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# Design and Implementation of an Economical Table Top CNC Coffee Art Machine

**Shivam Dehinwal**

*Delhi Technological University, Shahbad Daulatpur, Main Bawana Road, New Delhi*

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**Abstract-** *Machines that are controlled by levers, hand wheels etc. have become symbols of anachronism and the modern day machines are controlled by pre-programmed sequence of machine control commands. CNC machines started coming up in late 1950's and since then have become an indispensable part of any modern day manufacturing setup. Development in Food technology adds value to existing techniques of food production/consumption thus uplifting product value and quality. In this paper a method of adding value to a cup of coffee with use of CNC technology has been shown. Though there are Coffee art machines present in the market but they cost a minimum amount of 1500$. The machine discussed here is built within an extremely confined budget of INR 10,000 (approx. 160$). The paper discusses how a discreet selection of hardware and clever implementation of CNC technology led to the development of the product which can print images and text over coffee cups of variable sizes. An exhaustive flowchart shows the workflow of the machine.*

***Key Words:*** **CNC, Arduino, Automation, Coffee, Print Speed, Stepper, Gcode, Food Technology, latte art, GRBL.**

## 1. INTRODUCTION

The origin of coffee dates back to the 9th century when an Ethiopian goat-herd named "kaldi" noticed ardent behaviour of his goats after eating the beans from a coffee plant, coffee art on the other hand started developing in late 1980s and became more popular with development of latte. Latte art is a method of preparing coffee by pouring steamed milk into a shot of espresso which results in a pattern on the surface of latte. Latte art is pursuit of a skilled person commonly referred to as a barista and involves various complex techniques to result in an itemized pattern, because of the effort involved, a cup of latte with a pattern costs around 10 times the cost of regular latte. The aim of this paper is to make an economical latte art machine that could take up the role of a barista and print text along with patterns not only on latte but on other variants of coffee too. This would expunge the need of a skilled person for this particular job, cut the cost and would make latte art reach even the smallest coffee shops.

The machine needs to be highly precise as an error of even 0.5mm takes appreciable area on a cup of coffee, it should accurately perceive the printing area and should release just the right amount of coffee powder, also the coffee powder extruder should switch states between on and off swiftly as the machine should be able to challenge a professional barista.

Crucial effort has been made to build a cost effective coffee art machine that is easily affordable to small coffee shops and households while giving utmost attention to make the interface as much user friendly as possible.

This paper is organised as follows:

- Mechanical Design and assembly
- Electronics
- Software Implementation
- Conclusion
- Acknowledgement
- Future Scope
- References

## 2. MECHANICAL DESIGN

The coffee art machine is an example of fine modern day technology, being computer numerical controlled. It is very precisely actuated and drops just the right amount of coffee powder at a particular location commanded by the Gcode. Since the machine has to print texts as well as images no consequential error is desirable, also the vibrations have to be taken care of so that the coffee doesn't spill out of the cup. Due to this constraint the cup cannot be placed on a movable axis and the x and y axis has to be made in a single plane. After exhaustive research on forward kinematics, it was observed that a minimum of 4 independent parameters are needed for precise extrusions at any cartesian coordinate and thus a 4 degree of freedom mechanical assembly was finalized that can be classified into 2 parts:

1. Linear X, Y and Z axis
2. Coffee Powder Extruder Mechanism.

### 2.1 Linear X, Y and Z axis

In an attempt to keep the coffee cup stationary the base of the machine is kept fixed and the x-y plane is connected to z axis that brings the coffee powder extruder at the right height above the coffee cup. Initially x and y axis were planned to be controlled by dc motor with encoder using rack and pinion mechanism but due

to lack of precision a shift was made to 4.2 Kg-cm torque Nema 17 motor with a precision of 1.8 degrees coupled with GT2 series of belt and pulley which are designed specifically for linear motion. They use a rounded tooth profile to ensure that the belt tooth fits smoothly and accurately in the pulley groove, so when the pulley direction is reversed, there is no room for the belt to move in the groove. Decision to use belts was based on the fact that belts are faster than chains and lead screws.

