UNIVERSIDAD DE INVESTIGACIÓN DE TECNOLOGÍA EXPERIMENTAL YACHAY

Escuela de Ciencias Químicas e Ingeniería

TÍTULO: How to make an eco-friendly and unlimited printer?

Trabajo de integración curricular presentado como requisito para la obtención del título de Químico

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To my family,

for their unconditional love and support.

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Resumen

La impresión es una acción simple que casi todo el mundo realiza con tanta frecuencia que ya casi nadie piensa en el impacto que podría tener. Sin embargo, se utilizan diferentes productos químicos como componentes de las tintas y algunos pueden causar daños al medio ambiente. Peor aún, dado que la impresión se utiliza de manera tan masiva, el número de tintas producidas y consumidas asciende a una cantidad considerable. Incluso si se realizan esfuerzos hacia tintas más ecológicas a nivel mundial, el problema persiste y es necesario proponer nuevas soluciones.

Esta tesis es un intento de dar respuesta a esta problemática proponiendo un nuevo concepto: imprimir sin el uso de tintas o polvos sino con luz solar. Partiendo de esta idea, diseñamos y construimos una máquina completamente nueva capaz de imprimir. El concepto de la máquina es similar a una máquina Computer Numerical Control (CNC), pero se utiliza una lente simple para concentrar el sol en un punto de las hojas de papel. Esta lente puede moverse en una dirección mientras que el papel se puede mover en otra, dando grados 2D de libertad para reproducir una forma. Dado que es solo un primer prototipo, aún existe la necesidad de identificar los posibles límites de este tipo de máquina; uno de ellos identificado es la variación de la luz solar en presencia de nubes. Sin embargo, esta tesis posiblemente allana el camino hacia hábitos de impresión más ecológicos.

Palabras clave: *interacción luz-materia, papel, celulosa, sol, cnc, arduino, ecológico, óptica, combustión parcial*

Abstract

Printing is a simple action done by almost everyone so often that almost no one thinks about the impact it could have anymore. However, different chemical products are used as constituents of the inks, and some can have an ecological impact. Worse, as printing is so massively used, the number of inks produced and consumed sums to a considerable amount. Even if efforts towards more eco-friendly inks are made globally, the problem still exists, and new solutions need to be proposed.

This thesis is an attempt to respond to this problematic by proposing a new concept: printing without using ink but solar light. Starting from this idea, we designed and constructed an entirely new machine capable of printing. The machine concept is similar to a Computer Numerical Control (CNC) machine, but a simple lens is used to concentrate the sun on one spot on paper sheets. This lens can move in one direction while the paper can move in another, giving 2D degrees of liberty to reproduce a shape. Since it is only a first prototype, there is still a need to identify the possible limits of this kind of machine; one of them identified is the variation of the solar light in the presence of clouds. Nevertheless, this thesis possibly paves the way towards more eco-friendly printing habits.

Keywords: *light-matter interaction, paper, cellulose, sun exposure, cnc, arduino, eco-friendly, optics, partial combustion*

