ABSTRACT

The development of 3D printers over the last 10 years has been amazing and now it is possible to make your own printer with 50% of the parts printed on another machine. That brought the cost down several times. But current machines are limited by volume. One way to overcome that constraint is to use a robotic arm. Robotic manipulation and 3D printing are closely related, but they have remained mostly separate until now. The aim of this project is to join 3D printing and robotics together, to make 3D printing more flexible and to remove limits. To make it possible, in this project the following main aspects have been developed: designing and 3D printing the Robotic arm, programming software to control the necessary hardware like the stepper motor. Adapting provided software to our system to translate G-code to Rapid code.

The software's used in this project are FUSION 360, ABB Robot studio Arduino Software Therefore, in this project, brief and basic information about these technologies has been included.

TABLE OF CONTENTS

2. NOTATIONS AND ABBREVATIONS

AC	Alternating current
DC	Direct current
UART	Universal asynchronous transmitter/receiver
ARM	Advanced RISC machine
PWM	Pulse width modulation
CPU	Central processing unit
ABB	Asea brown boveri
SF	Shear force
M	Bending moment

3. INTRODUCTION

Project Motivation

In recent years the evolution in 3D printing has been fascinating and every time new possibilities appear. Endless opportunities to build and create things and shapes that were previously impossible. However, 3D printing is also a perfect technology for fixing the previously unfixable, when producing spare parts either is not viable or is prohibitively expensive.

The work and research fields opened are huge: medical, dental, aerospace, automotive, jewelry, art, architecture, fashion and even food.

Until now a 3D printer has been a box capable to print layers in 2D. With the inclusion of the robotics in this field the opportunities grow even more. The two main aspects of this merge are the increase of the printing surface, which now is the robot's reach instead a box with specific dimensions, and the possibility of 3D printing using 3D positions and different orientations instead of layer by layer.

Project Target

The main target of the current project is to attach a 3D printing system to a Robotic arm enabling the printing of horizontal layers. Achieving, at first, a larger printing surface and more freedom for future improvements. To reach the final goal it is necessary to accomplish some steps:

• Designing and 3D printing the housing for the extruder and the parts necessary for the filament guidance system

• Mounting the developed parts on the robotic arm

• Programming the controller for the required hardware like the stepper motor.

• Adapting the already created software to our system to translate G-code to Rapid code

• Testing and improving the results obtained

The target of this project is not to achieve to 3D print with different orientations. The goal is to achieve horizontal layer printing with a robotic arm.

Project layout

Chapter 2 Discuss on various 3d printing processes conventionally employed

Chapter 3 In this chapter the system of methods used in the development of 3d printing robotic arm is discussed

Chapter 4 Here the designing aspects of the arm is discussed. Models generated using fusion 360 software

Chapter 5 Here topology optimization is done and final practical model is generated

Chapter 6 Here future scopes of our model, its implementation in current statistics is outlined

4. 3D PRINTING PROCESSES

A variety of processes, equipment, and materials are used in the production of a three-dimensional object via additive manufacturing. 3D printing is also known as additive manufacturing, therefore the numerous available 3D printing processes tend to be additive in nature with a few key differences in the technologies and the materials used in this process

Some of the different types of physical transformations which are used in 3D printing include melt extrusion, light polymerization, continuous liquid interface production and sintering.

There are many different 3D printing processes that can be grouped into seven categories:

- Powder Bed Fusion
- Directed Energy Deposition
- Material Extrusion
- Vat Photo polymerization:

Each process and piece of equipment has pros and cons associated with it

- Powder Bed Fusion

  An additive manufacturing process in which thermal energy selectively fuses regions of a powder bed.