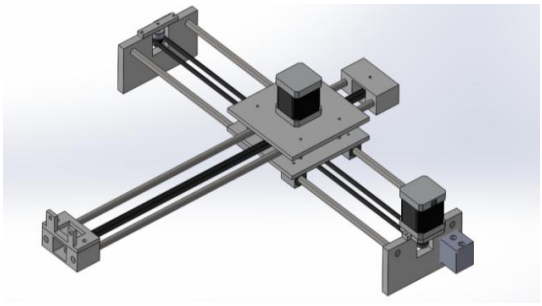


**Fig 1:** Design of linear X-Y axis

The whole x-y plane is mounted over two z axis rods also controlled by 4.2 kg-cm torque Nema 17 motors but this time coupled with M8 threaded rods with 1.25mm pitch. The following is a representation of the Z axis along with the drawing area.

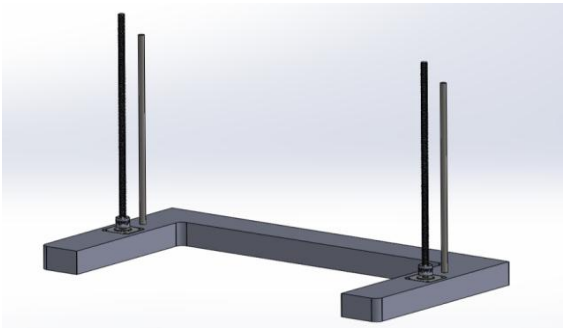


**Fig 2:** Z axis and base plate design

### 2.2 Coffee Powder extruder Mechanism

The coffee powder extruder mechanism is controlled by an sg-90 microservo motor which is connected to the gate of the extruder. Upon rotation of motor shaft the coffee powder extruder switches state from off (non extruding) to on (extruding).

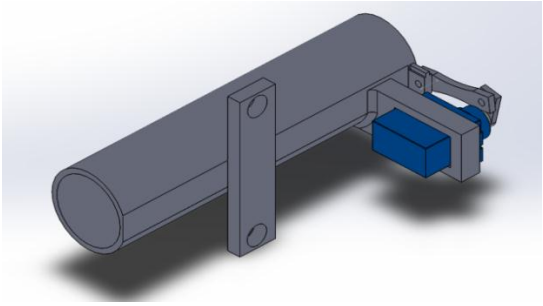


**Fig 3:** Isometric view of coffee extruder

### 2.3 Components required:

The necessary components required for the mechanical assembly along with their cost are briefly explained as follows:

#### 2.3.1 Guide rails

Guide rails play the role of fixed path support for linear traversal as the belts alone cannot carry weight without wobbling. 8mm hardened chrome rods were used as guide rails.

Cost- Rs 200 for 4 units

**Fig 4:** Guide Rails

#### 2.3.2 Linear slide bearings

LM8UU linear slide bearings were used for smooth traversal of coffee powder extruder over the x y axis. The bearings were firmly fixed to the frame using zip ties.

Cost- Rs 2880 for 8 units

**Fig 5:** Linear slide bearings on guide rail

### 2.3.3 Pulley and timing belt

Pulley and belts of GT2 series were used.
The specifications for pulley are:

Bore diameter: 5mm
Pitch: 2mm
Teeth number: 20
Outer diameter:12.22mm

The specifications for belt are:

Pitch: 2mm
Material: Rubber with fibreglass
Width: 6mm

Cost:

Pulley: Rs300 for 2 units
Belt: Rs 240 for 2 meters

**Fig 6:** GT2 timing pulley

### 2.3.4 M8 threaded rod

Two sections of 8mm diameter M8 rod of stainless steel 304 material with 1.25 mm pitch was used for smooth and non-erratic movement of the z axis to bring the x-y plane over the correct printing height over the cup. This feature accredits the use of coffee cups of distinct heights.

Cost: Rs 370 for 2 units of 500mm each.

**Fig 7:** M8 threaded rod

### 2.3.5 Stepper motor coupling

5*8*25 mm flexible shaft coupling having one end with 5 mm diameter bore and other end with 8mm diameter bore were used to couple stepper motor with threaded rod firmly and to absorb minimal vibrations that are bound to occur due to sudden start and stop actions of the stepper motor.

