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# Prototype of a CNC technology based 'Adire' fabric pattern sketcher

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**Abstract**

This work focuses on the application of CNC technology to designing and fabricating of pattern sketcher for 'Adire' fabrics popularly made by the Yoruba tribe in South Western Nigeria. Pattern making, being an operation that requires multi-axial movements of which CNC readily fit in, becomes easier to carry out unlike the local painting of fabrics as is currently being practiced amongst local 'Adire' manufacturers. In order to make the production of this machine readily available and affordable, effort is put on the usage of locally available materials where appropriate and efficient, to minimize cost of production and improve local technology. Computer Aided Design software is used for general components design, assembly, and simulation. Arduino technology is used for motor speed and position control. Fabrication is carried out in a local workshop using available technology as the benchmark for this prototype's production. Testing of computer infused pattern is carried out and comparison made with prototype sketcher's output. Encouraging results are obtained which could be improved upon.

**Keywords**: CNC, 'Adire' fabric, Prototype, Sketcher, CAD

## 1. Introduction

Computer Numerical Control (CNC) is a valuable piece of technology that makes machine fabrication very easy, fast, precise and efficient. The concept of numeric control makes the rigorous task of manual cutting, welding, milling, surface- engraving, drawing and so on very effortless and autonomous [1]. The idea behind this CNC technology is that one could draft a pattern using Computer Aided Design software (CAD), feed the design into a CNC machine which in turn replicates the design on a selected work piece easily and efficiently [2]. CNC technology has a wide range of industrial applications such as manufacturing of certain parts of machines, equipment, effects, gadgets, furniture, design, architecture, fabrics, and many more [3].

It is now a common practice to see many machine functions and movements that would otherwise have been traditionally performed by skilled mechanics being numerically controlled [4]. Adaptation of CNC technology to solve various production challenges is what is innovative as most CNC routers have a few unchanged part such as:

i A dedicated CNC controller
ii One or more spindle motors (router heads)
iii Stepper or servo motors for transmission
iv A work table.

These CNC routers are generally available in 3-axis and 5-axis CNC formats. The setting of axis coordinates is adjusted and uploaded into the machine controller from a separate program as demonstrated in this work [5].

CNC machine has been applied as a lathe to produce pistons. This provides a means of piston machining with ease and shows the economic advantage of local piston production using CNC technology over the imported version as currently being experienced in Nigeria [6]. CNC has also been applied to the design of low cost computer numerical control-printed circuit boards drilling machine involving components like; driver, drill, three stepper motors, cables and microcontroller PIC16f877A to control the movement of the machine. The means of control is by the use of C# programming language [7]. For the purpose of precision and design which could remain rigid given the vibration and stress involved in an average CNC machine, the base structure of a CNC router has also been specifically designed [8]. Focus is on the mechanical subsystems which includes the mechanical drive systems, the framing system, and the guide system. The guide and mechanical drive systems have several choices of material and structure type, and each of these choices are determined by cost and precision level desired [9].

In order to make CNC machine accessible for small scale industries, a low cost automatic mini CNC machine for PCB drawing, drilling, wood engraving, glass cutting has been developed as well [10]. This system reduces the cost of machine and increases its flexibility like the case of CNC machine assembly [11]. G-code is the bedrock of the machine control. This CNC router was developed specifically for engraving and glass cutting on small scale for home use with Printed Circuit Board (PCB) base structure to reduce cost. The structural integrity was affirmed with