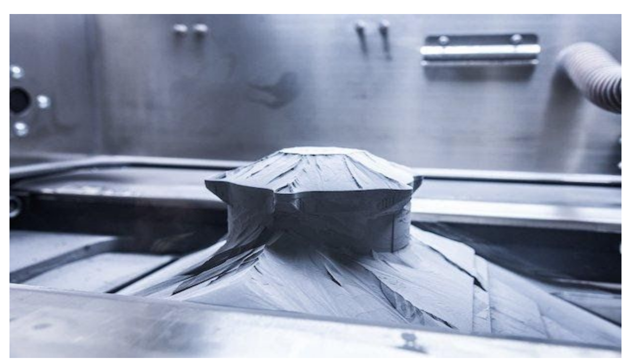


Fig 1: Powder bed fusion

- Directed Energy Deposition

An additive manufacturing process in which focused thermal energy is used to fuse materials by melting them as they are being deposited.

- Material Extrusion

An additive manufacturing

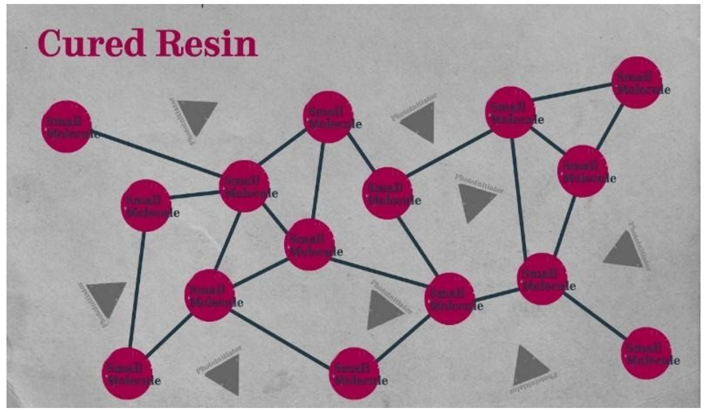
Fig 2: Material extrusion

Process in which material is selectively dispensed through a nozzle.

- Vat Photo polymerization:

An additive manufacturing process in which liquid photopolymer in a vat is selectively cured by light-activated polymerization. . [1]

Fig 3: Vat photo polymerization


Cured Resin
Small Molecule
Photoinitiator

5. METHODOLOGY

- We propose to use articulated robotic arm which helps in the maximum utilization of work space.
- Generative design (mimics natures evolutionary approach) for Robotic arm will help in reducing the material cost as well as in avoiding stress accumulation on certain points on arm while carrying payload.
- The 3D extruder attached to the arm end ejects material in liquid or semi-liquid form in order to deposit it in successive layers within the 3D printing volume.

3.0 ELECTRONICS

3.0.1 Motors

Motors and actuators are the devices which make the robot movable. Motors and actuators convert electrical energy into physical motion.

AC (alternating current) motors are rarely used in mobile robots because most of the robots are powered by direct current (DC) coming from batteries. Also, since electronic components use DC, it is more convenient to have the same type of power supply for the actuators. AC motors are mainly used in industrial environments where very high torque is required, or where the motors are connected to the mains / wall outlet. So, I will not explain about AC motors here. The motor used in our project is NEMA 17.

3.0.2 Motor controller and microcontroller

A motor controller is an electronic device that helps microcontroller to control the motor. Motor controller acts as an intermediate device between a microcontroller, a power supply or batteries, and the motors.

Although the microcontroller (the robot's brain) decides the speed and direction of the motors, it cannot drive them directly because of its very limited power (current and voltage) output. The motor controller, on the other hand, can provide the current at the required voltage but cannot decide how the motor should run.

Fig 4: Microcontroller

Thus, the microcontroller and the motor controller have to work together in order to make the motors move appropriately. Usually, the microcontroller can instruct the motor controller on how to power the motors via a standard and simple communication method such as UART or PWM. Also, some motor controllers can be manually controlled by an analogue voltage (usually created with a potentiometer). [2]

Fig 5: NEMA17

3.0.4 Functionality

The **Arduino Due** is a microcontroller board based on the Atmel SAM3X8E ARM Cortex-M3 CPU. It is the first Arduino board based on a 32-bit ARM core microcontroller. It has 54 digital input/output pins (of which 12 can be used as PWM outputs), 12 analog inputs, 4 UARTs (hardware serial ports).

