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DESIGN AND DEVELOPMENT OF PORTABLE FUSED FILAMENT FABRICATION MACHINE FOR PROTOYPING APPLICATIONS

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Abstract. The 3D printers are devices that can create a three-dimensional object from a digital model. The product is manufactured by adding material layer by layer and fusing these layers together. These machines can capable of doing complex and difficult tasks in one long step and it only requires a 3D model of the object to be made with a defined set of parameters and scaling ratios, which can then be converted into G-code. This data is then used for controlling the motors and extruding plastic, based on the G-code generated. These G-codes guide the machine to produce the part according to the requisite design. It’s an easy, economic and doesn’t require intense labor for processing. In this present work, a FDM based 3D printer is designed and the work is carried out using CATIA V5R21 software, further developed the working model.

Keywords: Additive Manufacturing, Rapid Prototyping, Fused Deposition Modeling.

1 Introduction

A method of manufacturing known as ‘Additive manufacturing’, due to the fact that instead of removing material to create a part, the process adds material in successive patterns to create the desired shape.

Main areas of use:

- Prototyping
- Specialized parts – aerospace, military, biomedical engineering, dental
- Hobbies and home use
- Future applications– medical (body parts), buildings and cars

3D Printing uses software that slices the 3D model into layers (0.01mm thick or less in most cases). Each layer is then traced onto the build plate by the printer, once the pattern is completed, the build plate is lowered and the next layer is added on top of the previous one.

1.1. Need of Rapid Prototyping

- Objects can be formed with any geometric complexity or intricacy without the need for elaborate machine set-up or final assembly.
- Freeform fabrication systems reduce the construction of complex objects to a manageable, straightforward, and relatively fast process.
- These techniques are currently being advanced further to such an extent that they can be used for low volume economical production of parts.
- It significantly cut costs as well as development times.

1.2 Rapid Prototyping

Rapid Prototyping has also been referred to as solid free-form manufacturing; computer automated manufacturing, and layered manufacturing. RP has obvious use as a vehicle for visualization. In addition, RP models can be used for testing, such as when an airfoil shape is put into a wind tunnel. RP models can be used to create molds for tooling, such as silicone rubber molds and investment casts. In some cases, the RP part can be the final part, but typically the RP material is not strong or accurate enough. When the RP material is suitable, highly convoluted shapes (including parts nested within parts) can be produced because of the nature of RP.

1.3 Methodology of Rapid Prototyping

The basic methodology for all current rapid prototyping techniques can be summarized as follows:

- A CAD model is constructed, and then converted to STL format. The resolution can be set to minimize stair stepping
- The RP machine processes the STL file by creating sliced layers of the model.
- The first layer of the physical model is created. The model is then lowered by the thickness of the next layer, and the process is repeated until completion of the model.
- The model and any supports are removed. The surface of the model is then finished and cleaned.

1.4 Additive Manufacturing Technologies

Additive Manufacturing Technologies are classified as:

- **Material Extrusion Technology**
  - Fused Deposition Modelling
- **Direct Energy Deposition Technology**
  - LENS - Laser Engineering Net shape
  - EBAM – Electron beam Additive manufacturing
- **Photo Polymerization Technology**
  - SLA - Stereolithography
  - DLP - Digital Light Processing
  - CDLP – Continuous Digital Light Processing
- **Material Jetting Technology**
  - MJ – Material Jetting
  - NPJ – Nano Particle Jetting
  - DOD – Drop on Demand
- **Binder Jetting Technology**
- **Power Bed Fusion Technology**
  - MJF – Multi Jet Fusion
  - SLS – Selective Laser Sintering / Direct Metal Laser Sintering
  - SLM/ DMLS – Selective Laser Melting
  - EBM – Electron beam Melting
- **Sheet Lamination Technology**
  - LOM – Laminated Object Manufacturing

(Or)

Rapid Prototyping Technologies are classified as:

- **Liquid Based Rapid Prototyping Systems**
  - Stereolithography
  - Solid Ground Curing
- **Solid Based Rapid Prototyping Systems**
  - Laminated Object Manufacturing
  - Fused Deposition Modeling
- **Powder Based Rapid Prototyping Systems**
  - Selective Laser Sintering
  - Three-Dimensional Printing / Binder jetting

2. Fused Deposition Modeling

Additive manufacturing or 3D printing has been a popular method of creating prototypes since the 1980s and is quickly becoming the fastest, most affordable way to create custom consumer goods, as well. There are several different methods of 3D printing, but the most widely used is a process known as Fused Deposition Modeling (FDM) or Fused Filament Fabrication (FFF). FDM printers use a thermoplastic filament, which is heated to its melting point and then extruded, layer by layer, to create a three-dimensional object.

