. As the longer beams were in direct contact will the guide rails from all directions, the stability of these columns was of major concern.

Welding it directly with the square supporters and then the shorter beams provided it with the needed stability and strength to hold the weight. With the end of welding, it marked the end of all the mechanical fabrication. The completed mechanical fabrication is shown in fig 2.11.

III. ELECTRICALS AND ELECTRONICS

1) Components used:

There were several different requirements from an electrical and electronics point of view that needed to be fulfilled to successfully execute an operational 3D printer. Apart from just hardware requirements, different software was also used for the implementation. The components used, both hardware and software are as follows:

- NEMA 17 Stepper motors
- RAMPS 1.4 Board
- Arduino Mega
- Slicer Software
- SOLIDWORKS
- PronterFace
- Motor driver A4988
- Lithium Polymer battery

The step angle for the stepper motor is the traversed angle in a single step by the motor. The step angle for this motor was calculated by dividing the number of steps a motor takes in a single revolution by 360. The step angle came out to be 1.8 degrees. The model used a total of 4 stepper motors. To connect all the motors to make them work simultaneously as up to 5 motors can be connected to the board. The most significant feature of the RAMPS boards is that all the capacitors and resistors are surface mounted which provides more space for other connections to be made properly. The microcontroller used was Arduino Mega which is based on ATMega. A programming environment for the Arduino Mega 2560 is provided by the Arduino IDE software, which is the official Arduino programming environment used to program all Arduino boards. This program is used for authoring, compiling, and uploading code to the Arduino board, among other things. The rest all the connections were made using connecting wires and were powered by a 12V, 7.5A lithium polymer battery.

2) Connections:

For the successful working of the prototype, 4 motors needed to be powered simultaneously. One motor for each axis except X-axis. For X-axis, 2 motors were to be controlled synchronously and at the same moment. Motors for X-axis were connected on either side of the parallel guide rails with the help of the universal coupling. The shaft of the motor was fitted inside the universal coupling and the coupling was tightened after that to make the motor stand rigid at the end. Each motor was supported with the help of custom-made spacers which were cut according to the screw and shaft dimensions. All 4 motors were connected with the RAMPS 1.4 board and the RAMPS board was attached on top of the Arduino as shown in fig 3.1. This whole system was powered with a 12V, 7.5A lithium polymer battery.

Earlier four motors of 4 windings were used for the test run, but moving in the later stages motors were upgraded to 6 windings to provide higher torque which would be sufficient to move the guide rails.

Fig 3.1 Test 3 with 4 motors

3) Interfacing:

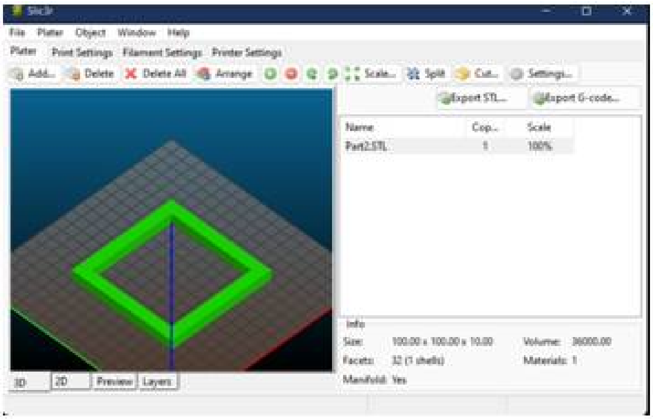
PronterFace and slicer software was used to help with the interfacing of hardware with software. first of all, a sample drawing was constructed in SOLIDWORKS. A cube of 100mmx100mm, wall thickness 10mm, and extrusion of 10mm was made (fig 3.2).

Fig 3.2: Sample print test 1

The sample cube was then uploaded to the Slicer software to generate the G codes as shown in fig 3.3. After the G codes were produced for the defined model, the main obstacle was to remove all the M codes. M codes were for the hot-end part of the 3D printer. but as for the model which was in the making, the hot-end part was missing.

With the missing hot end, it interfered with the overall printing algorithm. To rectify that issue, the code was copied to the notepad.