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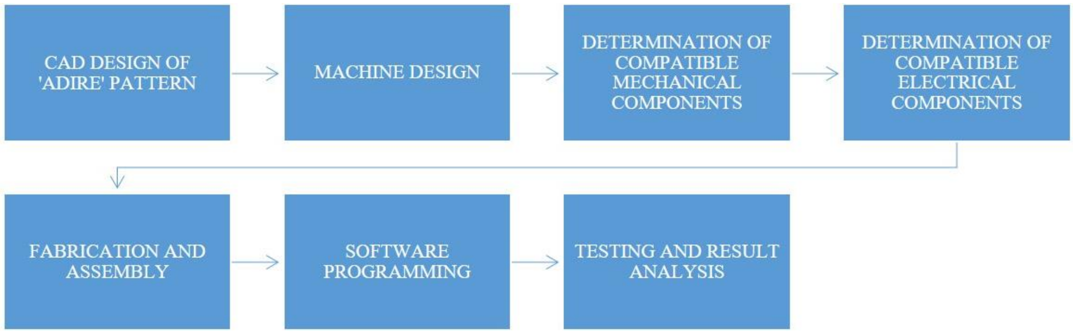


**Figure 1** 'Adire' CNC Sketcher development workflow

Arduino being the programming language for encoding the instructions. Efforts have been made to further reduce cost as shown in a mechanical prototype of a CNC plotter machine with locally sourced "spare parts" which was able to draw a Printed Circuit Board (PCB) layout on a given solid surface. This prototype CNC plotter machine consumes low power and works with high accuracy due to precise controlling of stepper motors employed [12]. The project was a low cost project as compared to other CNC products. It was made with easily available components and spare parts. The machine was designed with a very simple construction scheme and could be carried anywhere with ease. The pen could be replaced with a pinhead or laser head or any other tool for different purpose of use [13].

However, as extensive and beneficial as the application of CNC technology is, the patterns of 'Adire' fabrics are still largely done with the use of stencils and free hand [14] in South Western Nigeria. This limits its mass production and intended design precision. The need to meet the ever growing demand of 'Adire' in Nigeria and beyond has prompted new generation of producers to seek new technologies that would improve the quality of 'Adire', increasing its production volume, and its acceptability as a ceremonial attire rather than knockabout [15]. Moreover, since CNC machine's components are becoming affordable, a low cost prototype specifically for 'Adire' pattern sketcher could be developed to encourage mass production with improved quality designs.

The rest of this paper contains; methodology, construction processes, results and discussion, conclusion, and references.

## 2. Methodology

The workflow for this prototype development is shown in Figure 1. CAD design of 'Adire' is first carried out. The CNC machine design to suit the purpose of 'Adire' pattern sketching is made. Mechanical and electrical components are selected with low power consumption consideration. Fabrication and assembly of parts are done. The controller used is programmed. Testing and analysis of the machine is carried out accordingly.

### *2.1 Mechanical structure of the machine*

The structure of the CNC device integrates all the components into a functional system. The machine structure directly affects the static and dynamic stiffness as well as the damping response of the machine tool. A carefully designed structure provides high stiffness and less vibrations.

Gantry-Style closed frame structure is chosen for the setup because it offers high precision and optimum stability for small scale applications. The Gantry style consists of a gantry that slides along the longest axis (X-axis). The Y-axis is mounted on the gantry itself and it carries the cutting tool, that is, router or spindle head, along the axis. The Z-axis is assumed to be the height axis that determines the depth of the cutting tool as it cuts the work piece. The axis nomenclature selected here is not a standard but for ease, the X-axis is usually selected as the one that is perpendicular to the observer when he stands in front of the machine and it is usually the longest axis. Medium Density Fiber board (MDF) is the selected material for the machine frame, chosen because it possesses enough density to withstand vibrations from the machine and could easily be cut during fabrication.

The transmission system is supported by linear rails on which a linear bearing slides, two on each axis. The shafts are supported by support blocks attached to the main frame. The linear bearing and shaft is designed in such a way that friction is minimal. This allows for smooth operation without overloading the coil of the stepper motors. The shaft is selected such that it is rigid enough to support the weight of the components on each axis without deformation. Each axis has two shaft rails and the transmission mechanism is a screw thread coupled mechanism.