The FDM machines use production-grade thermoplastic material, such as ABS, PPSF and PC, including PC-ABS. The FDM parts made of those materials can withstand functional testing and have high heat resistance. Unlike other RP technologies using powders or resins to simulate the thermoplastics, the FDM parts and models are produced with real thermoplastics and more versatile. They can be sanded, painted, drilled and so on. The strength and temperature capability of the build material is the major advantage of FDM. Other advantages of FDM are safe, laser-free operation and easy post processing with the water-soluble support material. However, there are still certain shortcomings that are inherent with the FDM process.

3. Modeling of portable 3D Printer casing parts in CATIA software

3.1 Catia model of base plate

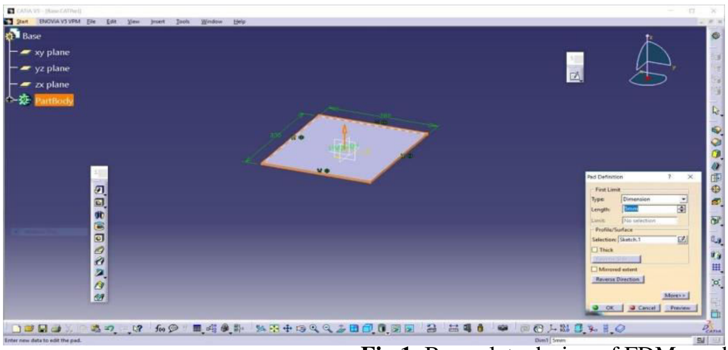

Fig.1. Base plate design of FDM machine

CATIA MODEL OF HORIZANTAL SUPPORT FRAME

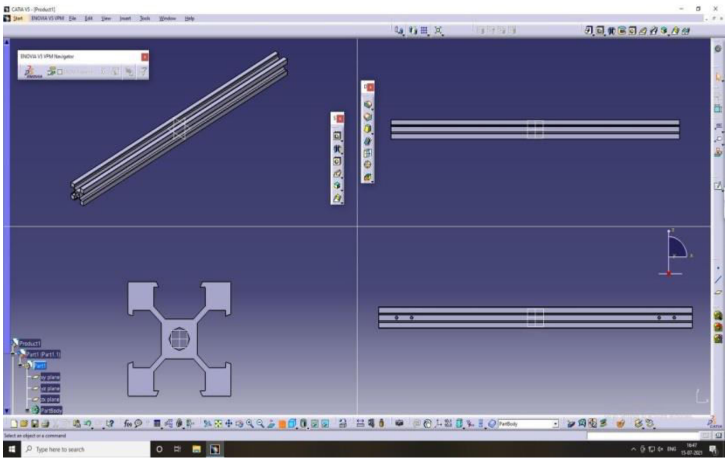

Fig.2. Horizontal support frame design of FDM machine

CATIA MODEL OF VERTICAL SUPPORT PLATE

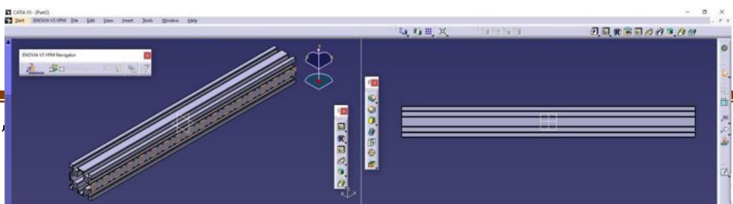

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Fig.3.vertical support frame design of FDM machine