ARDUINO ATMEGA 2560

The **Arduino Mega 2560** is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller.

Fig 6: Arduino chip

3.0.5 Strength

This includes the ability of the microprocessor for the simultaneous control of two or more motors thus the required output motion can be obtained. The Atmel SAM3X8E ARM Cortex-M3 CPU plays an important role here.

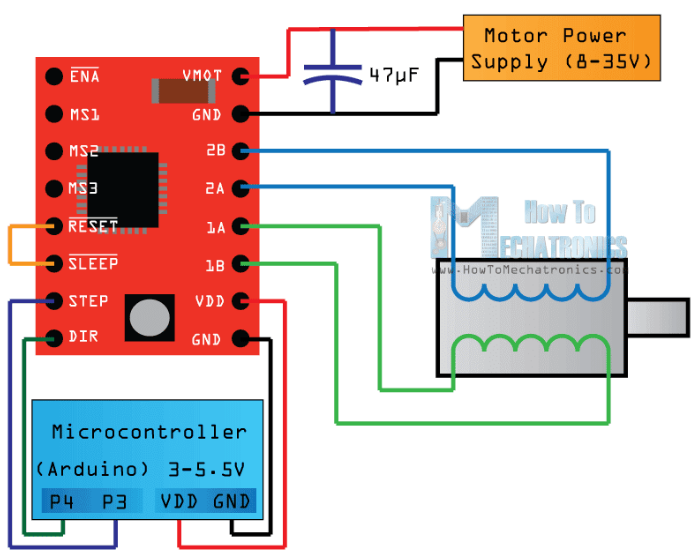


Fig 7: Micro controller

The jumper wires from the motor controller of the stepper motors are connected to the analog IN of the microprocessor (at mega 2560). The power to the motor is delivered from the battery through the motor controller and the amount of power to be delivered in order to get the required motion is governed by the microprocessor.

3.1ROBOTIC SOFTWARE

Before the robot can do certain tasks, it needs to be programmed. The programs that make the robot move are made with special software called an Integrated Development Environment (IDE).We are using a virtual simulation software called ABB robot studio to program the arm movements and to control its path and targets. With Robot Studio, programming can be done visually or by using a programming language that is made for robots [3]

3.1.1 Robot Studio

ABB Robot Studio is downloadable from the ABB site. However, a license is needed for Robot Studio. With Robot Studio the user can create virtual stations with one or more robots that can be selected from the ABB Library. The benefits of making a virtual station is that a physical robot is not needed to program it since Robot Studio has virtual controllers that can be used to simulate the behavior of a physical robot. If the program is finished it is possible to connect to a physical controller and transfer the program that was created in the virtual station to the controller and run it on the physical robot. Figure shows the window where the robot can be programmed visually and import different robots and geometries.