CONTENTS

Contents **viii**

List of Figures **xii**

List of Tables **xiv**

List of Abbreviations **xv**

Introduction **1**

1 Theoretical Frame **3**

1.1 Paper 3

1.1.1 How is fabricated paper? 4

1.1.2 Properties of paper-light interaction 5

1.1.3 Chemical structure of the paper 6

1.2 Paper printing technology 6

1.2.1 Chemical compositions of inks 7

1.2.2 Ink printers an ecological problem? 8

2 Problem Statement **10**

3 Objectives **12**

3.1 General objective . . . 12

3.2 Specific objectives . . . 12

4 Theory Behind the Idea **13**

4.1 What is known about paper burning? . . . 13

4.1.1 How to burn paper? . . . 13

4.1.2 General reactions . . . 14

4.1.3 Formation of levoglucosan . . . 15

4.1.4 Transformation and carbonization of cellulose . . . 15

4.1.5 Mechanism of pyrolysis and volatilization of cellulose . . . 15

4.1.6 Charring . . . 16

4.2 Optics . . . 16

4.2.1 Lens . . . 16

4.2.2 Convex lens . . . 17

4.3 Sun exposure . . . 17

4.3.1 Incident angle of sunlight . . . 17

4.3.2 Lux . . . 18

4.4 Technology implemented . . . 18

4.4.1 Arduino . . . 18

4.4.2 Driver A4998 . . . 19

4.4.3 Shield CNC GRBL v3.0 . . . 19

4.4.4 Sensor BH1750 . . . 19

4.4.5 Step motor Nema 17 . . . 20

4.5 Computer numerical control . . . 20
4.5.1 Open-loop CNC system . . . 20
4.6 CNCjs software . . . 21

5 Important Parts and Design **22**
5.1 Main idea and design . . . 22
5.1.1 The principle idea . . . 23
5.1.2 Design and development of CNC's controllers . . . 24
5.1.3 Design and development of CNC's structure . . . 24
5.1.4 Design the test . . . 25
5.1.5 Design of the light sensor . . . 25

6 Machine Calibration **27**
6.1 Calibration of A4988 driver . . . 27
6.1.1 Reference voltage . . . 27
6.1.2 Sensing resistor . . . 28
6.1.3 Adjusting the current . . . 28
6.2 Calibration of step motors . . . 29
6.3 Calibration of lens . . . 30

7 Results **31**
7.1 Prototype construction . . . 31
7.2 Prototype evolution . . . 32
7.3 Final prototype: Eco-friendly printer . . . 35
7.4 Burning paper . . . 38