CATIA MODEL OF FRONT VIEW VERTICAL SUPPORT FRAME

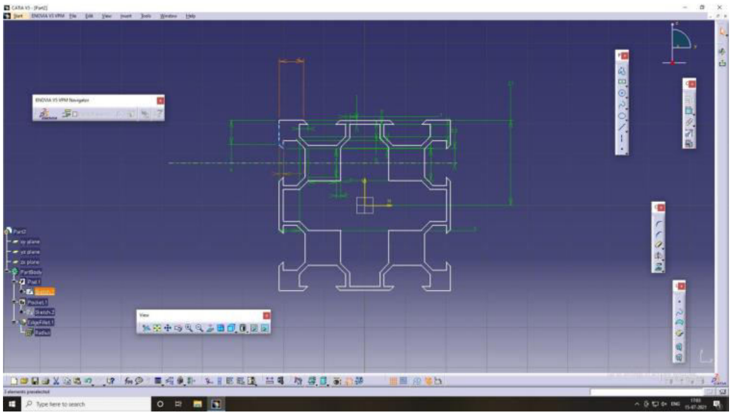


Fig.4.front view of support frame design of FDM machine

ASSEMBLY MODEL OF I - SECTION PORTABLE 3D PRINTER

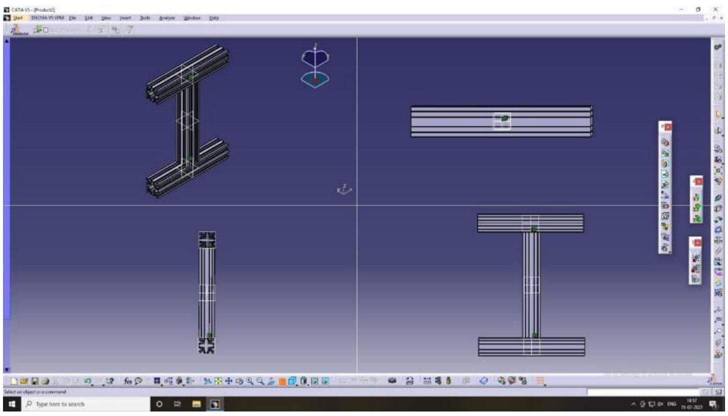


Fig.5. Assembly model of I - section portable 3d printer

4. DESIGNING FOR 3D PRINTING:

The first step in generating an FDM part is to create a three-dimensional solid model. This can be accomplished in many of the commonly available CAD packages. The model is then exported to the FDM Quick slice software via the stereolithography (STL) format. This format reduces the part to a set of triangles by tessellating it. The advantage of the STL format is that most CAD systems support it, and it simplifies the part geometry by reducing it to its most basic components. The disadvantage is that the part loses some resolution, as only triangles, and not true arcs, splines, etc., now represent it. However, the errors introduced by these approximations are acceptable as long as they are less than the inaccuracy inherent in the manufacturing process. Once the STL file has been exported to Quick slice, it is then horizontally sliced into many thin sections. These sections represent the two-dimensional contours that the FDM process will generate which, when stacked upon one another, will closely resemble the original three dimensional part. This sectioning approach is common to all currently available RP processes. Obviously, the thinner the sections, the more accurate the part. The software then uses this information to generate the process plan that controls the FDM machine's hardware.

5. COMPONENTS OF FDM MACHINE

5.1 The basic requirements to build portable 3D printer is suggested in the following:

- Frame
- Linear bearings
- Linear motion
- Electronics
- Stepper motors
- Stepper motor Drivers
- End stops
- Extruder
- Timing Belts
- Fasteners
- Pulleys

Frame:

The base frame is designed in designing software called CATIA V5 and then it is fabricated through band saw cutting technique using Aluminium profiles.

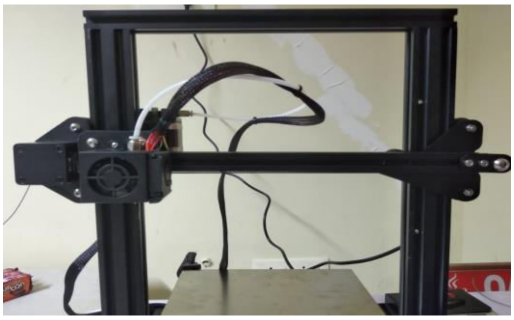


Fig.6. Aluminium frame Support

The Base frame gives the printer its stiffness. The three axes of the machine will be added to this frame. The frame consists of threaded rods connected together with printed parts (these are called the vertices.)

5.2 Linear Plain Bearings:

Linear plain bearings are based on extremely wear resistant polymers specially looped for the linear technology. The dimensions are compatible with**.** Dry Lin is a range of maintenance-free and lubricant-free linear bearings in four different type series. In addition, the range is complemented by complete linear units with spindle drive or toothed belt. Besides the freedom from maintenance and lubricants, the main features include ruggedness and the insensitivity to dirt, water, chemicals, heat or impacts.