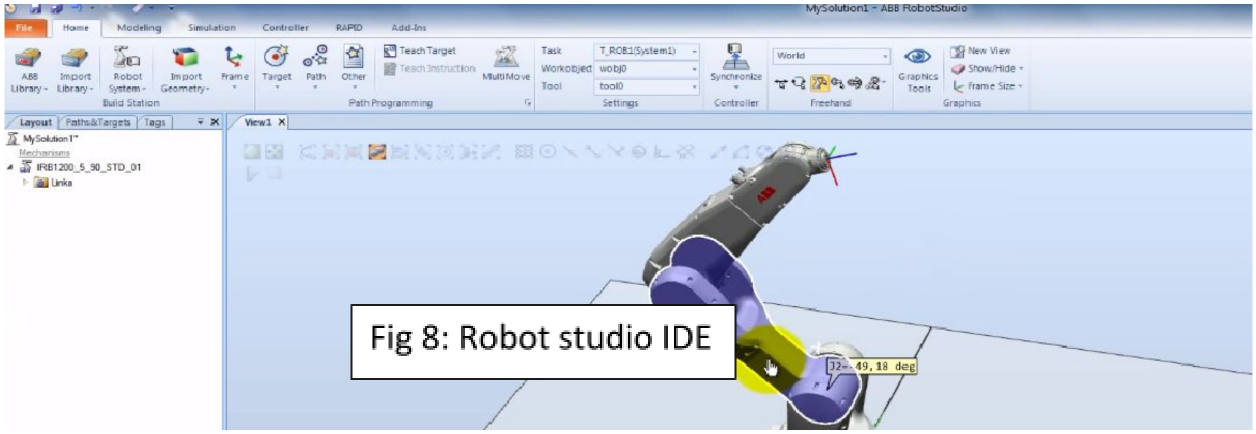


Fig 8: Robot studio IDE

3.1.2 Rapid code

RAPID is a high-level programming language used to control ABB industrial robots. RAPID was introduced along with S4 Control System in 1994 by ABB, superseding the ARLA programming language.

Features in the language include:

- Routine parameters:
  - Procedures - used as a subprogram.
  - Functions - return a value of a specific type and are used as an argument of an instruction.
  - Trap routines - a means of responding to interrupts.
- Arithmetic and logical expressions
- Automatic error handling
- Modular programs
- Multitasking

3.1.3 Software for the Tool Arduino

- The software programmed in Arduino includes the stepper motor, thermistor, heating element and the cooling system. The software created is time based, it means that at first, a time counter starts, and the different parts of the software systematically start when they are required.

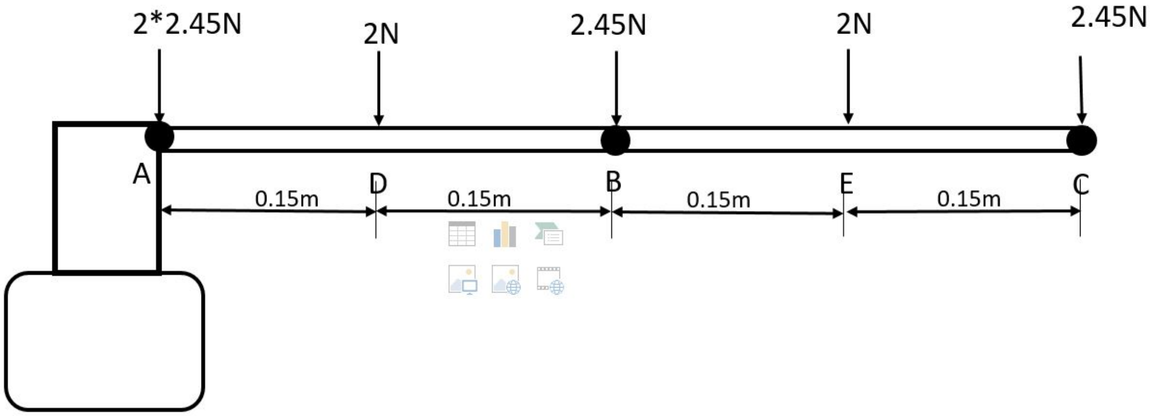
- The software is divided in three modules, one for each kind of hardware. First, the program starts with the stepper motor module. This module calculates the steps that must be done and the time between each step (extrusion speed), based on the data from the Gcode converter. In each execution, the current position is saved to compare with the next data from the Gcode. Once the calculation has been done, the software executes each step in the time required until the calculated number of steps is reached.

- The second module is the temperature control module. When the module starts, the output from the thermistor is obtained and compared with the calibration table of the sensor, giving the correct temperature and making an interpolation if is necessary. The temperature obtained is the input of the PID regulator [4]

6. PROBLEM FORMULATION

Load calculation in robotic arm

Considering the arm as a cantilever beam.