Cost: Rs 330 for 2 units

**Fig 8:** Stepper motor coupling mounted over motor

**Table1:** Cost wise split of Mechanical assembly components

| Serial No. | Component | Quantity | Cost (Rs) |
|---|---|---|---|
| 1. | Guide rails | 4 | 50/unit |
| 2. | Linear slide bearings | 8 | 360/unit |
| 3. | Gt2 pulley | 2 | 150/unit |
| 4. | Gt2 belt | 2 metres | 120/metre |
| 5. | M8 threaded rod | 1 metre | 370/metre |
| 6. | Stepper motor coupling | 2 | 115/unit |
| Total Cost | | | 4320 |

## 3. ELECTRONICS

Electronics form the communication link between the software and the mechanical hardware, for the coffee art machine play the role of bringing the coffee powder extruder to the correct height using lasers and LDR (light dependant resistor) and then translating the computer generated Gcode into precise coffee powder extrusions at the correct x-y coordinates. The job of electronics in the machine can be divided into 3 parts:

1. Detecting the coffee cup.
2. Establishing serial connection with computer.
3. Motor movement control

### 3.1 Detecting the coffee cup

The laser modules solve the problem of making the machine fit for cups of variable heights. Two laser emitted in the x and y directions continue to feed their respective LDR's while the threaded rods on the z axis keep bringing the x-y assembly down until the cup breaks both the laser beams, as the laser beams are blocked by the cup the resistance of LDR's change, this change is detected by the microcontroller and it stops the z axis motors. Now the x-y plane has reached the optimal extrusion height and the coffee powder extrusion process starts.

### 3.2 Establishing serial connection with computer

A serial bus consists of just two wires one for sending data and the other one for receiving data. Here we have used asynchronous serial protocol which means no clock data is transmitted and devices must agree ahead of time over a data rate for robust and error free data transfer. Serial protocol is highly configurable and the rules or features that govern the communication are:

- Baud rate: rate of data transfer over serial line.
- Synchronization bits: start and stop bits that define packets of data.
- Parity bits: bits for checking errors that creep in during communication.

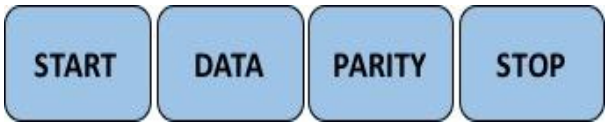



**Fig 9:** A serial frame

### 3.3 Motor Movement Control

The microcontroller makes use of motor drivers as the controlling unit for the motors, the maximum 5V output from microcontroller cannot power the motors and thus external 12V supply is given to the motor drivers.

### 3.4 Components required:

- Arduino Mega 2560 R3
- DRV8825 Motor driver
- 12V 30A power supply
- Nema 17 stepper motors
- LDR
- M586 laser module
- Microservo motor

The functioning, specifications, selection criteria and cost for the electronics components is stated as follows:

#### 3.4.1 Arduino Mega 2560 R3

The brain of the machine, its microcontroller Arduino Mega 2560 R3 based on atmega 2560 plays the role of actuating the laser modules, reading inputs from the LDR's and actuating the motors in synchronism based on the gcode.

Selection criteria: Memory space, cost effectiveness and community support.

Cost: Rs 675 for 1 unit

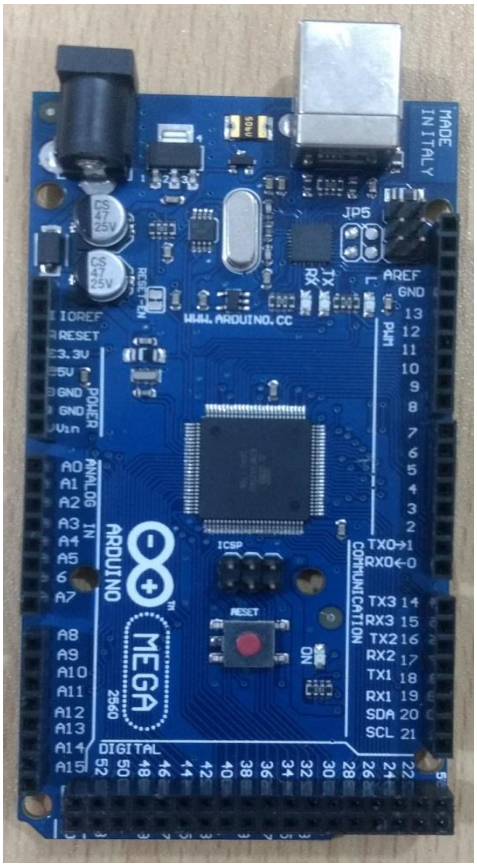



**Fig 10:** Arduino Mega

#### 3.4.2 DRV8825 Motor Driver

DRV8825 is a high current motor driver by pololu and bridges the gap between the motor and the microcontroller.