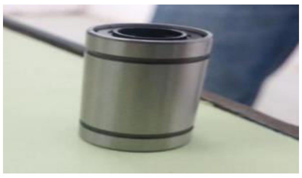


Fig.7.linear bearing

This bearing is choosing for the construction of the 3d printer especially due to its unique

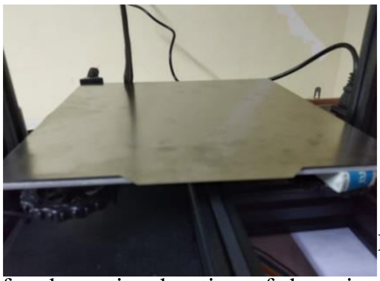
- 100% lubrication free
- Dimensionally interchangeable with recirculating ball bearings
- Large variety of choice in housing shapes
- Replaceable liner
- Dirt resistant
- Weight saving
- High speed
- Silent and light weight
- Corrosion-resistant
- Insensitive to impacts and vibrations
- Low coefficients of friction
- High static load capacity
- High speeds and accelerations possible
- Low magnetism

5.3 Threaded Rod: 6x340x8 mm precision threaded rod. Drill rod is probably okay too, but some report that the bearings wear grooves into the surface as drill rod is not as hard as threaded rod.

Fig.8.threaded rod

5.4 Print Plate:

Printed parts are printed on the print plate. The three axes move together so that the nozzle can move above the print plate in an area of bed.Warping is the main issue, caused by the uneven cooling of outer and inner sections of a printed part. The material at the outside of a part will cool and thus shrink faster than the material inside. This will cause the cooler material to warp or bend while the hot material won't. This uneven shrinking will cause straight edges to bend and might cause structural failure in parts. Warping is especially a problem for the lower layers of a part since the print plate will cool those layers much faster than higher layers.



Plate

The heat bed remains on for the entire duration of the print. Usually a glass plate is installed on top of the heat bed. If the heat would be turned off after a few layers the printed part would eventually come loose due to the temperature drop and the print would fail. A heat bed can either be bought or home-made. Buying is of course easier but building it yourself is feasible and cheaper. While installing a heat bed checking the temperature of the transistor on electronics board must be necessary.

5.5 Electronics:

- Stepper motors : 4x NEMA 17 (3 positioning, 1 extruder). Stepper torque of at least 4600 g/cm.
- End stops : 3x ZM switch (pin plunger, no lever).
- Electronics : RAMPS 1.4, Arduino Mega.
- Power Supply : 12v 10A
- Firmware : Repetier Host.
- Software : CURA, Pronterface.

General Electronic Parts are

- Blower fan
- Heating resistor
- ATX power supply
- LCD smart controller
- LCD to ramps Adapter
- PCB heat bed
- Electronics controller
- Thermistor

5.6 Linear Motion:

- Timing belt: 3x 1524 mm GT2 belt (2 mm pitch, 6 mm width). Closed loops or open end is okay.
- Timing belt pulleys: 3x GT2 plastic pulleys with 40 teeth. Smaller would perhaps work better.
- Threaded rod: 6x497x8 mm precision threaded rod. Drill rod is probably okay too, but some report that the bearings wear grooves into the surface as drill rod is not as hard as threaded rod.

Fig.10.TIMING BELT 2MM PITCH

5.7 Stepper Motors:

Nema 17 Stepper Motor is the most popular in hybrid stepper motor family. Distinguish can also be made with 0.9 Degree Stepper Motor (400 steps/revolution) and 1.8 Degree Stepper Motor (200 steps/revolution), 3 Phase Stepper Motor (96 steps/revolution), Unipolar Stepper Motor and Bipolar Stepper Motor. Nema 17 stepper motor can be applied in various applications: 3D printer, CNC machines, Prototyping machines, Precision Telescope, Pick and place machines, linear actuators, Analytical and Medical Instruments.

Fig.11.NEMA 17 STEPPER MOTOR

The NEMA 17 stepper motor has a holding torque of 4.8Kg, and a 1.8° step angle with 5% step error. The NEMA 17 motors used in the 3D printer have a step angle of 1.8° which allows for high sensitivity, and accuracy, in the movement of the arms. It is possible to control the stepper motor through micro-stepping. If a stepper motor has a 1.8° (200 step per revolution) step size, 1.8° signifies the quantity the shaft rotates in one step, the driver can let for higher resolution by allowing intermediate steps, by rigging the current supply levels.