8 Main factors of the printing process 40

8.1 The influence of burning time 40

8.2 The influence of the material 41

8.3 The influence of weather 41

8.4 The influence of time in the day 41

9 Conclusion and Recommendation 42

9.1 Conclusions 42

9.2 Recommendations 43

Bibliography 44

LIST OF FIGURES

1.1 Schematic representation of chemical pulping and papermaking 4

1.2 Light−sheet interactions 5

1.3 Structure of cellulose 6

4.1 General Reactions Involved in Pyrolysis and Combustion of Cellulose . . 14

4.2 Scheme of how convex lens works 17

4.3 Effect of the angle of incidence of solar rays on irradiance 18

4.4 Open-loop CNC system 21

4.5 CNCjs window 21

5.1 General scheme of the strategy used during this work, to design and improve the eco-friendly printer 22

5.2 Burning paper using a convex lens. 23

5.3 Sheme of CNC shield connected to step Nema motors. 24

5.4 Scheme of experimental test. 25

5.5 Scheme of light sensor. 26

6.1 Parameters of CNC controller in CNCjs software 29

7.1 Prototype 1.0 33

7.2 Prototype 2.0 33

7.3 Prototype 3.0 34

7.4 Prototype 4.0 35

7.5 CNC Shield controller 35

7.6 Eco-friendly printer. 36

7.7 Eco-friendly printer frontal face. 36

7.8 Eco-friendly printer back face. 37

7.9 Eco-friendly printer side face. 37

7.10 Eco-friendly printer transversal face. 37

7.11 Points made by the eco-friendly printer 38

7.12 Points made by the eco-friendly printer 39

7.13 Points made by the eco-friendly printer. 39

LIST OF TABLES

7.1 Materials and devices used during the experimental process 32

LIST OF ABBREVIATIONS

A Amperes

cm centimeters

CNC Computer Numerical Control

DCP dichloropropane

$\mathbf{I}_{max}$ Maximun Current

ISO International Organization for Standardization

nm nanometers

TAPPI Technical Association of the Pulp and Paper Industry

$\mathbf{V}_{ref}$ Reference Voltage

VOCs Volatile Organic Compounds

V Volts

INTRODUCTION

Writing is an ability that changed humankind's history drastically and allowed to remember knowledge beyond only oral transmission. Centuries after, the invention of printing was determinant in our modern world because knowledge could be transmitted on a large scale. Nowadays, despite the virtualization of information, printers are still massively used in many aspects of life. Basically, printers need a power supply, paper, and ink to function. However, the industry behind ink printers is more complex and has an environmental impact in several ways. In fact, the companies that develop and commercialize printers have one principal problem: the management of waste generation of printers or ink cartridges; along with the world competition provoking the apparition of clone cartridges[1,2,3], which are cheaper but generate 26% environmental impact according to some studies.[1] Another defect from the user-end of ink is the necessity to change the cartridge regularly because the system of printers does not typically allow manual ink recharge. Therefore, this project explores the potential of using sunlight to solve both problems at the same time.

Almost every child at one point in his life used a magnifying glass to burn paper: this exact idea is at the center of this project, use sunlight to burn the paper in a controlled manner in a specific pattern. A part of this project is to know the exact kinetic of this process to safely and control contrast. In addition, the chemical analysis would be carried out to know which compounds are formed upon partial combustion of paper. Another critical aspect of this research is automatizing the tests. It can achieve it through the eco-friendly printer. The design of the prototype is a critical point as it will ensure its effectiveness. Finally, the printer would print in different colors. This aspect is challenging to realize using sunlight for burning paper. However, different physic-chemical processes would be tried to form different burning colors. Imagination and bibliographic research will be the keys to find potentially a manner of changing printing color.

CHAPTER 1

THEORETICAL FRAME

1.1 Paper

Paper is commonly known as a thin layer of cellulosic plant fibers produced on a screen by dewatering a slurry of fibers in water. The cellulosic plant fiber is the primary, but not exclusive component of paper, and inclusive water is used to prepare the pulp and form the paper web.[4] Likewise, paper is a composite material, and its composite nature is a significant factor in its wide variability. Indeed, variability in properties due to variability in plant composition is also present in fibers such as flax, cotton, grasses, hemp, and jute. Therefore paper properties are dependent on the network matrix, the bonding within that matrix, and the fibers' properties responsible for the bonding.[5]

A sheet of paper's appearance depends on its structure, chromophores, refractive indices of its components, weight, and surface reflective characteristics. In addition, paper's appearance depends on its manufacturing processes, being that additives, bleaching agents, mineral particles, dyes, and fluorescent whitening agents. Appart from these, at least half of the volume in a normal sheet of paper is occupied by air.[6]

1.1.1 How is fabricated paper?

Paper production is mainly a two-step process in which a fibrous raw material is first converted into pulp, and then in turn the pulp is converted into paper. Most paper is made from wood fibers, but rags, flax, cotton linters, and sugar cane residue are also used. In principle, the pulp is made from cellulosic fibers and other plant materials. So, fibers are separated, cleaned, beaten, refined, and diluted to form a thin fiber slurry. Then, a network of fibers on a thin screen is pressed to increase the material's density. Finally, it is dried to remove the remaining moisture and provide a suitable surface for the intended end-use. Some synthetic materials, pulp, and paper may be used to impart unique qualities to the finished product. Figure 1.1 illustrates the steps in making paper for manufacturing process.[7]