Selection Criteria: The motor driver was chosen as it can control a bipolar stepper motor at upto 2.2A output current per coil and needs no external logic voltage supply i.e. it can be interfaced with both 3.3V and 5V voltage levels directly.

Cost: Rs 800 for 4 units

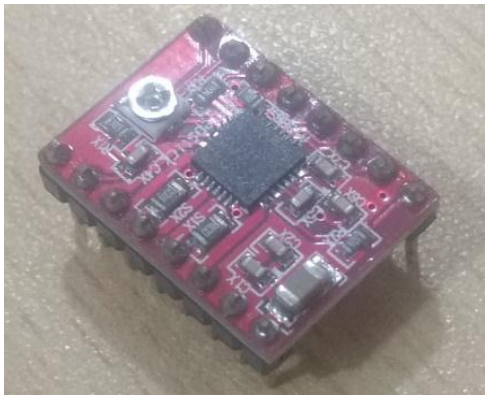


**Fig 11**: DRV8825 motor driver

### 3.4.3 12V 30A Power supply

12V 30A 360 W switching switch power supply was used to externally power the motors.

Selection Criteria: Cost effective, easy to use, provides enough current.

Cost: Rs 850 for 1 unit

**Fig 12:** 12V 30A power supply

### 3.4.4 Nema 17 Stepper Motor

The Nema 17 stepper motor plays the role of actuating the x, y and z axis for positioning the coffee powder extruder at any point in the cartesian frame. It provides high torque, consume less power and is very precise owing to its property of micro stepping.

Selection criteria: Torque; rotational and torque speed for stepper motors have an inverse relationship, required torque depends on mass of the system and the drive mechanism. It is desired to operate motors at maximum torque for non-erratic functioning.

No. of steps: The selected Nema 17 motor takes 200 steps for one complete rotation giving a precision of 1.8 degrees, this can be increased by using microstepping technique.

Cost: Rs 2800 for 4 units

**Fig 13:** Nema 17 stepper motor

### 3.4.5 LDR

Light dependent resistors (LDR) are basically variable resistors that change value based upon the availability of light. In ambient light the resistance is typically 8K ohms and in absence of light resistance becomes up to 100k ohms. LDR here is used in potential divider circuit with a resistor of 40k in series with it connected to a power source of 5v.

Selection Criteria: Easy to use, cost effective, fast and can be threshold values can be changed easily.

Cost: Rs 10 for 2 units

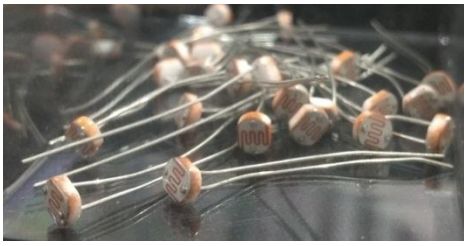


**Fig 14:** Light Dependent Resistors

### 3.4.6 M586 Laser Module

The M586 Laser module can be powered and controlled by arduino as it draws a current of 30mA and provides 650nm laser by consuming 5mW power at an operational voltage of 5V. It is used to create a trip wire alarm like system to detect the coffee cup.

Selection criteria: Power efficiency

Cost: Rs 360 for 2 units

**Fig 15:** M586 laser module

### 3.4.7 Micro servo motor

The micro servo motors is a type of servo motor based on feedback mechanism in a smaller size. SG-90 micro servo was used in the machine to rapidly open and close the coffee powder tank.

Selection criteria: Fast and precise.