The movement along the three (3) axes is accomplished by stepper motors actuating a kinematic pair consisting of a lead screw and nut. The theory behind the movement could be seen in the conversion of rotary motion to linear motion by a bolt and nut. The stepper motor turns a screw rod in which a nut is attached. The nut carries the machine part required to be moved linearly and as it turns, the parts slides along its axis. The direction of travel could be controlled by changing the direction of the stepper motion simultaneously . A square thread is used in this work because it is suitable for high load application. It is the lowest friction and most efficient thread form.

The rotary motion is converted to linear translation at the interface of lead screw and nut threads. The kinematic relationship defining a lead screw as given by [16] is:

$$x = \gamma_m \tan(\alpha * \theta) \tag{1}$$

where $x$ is the nut translation, $\gamma_m$ is the pitch circle radius, $\alpha$ is the lead angle, and $\theta$ is the lead screw rotation. Obviously from the relation, the steeper the lead angle, $\alpha$, the faster the nut moves linearly and the frictional force caused by the load the pair carries is given by equation (2).

$$Ft = \mu |N| sgn(v_s) \tag{2}$$

where $\mu$ is the coefficient of friction (possibly velocity dependent) and $v_s$ is the relative sliding velocity. The frictional force always acts tangentially to the contacting thread surfaces and always opposes the direction of motion but does not change direction when the normal force N, changes direction.

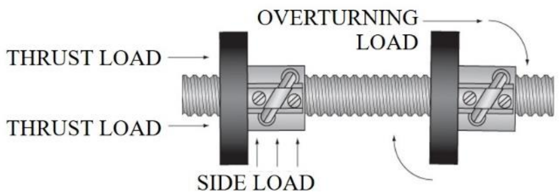


**Figure 2** Guide for loads distribution in a lead screw [17]

Selected dimensions for lead screw:

- X- axis lead screw
  The movement required is 300mm
  For allowance, the selected lead screw length will be 400mm

$Size\ of\ lead\ screw = M8 \times 1$
$Pitch\ of\ screw(p) = 1mm$
$Screw\ major\ diameter\ (do) = 8mm$
$Screw\ mean\ diameter(d) = do - \frac{p}{2} = 8 - \frac{1}{2} = 7.5mm$

- Y- axis lead screw
  The movement required is 250mm
  For allowance, the selected lead screw length will be 400mm

$Size\ of\ lead\ screw = M8 \times 1$
$Pitch\ of\ screw(p) = 2mm$
$Screw\ major\ diameter\ (do) = 8mm$
$Screw\ mean\ diameter(d) = do - \frac{p}{2} = 8 - \frac{2}{2} = 7mm$

- Z - axis lead screw
  The movement required is 100mm
  For allowance, the selected lead screw length will be 150mm

$Size\ of\ lead\ screw = M8 \times 1$
$Pitch\ of\ screw(p) = 1mm$
$Screw\ major\ diameter\ (do) = 10mm$
$Screw\ mean\ diameter(d) = do - \frac{p}{2} = 10 - \frac{1}{2} = 9.5mm$

The lead screw mechanism would be used because of its available features such as:

i Quieter operation due to the absence of re-circulating balls used in ball screws;
ii Smaller moving mass and smaller packaging;
iii Availability of high helix angles resulting in very fast leads;
iv Availability of very fine threads for high resolution applications;
v Possibility of self-locking to prevent the drive from being back-drivable thus eliminating the need for a separate brake system.

Both ends of the screw are supported by a ball bearings that support both axial and radial loads of the axes as shown in Figure 2. They are affixed to the ends of the screw to ensure a frictionless rotation of the screw as the stepper motor rotates on one end. In power transmission applications, lead screws are also known as “power screws”.

*2.2 Stepper motor model*

The armature controlled stepper motor is shown in Figure 3.