5.8 Endstops:

End stops at the top where the print head zeros before each print. The wiring configuration is and error working is possible by the use two terminals on the mechanical end stops complex but by trial. To ensure precision for the build, it is significant to have a home position to measure your movements from the commencing position. The end-stop provides this homing position. The position of the end-stop is measured to be 0, and is the position in which the axes can't interchange beyond. In the 3D printer these end-stops are positioned at the top of the triangular prism mount. The arms won't be able to travel any higher than these axes, or indeed, travel to a negative position. One end-stop is installed for each axis. Mechanical end-stops will be used, as they offer a simpler economic solution than the alternative optical-end stops.

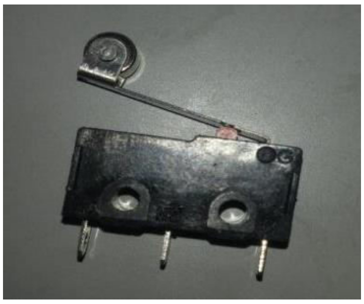


Fig.12. Endstop switch

In the end-stops there are three pins, Normally Closed (NC), Normally Open (NO) and Common (C). The NC and NO pins are set to ground, and the C pin is wired to the SIG port on the controller. When the button is triggered the end-stop will send a signal to the controller to let it know that that axis has touched its home location.

5.9 Extruder:

The printer requires a tool-head that extrudes the molten plastic. In CNC machinery, the protracted arm of the machine is a milling tool. This printer, effectively have the same set-up as a CNC machine but possesses an extruder instead of a cutter. The commands for this device will be analogous to the commands directed to a CNC machine.

Extruder is the crucial part of the any printer because it feeds the material to the nozzle. The latest extruder design consists of both hot end and the cold end separately. In this project, the 3D printer the Extruder design consists of only hot end design and the cold end is the part of the extruder that feeds the filament through to the heated channel. It requires a motor, and a gear. Depending on the rotation and the strength of the motor and gear the feed is operated through the planetary gear of another stepper motor fixed below the base plate.

Filament feeder that is the fixed below the base attached to the stepper motor is shown in the below figure.

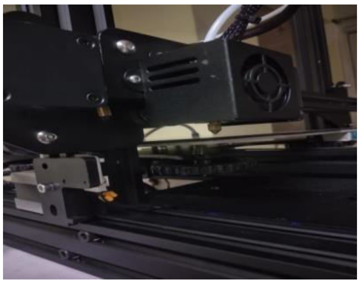


Fig.13.extruder motor

5.10 Printer Board

The printer board is connected to all the components and used to operate them which include end stops, nozzle, stepper motors, extruder etc. Also it's the central facility that continuously monitors the temperature of the hot end of the J-head nozzle and controls the step movements of the stepper motors for the x, y and z movements of the nozzle.

Fig.14.arduino board and ramps board

6. Design Methodology:

To develop the 3d printer, key segment is to focus on the existing different types of printers, their design specifications and their working methodologies concentrating on ABS and PLA extruders then it is easier to produce a conceptual design of the particular 3D printer and to perform any required design analysis. From the literature survey basis a conceptual design of 3D printer is primed.

The motion system comprises of the extruder assembly have both X and Y movement. It is operated by belts moving a double bar cross-beam in the y-direction whiles the extruded is moved up and down this cross beam in the x-directions. The z-axis motion is produced by raising and lowering the printing plate. This is operated by use of a threaded rod. This greatly reduces printing errors due to the printing object having no lateral movement during the printing process and so is unlikely to be disturbed. This is an advantage over printers with lateral y- or x-axis movement of the printing bed which may cause problems. Building a 3D printer compels the arrangement of software, electronics, and mechanics, for a simple breakdown of the different technologies behind a 3D printer design. This flowchart can be used to visualize how all the components connect and interact with each other to make the device work together as a unit.