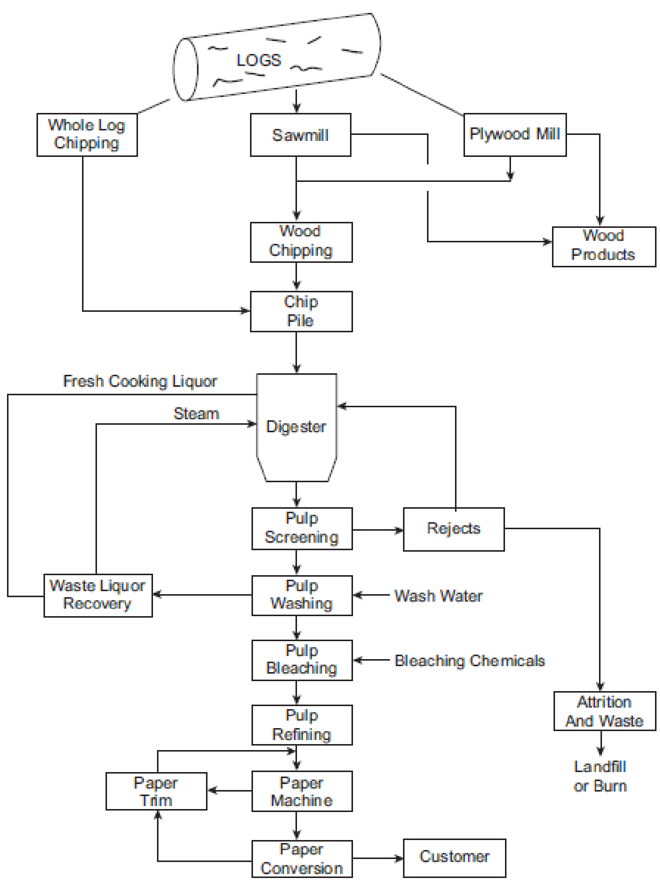

Figure 1.1: Schematic representation of chemical pulping and papermaking.[7]

1.1.2 Properties of paper-light interaction

Paper is tested to ensure that it meets the basic requirements to be used. Furthermore, testing provides the papermaker with enough information to maintain an acceptable quality standard. To comprehend the appearance and optical characteristics of paper, it is necessary to understand how paper interacts with light.[8]

Reflectance, Transmittance, and Absorptance

These parameters are associated with how the light interacts with the paper. Due to the multitude, complexity, and proximity of light-interacting particles in a sheet of paper, it is common to consider the general effect rather than the exact nature of light−sheet interactions when carrying out routine paper optics measurements. The radiation is either reflected from, transmitted through, or absorbed in the sheet structure, as shown in Figure 1.2[8]

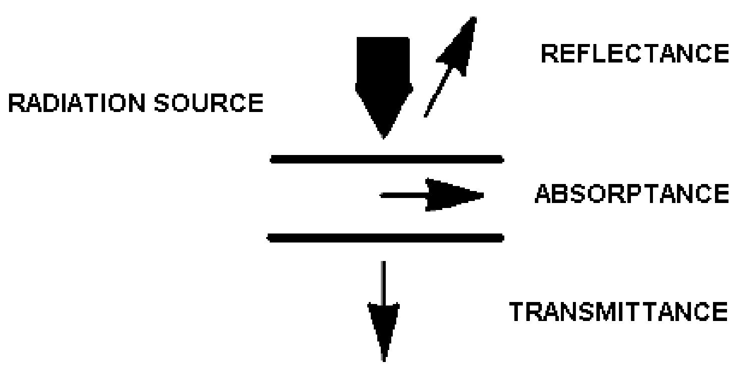

Figure 1.2: Light−sheet interactions[8]

Brightness and Opacity

The brightness and opacity are characteristics produced by the reflectance of the paper. However, opacity and brightness varying measurement depends on conditions and instrumentation design. Therefore, the meaning of paper reflectance in terms such as brightness, opacity is nonspecific nonspecific unless definitions are provided through standard methods. The standard methods established by Technical Pulp and Paper Association (TAPPI) or International Organization for Standardization (ISO) are used. *Brightness* is a measurement of the reflectance amount at a specific wavelength of blue light (457 nm). *Opacity* is an appearance term that concerns how paper diffusely reflects light of all wavelengths throughout the visible spectrum.[8]

1.1.3 Chemical structure of the paper

Paper is a network of the three most abundant natural polymers in wood: cellulose, hemicellulose, and lignin. Among them, cellulose is the most prominent one, while the other two are considerably eliminated during the pulping process.[4] Cellulose structure is now well established and consists of β-anhydroglucose units with dominant hydroxyl groups, which are appropriate groups for subsequent reactions. These are mainly due to the one primary and two secondary hydroxyl groups in each monomer unit in the polymer structure as shown in figure 1.3. Furthermore, due to cellulose's specific chemical arrangements, it is an entirely linear polysaccharide and can form extensive intra and intermolecular hydrogen bonds.[9,10]