Weight of limb AB =limb BC =2N [right downwards=positive]

SF at C = 2.45N

SF at E = 2+2.45 = 4.45N

SF at B = 2.45+2+2.45= 6.9N

SF at D =2+2.45+2+2.45 = 8.9N

Bending moment [right clockwise=positive]

M_C =0

M_E =2.45*0.15 =0.3675Nm.

M_B = (2*0.15)+(0.3*2.45) =1.035Nm

M_D =(2.45*0.15)+(0.3*2)+(0.45*2.45) = 2.07Nm

M_A =(2.45*0.6)+(2*0.45)+(2.45*0.3)+(2*0.15) = 3.405Nm

7.ARM DESIGN

The arm was designed using fusion 360 .As per the load calculations obtained by considering the arm as a cantilever beam, the following design was made. The initial design of the arm is shown below.

The modified design of the arm is shown below.

Fig 9: Arm degrees of freedom

4.1 Functionality

The arm consists of two limbs and a mount for different types of printing methods like extrusion, laser atc.which can be attached to the mount at the end of limb.

8. TOPOLOGY OPTIMISATION

Topology optimization (**TO**) is a mathematical method that optimizes material layout within a given design space, for a given set of loads, boundary conditions and constraints with the goal of maximizing the performance of the system. TO is different from shape optimization and sizing optimization in the sense that the design can attain any shape within the design space, instead of dealing with predefined configurations. [5]

Fig 10: Sample model

5.1 Implementation

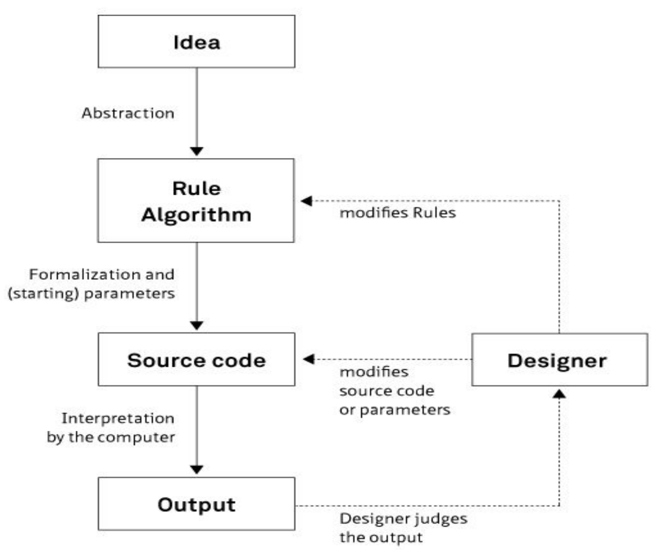
The proposed arm can be used for 3D printing parts with higher accuracy for prototyping and testing

5.2 Proposed Design (Basic Idea)

The proposed design is a robotic arm with the 3Dprinting extruder module attached to it.
The robotic arm structure is made using generative design model

5.3 Generative model

These simulation techniques allow customers to design lightweight and per formative parts using a simulation-driven design approach. Advances in manufacturing technology also allow these sometimes complex designs to be built using both traditional processes like casting, injection molding, and forging, but also through Additive Manufacturing (AM) or 3D printing.