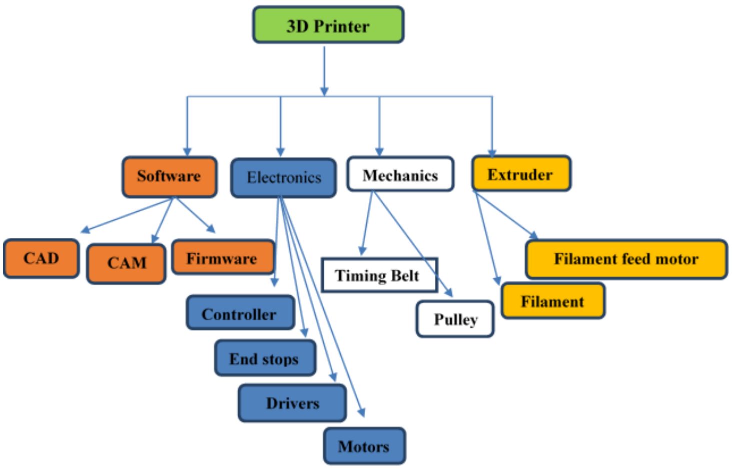


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Fig.15.FLOW CHART

6.1 Process involved in installing the FDM machine:

Nema 17 motor is assigned to the printed motor mount using four M3 10 screws and four M3 washers. The wires are on the side or top.


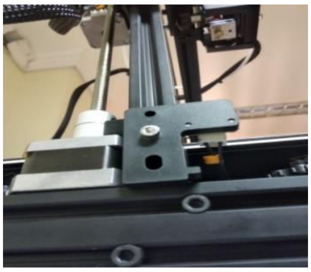

Fig.16. Stepped Motorsfixed to the fdm machine

Placing linear bearing and fixing the nozzle extruder part to the horizontal rod with respect to the axis. Also, attached the motor to the left and right side of the frame.


Fig.17.attaching the nozzle extruder part

6.2 Machinery Fragment:

Most of the machinery of FDM machine will be on bottom of the printer. The Nema 17 motors are already there. It's time for the rest. The easiest way to complete the next steps, is to turn the printer upside down.

1. The extruder motor is mounted with gearbox to the bottom piece with the supplied tie wraps firmly.
2. The Teflon tube is pushed into the extruder
3. The RAMPS 1.4 electronics is taken from its protective bag and the green connector is removed carefully.
4. Two M3 x 30 bolts are used to mount the electronics to the bottom piece. Gently tightened the bolts.

6.3 Fixing Wires:

The end of the wires of the heater element (the big red wires), tin them with a soldering iron is stripped and connected them with the Heat 1 connector. Polarity is not important. The end of the wires of the 40 mm fans is stripped and tin them with a soldering iron and connect them with the Heat 2 connector. Pay attention to the polarity: the black wires should go left, the red ones should go right.

6.4Software

Open Source (Slic3r, Cura, Kisslicer, Repetier Host etc.)
File Type: STL, OBJ, DAE/AMF
OS: Windows/Mac/Linux

6.5 Preliminary work before Testing and Calibration:

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While starting print test and calibrate your printer is the prime step. In order to do so, software has to be installed first. Download the Arduino installer and install it on computer.

Once installation is primed then connect the printer to one of the USB ports of computer. Using Windows takes extra time, until the driver for the printer is installed.

Next step is to download the firm ware which interlinks the software and hardware the firmware using in PORTABLE 3D printer is Cura.

6.6 Print Quality/Resolution

In the CURA software program window, we can find the Print Quality, Material, Diameter, and Support options. Here we can specify the quality level (or resolution) for your model. There is always a tradeoff between quality and the time required for a 3D print. Higher resolutions result in smoother surfaces, which take longer to print. We have optimized the settings in Quick Print mode to balance speed and quality. When we select a new quality setting for a model, the program will automatically update the time estimate for printing. That allows us to experiment with different quality settings and select the one that best fits for any prototyping project within the time frame.

Table.1. Print quality in Microns

Final	**50 microns (0.05mm)**
High	100 microns (0.10mm)
Normal	150 microns (0.15mm)
Low	200 microns (0.20mm)
Draft	250 microns (0.25mm)

Fig.18. Developed FFF machine

CONCLUSION

It is an exciting concept and one that will certainly help push the boundaries on terms of technology. The list of potential applications for 3D printing devices is endless, and in Mechatronic engineering, it is a good starting ground for gaining experience in integrating mechanical, electronic, control and software engineering. Upon completion of the project many problems were encountered, and it is through this and the practical aspect of the project as a whole that ample knowledge was gained.The Portable design enables the extruder to change direction in quick, smooth movements thereby reducing the build time where every second in a build costs money.

FDM is the Prototyping and modelling method of choice for engineers and designers in the automotive, technology, military, consumer goods, medical and architecture fields because of its capability to build in durable ABS plastic. The inexpensive and rapid development of FDM prototypes greatly reduces design to production time and allows for much higher return on investment (ROI). Rapid prototyping and Manufacturing is a fundamental shift in making parts and it is going to serve ad next Industrial Revolution.

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