Cost: Rs 150 for 1 unit

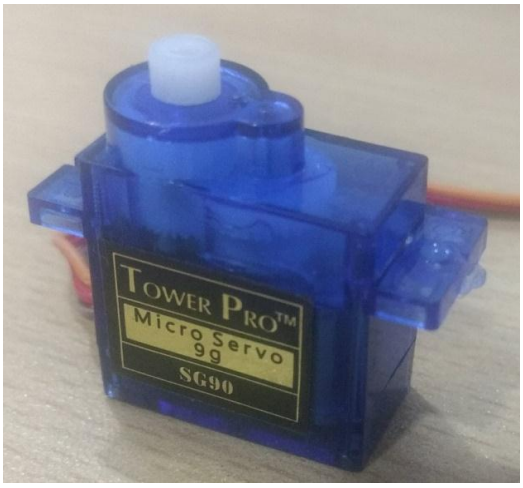



**Fig 16:** Microservo motor

**Table2:** Cost wise split of Electronic components

| Serial no. | Component | Quantity | Cost per unit (Rs) |
|---|---|---|---|
| 1. | Arduino Mega 2560 R3 | 1 | 675 |
| 2. | DRV8825 motor driver | 4 | 200 |
| 3. | 12V 30A power supply | 1 | 850 |
| 4. | Nema 17 Stepper Motor | 4 | 700 |
| 5. | LDR | 2 | 5 |
| 6. | M586 Laser Module | 2 | 180 |
| 7. | Micro Servo Motor | 2 | 150 |
| Total Cost | | | 5,645 |

## 4. SOFTWARE IMPLEMENTATION

The software of coffee art machine gives us the competence to print any text or image over a coffee cup of any size. The application software at the computer lets us convert images with transparent background and texts into arduino readable gcode and the firmware at arduino end, based on GRBL, a high performance, open source CNC controller software written in optimized C lets the arduino read the code and extrude coffee powder at the correct coordinates.

The tasks achieved by software implementation can be divided into two parts:

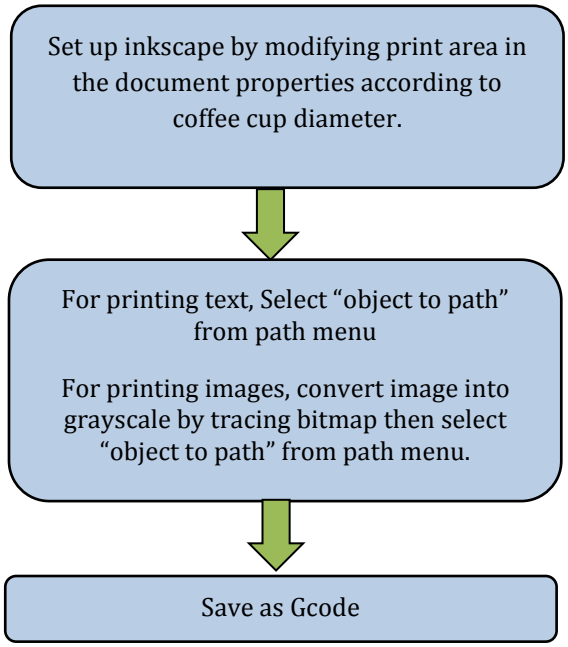
- Conversion of images and text into gcode.
- Gcode interpretation by arduino using GRBL

The two processes are discussed in detail as follows and functions of microcontroller are summarized at the end:

### 4.1 Conversion of images and text into Gcode

Gcode is a CNC control language which lets us communicate to the machine to make it move to various positions at a desired speed, control the end effector actuation and a lot of other things. To convert text and images into gcode we use “Inkscape” which is an open source vector graphics software and install the “makerbot unicorn gcode output” as an add on to enable it to give gcode outputs.

An exhaustive flowchart ahead summarizes the process of turning images and text into gcode.

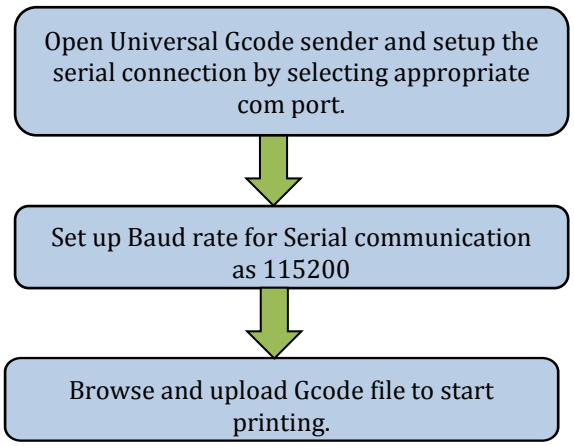



**Flowchart 1:** Process of converting images and text into gcode

### 4.2 Gcode interpretation by arduino

The GRBL firmware file was uploaded to arduino to interpret the Gcode. Now to establish a serial communication link between the computer and the arduino, “universal Gcode Sender” which is a self