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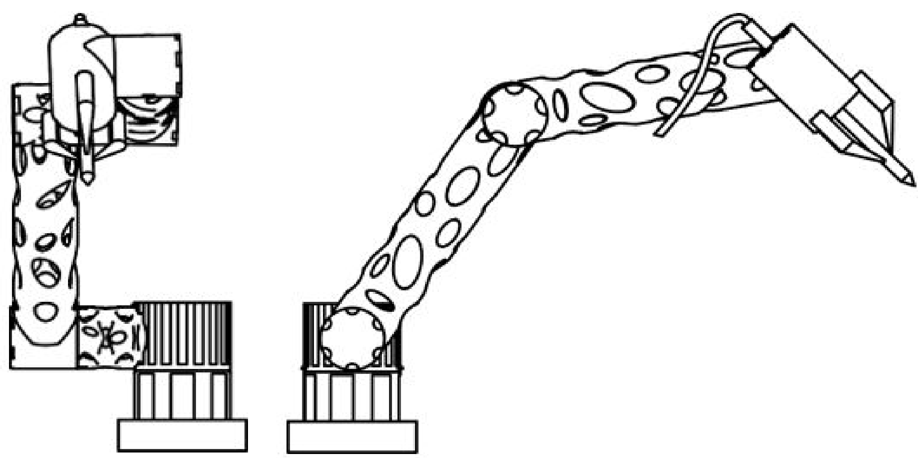
Book „Generative Gestaltung", www.generative-gestaltung.de

Fig 11: Flowchart generative model



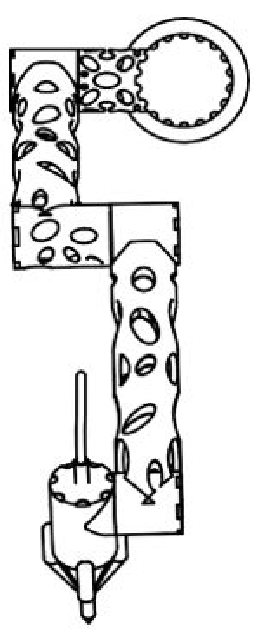


Fig 12: Front views

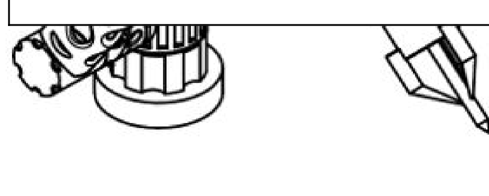


Fig 13 : Top view

Fig 14 : Side view

9. CONCLUSIONS

The project fulfils the requirements set at the beginning. Firstly, a functional design, 3D printing and mounting of the tool has been achieved, doing possible the simulation of the tool in the different software like fusion 360 and Robot Studio.

Then the software developed for the tool in Arduino and the robot in Rapid has accomplished the required features. Without forgetting about other characteristics developed like the guidance system or the printing bed and all the research needed to find out the best solutions.

Overall, a system with the basic characteristics of a 3D printer has been developed, but in an ideal environment that makes the continuous development of the system possible, both at the hardware level and at the software level.

During one of the tests the team tried to print a circular object. During the test, the robot arm was having difficulties to make the circular movements. This is understandable because the G-code consists only linear movements. The robot cannot move such close distances without hiccups. With other models, this behavior was visible as well. The time that is was standing at the same place was significantly less than the object with curves in it.

At last, the team can conclude that 3D-printing with a robot arm is possible. The system that was created contains basic functionality. The system could be extended and improved upon.

10. FUTURE SCOPE

1. Robotic Arm Extruders

The Contour Crafting method involves the building material Being deposited to create a large-scale 3D model with a smooth surface finish. Rails are installed around the building ground that will act as a structure to direct the robotic arm.

Fig 15: Using robotic arms in construction

It moves back and forth to extrude the concrete, layer-by-layer. Trowels placed on the side and above the nozzle to flatten the extruded layers and ensure the model's strength

2. 3D printing in construction

In terms of materials usage, 3D printing is economical. With additive rather than subtractive processes, less materials are used than traditional manufacturing processes. This reduces the environmental impact as less waste is produced. Romaine Doublet, one of the co-founders of XtreeE, explains "with an increased geometric mastery, we can build optimized shapes to limit the amount of materials used."

3. 3D Printing in Space?

Additive manufacturing could also be a way for humanity to explore space. NASA has launched the '3D Printed Habitat Challenge examining technologies used to build homes in space, such as on the Moon or on Mars. Although ambitious, it is too early to tell if 3D printing is a viable solution. We can tell however, that 3D printing in construction is to become a very real global force.

11. REFERENCES

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