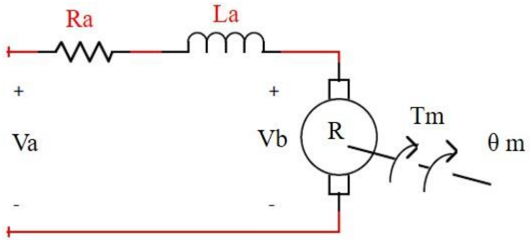


**Figure 3** Armature controlled stepper motor

For a DC stepper motor with applied voltage per phase $U_J$ the following relations could be written for the Electrical and Mechanical models respectively according to [18]:

$$U_J = E + RI(t) + \frac{LdI(t)}{dt} \quad (3)$$

$$\frac{Jd^2\theta}{dt^2} + \frac{D\theta}{dt} = T \quad (4)$$

Assumptions include –

$$E = K_B \frac{D\theta}{dt} \quad (5)$$

$$T = KI(t) \quad (6)$$

where

T = resultant torque of the motor
E = back EMF of armature circuit
R = armature resistance
L = phase inductance of the motor
$I(t)$ = phase current of the motor
$U_J(s)$ = V(s) = terminal voltage of the motor (where j represents phase A and B of the motor)
J = moment of inertia
B = viscous friction coefficient
$\theta$ = rotation of motor shaft

Finding the Laplace transform of (3) and (4)

$$U_J(s) - K_B S\theta(s) = RI(s) + LSI(S) \quad (7)$$

$$\theta(s)JS^2 + \theta(s)DS = K\ I(S) \quad (8)$$

from (8),

$$I(S) = \theta(s)\frac{(JS^2+DS)}{K} \quad (*)$$

Putting (*) in (7)

$$U_J(s) - K_B S\theta(s) = \theta(s)\frac{(JS^2+DS)(R+LS)}{K} \quad (9)$$

Simplifying (9), $U_J(s) = \theta(s)\left[\frac{(JS^2+DS)(R+LS)}{K} + K_B S\right]$

$$\theta(s) = U_J(s)\frac{K}{(JS^2+DS)(R+LS)+KK_B S} \quad (10)$$

Equation (10) shows the relationship between the applied voltage and the motor rotation.

The block diagram showing the transfer function of the stepper motor used is shown in Figure 4.

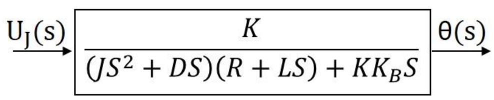


**Figure 4** Stepper motor transfer function

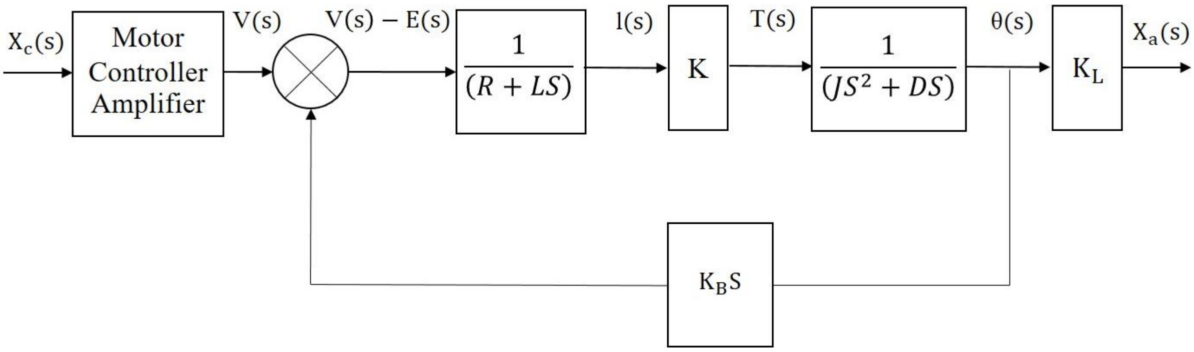


**Figure 5** CNC router model


**Figure 6** Components of the software subsystem used

*2.3 CNC router model*

For a lead screw, given the parameters: $\alpha$ = lead angle of screw, $Y_m$ = Pitch radius of screw, $\mathrm{Xa}(s)$ = Translation of nut along the screw, $\theta(s)$ = rotation of motor shaft = rotation of lead screw

From (1) we could write:

$$\mathrm{Xa}(s) = Y_m tan\ \alpha\ \theta(s) \quad (11)$$

Assume open loop transfer function of lead screw is given by gain $K_L$

We could draw the block diagram of the CNC router model as contained in Figure 5.