All the M codes were deleted from 18,000 lines of codes. After the M codes were completely removed, the entire process smoothened.



Name	Cop...	Scale
Part2.STL	1	100%

Info
Size: 100.00 x 100.00 x 10.00 Volume: 36000.00
Facets: 32 (1 shells) Materials: 1
Manifold: Yes

Fig 3.3: Slicer Software

After the coding issue was rectified, the G- code file was uploaded to PronterFace. Baud rate was set to 250000 with the least printing speed of 10%. The printing speed was set to the least to match the movements of all the 3 axes. After the connections were complete and the code file was loaded, the movement of the motors was controlled by PronterFace. The software was reset and was set to printing shown in fig 3.4.

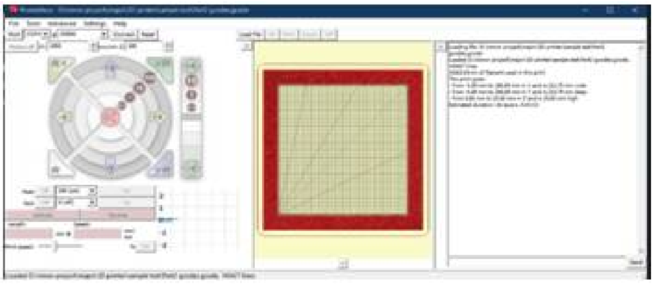


Fig 3.4: PronterFace software

IV. CLEARANCE CALCULATIONS

Calculations for the end-effector were done as keeping it a major moving part in the whole prototype. All the conditions of the end effector were considered i.e., upwards, and downwards, that too with the z y and x- axis moving simultaneously. All the calculations were done in SI units.

The maximum height that the end effector would cover was calculated by considering the individual height of the subject. It is the sum of piece height, end effector height, and allowance.

Allowance- the minimum distance required for the gripper to move effectively in the work envelope so that it does not interfere with other parts that are moving simultaneously in the work arena.

Two conditions should be mandatorily fulfilled for successfully picking up the piece:

1. More than half of the end effector should be attached to the z-axis so that it can bear the weight of the whole moving axis
2. End effector height should be feasible.

The workload of the end effector was calculated by taking the product of the weight of the piece and the height of the piece.

The total frame height was about 650mm, and the Z-axis arm length was taken to be 500mm, thus giving out the allowance to be 150mm.

This allowance would be used by the Z-axis to efficiently move in the work arena, as the Z-axis covers both positive and negative axis.

1) The calculation for allowance:

FH: 650mm ZL: 500mm
AEE: 650mm-500mm
i.e., 150mm

Fig 4.1: Allowance

The allowance is visible in fig 4.1

The calculation for the number of steps for the motor:

Ø: 1.8°
TA: 360°
NSR: 360°/1.8°
i.e., 200

Hence, to complete one rotation requires 200 steps. The stepper motor which was used is shown in fig 4.2

Fig 4.2: Stepper motor

V. CHALLENGES AND SOLUTIONS

IoT: Initially, the idea was to implement the end effector using IoT by using NodeMCU (ESP8266). The NodeMCU would have controlled the flow from the end effector and the IoT idea was also implemented as a security feature just in case any error arises from the end effector and the entire movement of the robot would stop. Unfortunately, all the drivers were deleted from Arduino's latest update and also from tinker CAD software. because of this the idea of using IoT was removed and continued with standard Glue gun- based end effector.

Controlling three motors simultaneously: After successfully running one motor, another major task was to run all the 3 motors simultaneously. After getting G- codes from the Slicer software the G- codes were uploaded but the motors were not running according to the G- codes. Initially, only the first line of the G-codes was deleted which was turning on the hot end and setting the temperature. After those motors did run for a few lines synchronously but in the end, it stopped again. Hence it was confirmed that all the M-codes needed to be erased. Thorough research was done regarding G-codes and M-codes and all the unnecessary M-codes were deleted from 8000+ lines of G-codes at the end all the motors were running successfully in a synchronous manner.