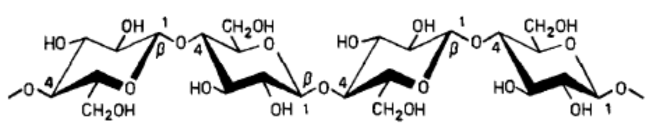

Figure 1.3: Structure of cellulose[10]

1.2 Paper printing technology

Printing is a process for mass reproducing text and images from a master form or template using usually inks. In modern days, there exists many ways to print in almost all materials for several purpose giving rise to almost infinite possibilities. Specifically, the technologies related to printing in paper materials are:

Offset Lithography

Also known as offset printing or litho, offset lithography is a modern method of mass-production printing. In this technique in which the inked image is transferred from a plate to a rubber blanket, and then, to the printing surface.[11][12]

Digital Printing

Digital printing is a recent method, or rather a family that covers various techniques, such as inkjet printing or laser. In digital printing, images are sent to the printer using digital files. Therefore, printing plates are not used like in other types of printing, such as lithography.[11] However, it has a higher cost per page than more traditional offset printing methods, but shows one main advantage over hard-support techniques: the possibility of modifying the image for each impression.[13]

Large Format Printing

Large-format printers employ similar technology pertaining to the digital printing family, like inkjet or toner-based printers to produce the printed image. This printing method provides large format printing that uses rolls of prints fed incrementally to produce one large sheet. Therefore, it gives a more extensive area to work on than the other digital printing methods. The principal use of large format printer is to produce banners, posters, trade show graphics, wallpaper, murals, backlit film, includes artwork.[11][14]

1.2.1 Chemical compositions of inks

Interestingly, the evolution of inks considering that the earliest black writing inks, developed before 2500 B.C., were suspensions of carbon, usually lampblack, in water stabilized with materials like egg albumen.[15]

Ink systems are in principle dye or pigment in combination with a resin binder carried in a highly volatile solvent.[16,17] Pigments and dyes are organic compounds that provides of color to ink-jet. Dyes are favored to pigments because they show high solubility in the solvent system and possess low levels of impurities with the minimal insoluble matter, less than 0.02%.[16]. These colourant represents a low percent of ink, around 5-10%[18,19,20,21,22,23].

The binder of an ink-jet contains one or more polymers, which promotes droplet formation, control viscosity, provide adhesion to the surface.It is also responsible for the properties such as steam sterilization, high gloss,and alkali solubility.[17] An example of a binder is triethanolamine.[18,19,20,21,22,23]

Solvents are substances designed to dissolve the binder and mix with the other components of the paint.[24] Almost all the inks use around 50-65% water, as solvent. Also, glycerol is used but in a low quantities around 5-7%.[18,19,20,21,22,23] Drying time depends on the amount and volatility of the solvent. It needed to find an equilibrium because if the ink contains highly volatile solvent, it evaporates fast at the surface which can lead to the formation of skin and slow down the drying of the entire droplet. In another hand, the solvent of low volatility slows the drying process doing impossible to work.[16]

1.2.2 Ink printers an ecological problem?

The world face the industry printers and the serious problems at the moment to management of waste generation. Constantly, they are generating a great quantities of cartridge to supply the demand. They have a process to recover some parts and reuse these old cartridge. However, the expensive costs for the customers generated a world industry of clone cartridges. These clone cartridges have not a plan for the end of life.[1,2,3]. In any case the possibilities for the end-of-life ink jet cartridges are: to go a landfill deposit, to convert in energy and recycling[25].