*2.4 Software subsystem*

This comprises of the various software and source codes required to operate the CNC router. The most important software here is the Graph Based Relational Learning (GBRL) which mainly provides the Pulse Width Modulation (PWM) outputs needed for stepping depicted by Figure 6.

**3. Construction processes**

*3.1 Construction*

For the gantry style configuration, the x-axis carries the most load, hence the need to ensure its stable platform.

i Marking out of points where the end supports for the shafts and the ball bearings for the lead screw is carried out.

ii Locations of screw nut and linear bearings is also determined on the base of the gantry.

iii Drilling of hole for screws accommodation is done.

The various components used are shown in Figure 7.

Parts assembly process is shown in Figure 8.

All wood to wood attachments were carried out using copper brackets and screws for X-axis parts in Figure 9, Y-axis parts, and Z-axis parts in Figure 10.

**Figure 7** Locally sourced CNC components

**Figure 8** CNC prototype part assembly

**Figure 9** Assembly of the X-axis parts

**Figure 10** Attaching the Z-axis assembly to the Y-axis

*3.2 Electrical section*

The electrical connections did not involve soldering because the controllers have connectors that only need to be properly terminated using screws and pins that need to be fixed inside sockets.

i The stepper motors were fixed on the lead screws using brackets to support them and connected to their designated ports on the CNC shield;
ii The 12V power supply was connected to the designated port on the CNC shield;
iii The motor wires were attached to the frame using wire clips;
iv The Emergency Stop button was wired and placed in a conspicuous location (top left corner of the gantry) on the machine frame as shown in Figure 11.

The controller is arranged in an electronic box and attached to the gantry back as shown in Figure 12.

The complete CNC Design Sketcher is shown in Figure 13.