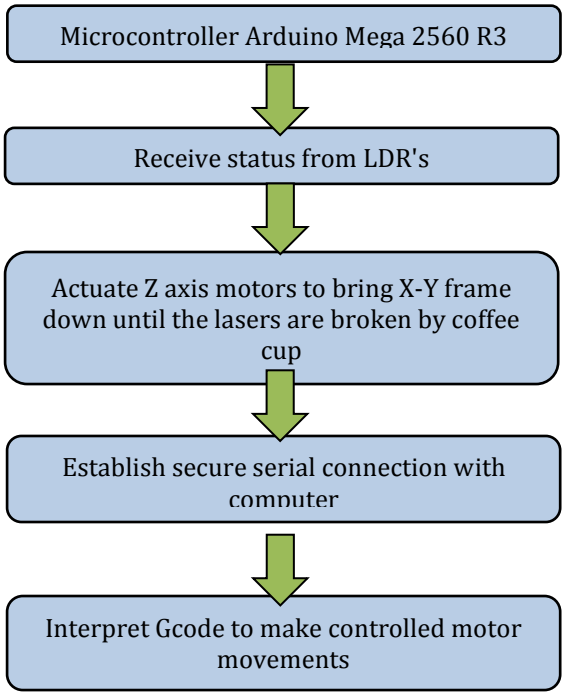
contained java application to interface CNC controllers like GRBL is used. The rest process is clarified in the flowchart ahead.




**Flowchart 2:** Arduino, gcode sender communication setup

### 4.3 Microcontroller Functioning

The Microcontroller plays many roles simultaneously for smooth functioning of the coffee art machine. Initially in the setup stage it acquires the status of both LDR's continuously and keeps moving the X-Y plane down, upon detecting change in values of LDR's which signifies that the distance between the cup and the extruder assembly is just perfect it commands the z axis motors to stop and starts communicating with the computer to receive the gcode and commands the motors to move in a particular order to draw a pattern over the cup.




**Flowchart 3:** Complete functioning algorithm

## 5. CONCLUSION

Food technology is a relatively new term and has emerged as a ground of massive research and improvement in past few years, one little aspect of it is value addition to regular products/methods of preparation. Little value addition to common consumables increases their selling price largely and symbolises better service. The economical coffee art machine is one step in the direction of adding value to one of the most common beverage, coffee. If such technology which is easy to use and is affordable is made available to the little coffee shops in the nation, it would certainly uplift the quality of one's experience. I hope this effort would initiate more of such experimentation in field of food technology, to add value to products and thus helping the economy.

## 6. FUTURE PROSPECTS

Robotics and automation will surely shape the way humans collect, prepare and consume food in future. Combining techniques like CNC with food preparation would result in uniformity of food preparation across the world. The coffee art machine will be used to print signature graphics, texts and logos by companies. While the present stage of machine can draw images easily, there is large scope of improvement by understanding the image as an RGB array instead of a binary one and as a result extruding different amounts of coffee powder to give depth to the images. Experimentation in this direction with different extruder designs has been started and the preliminary results are encouraging.

## 7. ACKNOWLEDGEMENTS

The idea of coffee art machine would have not turned into reality without positive feedbacks, guidance and constructive criticism from my friends and teachers at Delhi Technological University.

I would like to express my deep sense of gratitude to my parents who always supported me in every way possible. This project wouldn't have been complete without my sisters who gave quality input and made me think in various directions while working on the machine.

I am also thankful to the Robotics team of DTU, DTU Altair for their unparalleled support and assistance.

## 8. REFERENCES

1. http://www.instructables.com/id/AXIBOT

2. Javed, F. and Javed, S., "Design Methodology and Development of an Economical 3D Printer," SAE Technical Paper 2016-01-0325, 2016, doi:10.4271/2016-01-0325

3. http://www.instructables.com/id/Installing-and-Configuring-DRV8825-Stepper-Drivers/

4. http://www.instructables.com/id/Controll-a-Stepper-Motor-With-the-DRV8825/

5. Varun Gupta, Amit Kumar, Shilpi Agrawal, Saumya Jaiswal, "Autonomous Chess Playing Robot", International Journal of Engineering Research and Technology, ISSN: 2278-0181 Vol. 4, Issue 3, March 2015

6. http://www.explainthatstuff.com/how-stepper-motors-work.html