Motor's wiring: The first obstacle was to find the 2 terminals of each coil from the 6 pins of the Stepper motor, to find the 2 common connections a multimeter was used. This was done for a lesser torque motor to check if the connection was successful or not. After purchasing a new and higher torque motor (which had only 4 connectors) then the wire harness for that connector was connected normally but then the motor coils started to misfire, then all the connections were redone, and wire harnessing was done again to find the common terminals of the stepper motor. And then the motor coil stopped misfiring.

Fabrication: The first problem which was faced was how to join 2 different metals i.e., Aluminum and Mild steel columns, the L-clamps were bought which were attached between the column and the guide rails. Each column required 2 L-clamps. After successfully connecting 4 columns on 2 guide rails. The second problem which was faced was connecting a guide rail between 2 parallel guide rails (2 X- axis guide rails). A custom L-shaped clamp was made from a 2mm thick aluminum sheet and holes were drilled according to the non-stationary piece on guide rails. To mark the holes, guide rails were disassembled and then assembled again. To join the clamp and the guide rails 5mm diameter and 10mm length screws were cut down to 5mm length to avoid the screws to create friction by rubbing against the guide rails. The third issue which was faced was with the stability of the frame, to make it more stable 4 beams were bought 2 beams of length 585mm length and 2 beams of 850 mm in length, base support for each column was also added which was a 100mmx100mm square. All of these materials were of mild steel. The final obstacle faced was welding, initially, all the components that were welded broke easily hence all the welding had to be removed by grinding and redone with a different filling material. To weld, the entire frame had to be disassembled and reassembled.

End-effector: to operate the glue gun, the gun's trigger needs to be actuated continuously and since the IoT was not being implemented an alternate solution had to be implemented, the first solution was to implement using white cement and a syringe, but the piston of the syringe was not enough itself to create pressure and the Z-axis was only suspended with 2 screws so extra weight couldn't be added, even after removing the piston the gravitational force was also not enough to pull the drops of white cement out as it would start to settle and become hard. The second solution was to use a Glue-gun as an end effector, but the trigger of the glue gun was an issue, the solution which was implemented for the trigger was to attach an iron rod through which the glue stick would pass easily and make parallel slits through which a thin iron rod could pass, now to create pressure on glue gun for uniform flow rubber band was attached to the iron rod on each side to pull the metal rod down and due to elasticity of rubber band it pulled the metal rod down and created pressure on glue sticks which created pressure on the hot end of glue gun and melted the glue and made uniform flow.

VI. CONCLUSION

In the end, the project was completed and was running without any issues. But there are always some issues nothing is 100% perfect. Similarly, the project "Contour Crafting Based 3D Printer" is no different there is always space for betterment and improvement. The concept for the frame which was used was a Gantry type frame which is most suitable for heavy and lightweight applications.

Fig 8.1: Final Completed after test runs

Project outcome:

The project was tested by uploading the CAD drawing to check if the printing speed is matching with the speed of the motor. A pencil was attached as an end effector to check if it is correctly making the model which was uploaded for the dry run. The test result is shown in fig 8.2

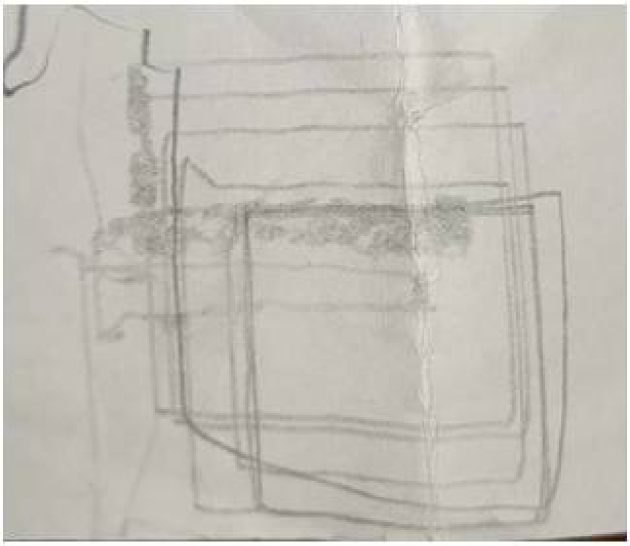


Fig 8.2: Test Run for Printing

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