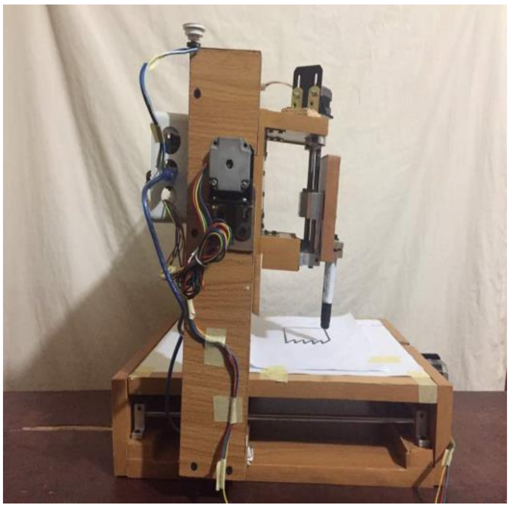

**Figure 11** Fully assembled prototype CNC Sketcher

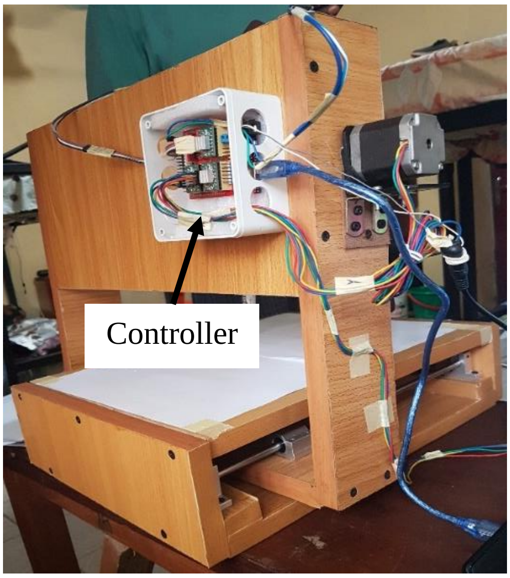


**Figure 12** The controllers in a casing at the back of the gantry

**Figure 13** The completed CNC technology based sketcher

**Table 1** Bill of Engineering Measurements and Evaluation (BEME)

| Part needed | Source Description | Part Description | Quantity | Price per part(₦) | Total (₦) |
|---|---|---|---|---|---|
| Stepper motors | HIC Mikrolab | NEMA 17 stepper motors. | 3 | 8,000 | 24,000 |
| Arduino board | HIC Mikrolab | ARDUINO UNO. | 1 | 4,000 | 4,000 |
| CNC shield | HIC Mikrolab | One piece driver for the trio of stepper motors. | 1 | 8,000 | 8,000 |
| Motor brackets | HIC Mikrolab | Brackets to support the motors, attached to the MDF boards. | 3 | 1,700 | 5,000 |
| Power pack | HIC Mikrolab | 12Volts, 5 Amps power pack to power the stepper motors. | | | |
| T8 set 400mm | HIC Mikrolab | 8mm*400mm Lead screw, nut, 8mm*400mm support rods, support bearings, linear bearings and connector. | 2 | 16,000 | 32,000 |
| T8 set 150mm | HIC Mikrolab | 8mm*150mm Lead screw, nut, 8mm*150mm support rods, support bearings, linear bearings and connector. | 1 | 11,000 | 11,000 |
| MDF wood | Sawmill Ota. | Slabs of wood wherein the bearings, motors and rods lie on. | | 8000 | 10,000 |
| Self-drilling screws | Sawmill Ota. | Pack of one inch and half inch self-drilling screw. | 2 packs | 2000 | 2000 |
| Gum | Furniture vendor. | Gum used to attach the tapings to the workpiece during the finishing phase. | ½ a bottle | 500 | 500 |
| Taping | Furniture vendor. | Taping (Akala) surrounding the edges of the NDF wood. | 10 yards | 30 | 800 |
| Brackets | Furniture vendor. | Medium sized brackets. | 20 | 50 | 1000 |
| TOTAL: | | | | | 98,300 |


**Figure 14** AutoCAD text sample


**Figure 15** Corresponding CNC Prototype output

## 4. Results

The cost implication in Nigerian Naira (₦) of various components used for the production of the developed CNC based pattern sketcher are contained in Table 1.

The performance of the developed CNC based sketcher was tested by sending the G-codes of some texts and designs. The results obtained based on pre-fed texts and patterns through a computer system are displayed hereunder.

The first test sample is the word "BELLSTECH" written with the use of AutoCAD software as contained in Figure 14 after which its corresponding G-codes is sent to the input port of the developed prototype CNC machine which in turn automatically produces, through its sketcher point end, the word "BELLSTECH" as contained in Figure 15. The height of each character in AutoCAD is 29 mm and that of the corresponding CNC output is 24 mm taking a time of 120s with a total length of 58mm.

The second test sample is the pattern contained in Figure 16 designed using AutoCAD software, converted to CNC machine readable codes with the help of G-code and produces a corresponding output as displayed in Figure 17. The height of the design in AutoCAD is 50 mm and that of the corresponding CNC output is 48mm taking a time of 59s with a total length of 38mm.

The third test sample is the 'thumbs-up' pattern contained in Figure 18 designed using AutoCAD software, converted to CNC machine readable codes with the help of G-code and produces a corresponding output as displayed in Figure 19. The height of the design in AutoCAD is 59 mm and that of the corresponding CNC output is 58 mm taking a time of 48s with a total length of 39 mm.

## 5. Discussion

The amount for producing the prototype CNC sketcher as contained in Table 1 is 98,300 Nigerian Naira which is 252.52 United States Dollar equivalent while the price for the same specifications (three axis CNC machine) of imported equivalent ranges between 2,500 United States Dollar and 10,000 United States Dollar on amazon store

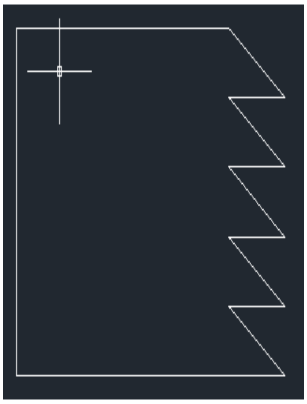

**Figure 16** AutoCAD design sample

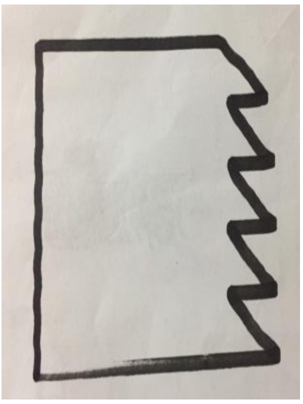

**Figure 17** Corresponding CNC prototype output

**Figure 18** AutoCAD design sample

**Figure 19** Corresponding CNC prototype output

shipped to Nigeria. This is a significant savings that would encourage local production and adoption. In terms of manpower, prototype CNC sketcher would require one handling operator and another one worker for packing finished ‘Adire’ product while for manual production that involves stenciling and freehand, at least five workers are involved in the production processes, one for tying operation, one for dying operation, one for planking operation, one for drying operation, and one for packing operation. Production is faster when CNC sketcher is adopted compared to manual processes of production of ‘Adire’ in that there is a reduction in the processes involved when CNC sketcher is used. This has also shown reduction in manpower and errors which could occur due to fatigue of human operators.

The sample outputs of prototype CNC machine as contained in Figure 15, 17 and 19, show some unsmooth lines when compared with the smooth AutoCAD inputs of Figure 14, 16 and 18. These are as a result of:

i The soft sketcher point-end used and the viscosity of the ink applied typical of the white board marker used;

ii The inaccurate alignment of the support rods and their linear bearings.

These factors point out that a stainless steel point-end material having adjustable opening would be highly suitable for ‘Adire’ pattern making operation and the alignment of the support rods alongside its linear bearings should be well in place. Outright replacement of sliding rods and the ball bearings with a drawer-slider or addition of linear bearings to supporting rod during the forward and backward motions are some of the options that could be explored. The timing for the execution of a given task could be improved by incorporating a frequency range selector that would be adjusted to increase or decrease the speed of operation of CNC machine.

Power interruption during machine operation, as observed, automatically resets the machine process. So, back-up power must be provided during machine operation to avoid losses in terms of materials, time and product quality. The various adjustments that could be made to improve the quality of production in prototype CNC pattern sketcher with a singular sample are not possible with the popular manual production technique, once an error occurs, the whole production processes is affected resulting in material and time losses.

Also, there are differences in the length of AutoCAD design samples which are reference inputs and their corresponding CNC prototype outputs. These variations are due to feedback gain that is an assumed constant in the CNC closed loop system. The output of CNC machine could be improved by incorporating a better error correcting controller such as a well- tuned Proportional Integral Derivative (PID) controller and fuzzy logic controller. This is to avoid over-correction of error that could result into instability of the overall system, typical of closed loop systems.

## 6. Conclusion

This prototype CNC machine is capable of replicating texts and carry out sketches of different patterns. This shows its suitability to ‘Adire’ fabric making industry since texts and designs are the two important criteria for classification and customization of products. Though this prototype CNC machine is not perfect yet in terms of efficiency and aesthetics, it is a good starting point for further works that would lead to production of low cost and improved quality

CNC machine for ‘Adire’ pattern sketcher for small and medium scale enterprises.

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