The compounds in printer inks can be harmful to the environment, along with petroleum oil and polymers found in some ink and toner cartridges. Furthermore, the volatile organic compounds (VOCs) and heavy metals in ink can lead to soil and even water pollution when left in a landfill, while plastic can take thousands of years to degrade, and even then, they will continue to pollute the soil.[26] Printing ink manufacture results in emissions of VOCs and pigment dusts to atmosphere.Also, emissions result from evaporation of VOCs contained in the inks during the printing process. Therefore, it is a technical imperative to reduce VOCs in petroleum-based printing inks to meet environmental regulations without sacrificing functional properties.[27]

CHAPTER 2

PROBLEM STATEMENT

Climate change is a fact, and both industries and consumers cause it. Specifically, while beneficial, the printing industry does not represent an eco-friendly category. Ink printers and their ink are involve of several ingredients, most of them that have potential to be damaging to humans and the environment. Butyl urea, which prevents paper from curling; cyclohexanone, which helps the ink to adhere to polymers; several dyes including reactive red 23 dye, acid yellow 23 dye, and direct blue 199 dye, which contains sulfur; ethoxylated acetylenic diols, which modify the surface tension of the water and colors; ethylenediaminetetraacetic acid which is full of contaminants and ethylene glycol are some representatives members of the dangerous products used. Moreover, the main problem resides in the mass consumption of printing: almost every working person is printing different reports, advertisements, works, administrative tables. Not only is a massive production of ink needed, but the cartridges are still not all recycled. While a small quantity is deposited on each paper, the accumulation of ink originating from all the printed paper amounts to a non-negligible quantity. Additionally, people have little remorse for throwing printed paper in nature, while only the paper is biodegradable. Thus, while a global effort is made in making more ecological ink, there is a vital ecological interest in searching for alternatives.

Then, the main challenge is to propose a new method to print on paper that can be as viable as the traditional technology, in a way where the ink can be avoided and generate an eco-friendly printer. Finally, printers are not always accessible to everyone, especially in rural areas far from the cities. Therefore, the central idea of this thesis is to propose a machine capable of printing using an infinite natural resource: the sun. However, is it possible?

CHAPTER 3

OBJECTIVES

3.1 General objective

- Design and develop a new machine based on sunlight in order to print in an eco-friendly manner.

3.2 Specific objectives

- To identify the main process during paper burning and how to realize it.
- To design and make a plan for a new machine, fixing the main requirements and necessary parts.
- Identify the specific parts of the machine and mount it.
- Find how to automatize the machine, in the same manner as a classical printer.
- If the prototype is done successfully, test the machine in different conditions and find its limits.
- Propose new methods and ideas which can be included in the following prototype.

CHAPTER 4

THEORY BEHIND THE IDEA

The objective of this chapter is to lay down the theoretical framework necessary to the construction of our machine. It is focused on the processes behind paper burning, on the optical aspect, on the electronic aspect and finally on the programmed automatic aspect.

4.1 What is known about paper burning?

4.1.1 How to burn paper?

As the paper is heated, it goes through a series of physical and chemical changes that affect the physical properties and ultimately lead to charring, pyrolysis, and destruction. The deterioration can be amplified by increasing temperature, the pressure of oxygen and water, and adding reactive compounds that produce an autocatalytic effect.[8] In general the reactions can be divided into primary and secondary reactions, according to whether they directly affect the cellulosic substrate or one of the intermediate degradation products. Levoglucosan is formed, as principal intermediate compound, and takes place at somewhat higher temperatures and leads to further decomposition reactions at elevated temperatures[28]

Thermal degradation precedes the combustion of cellulosic materials and affects the flammability, how the material burns, and how the combustion can be controlled. Therefore, thermal degradation may provides the basis for analytical pyrolysis that is a powerful tool for analyzing polymer materials, including pulp and paper. The thermal reactions are complex, and the substrates are generally inhomogeneous. Therefore, it is difficult to generalize on the subject. Paper contains mainly cellulose and hemicellulose, it is logical that most basic studies have been focused on the thermal degradation of cellulose.[8]

4.1.2 General reactions

Thermal degradation of cellulosic materials proceeds through a complex series of concurrent and consecutive chemical reactions of cellulose that could lead to the flaming combustion or glowing ignition of this material. However, the nature and extent of many individual reactions involved in this process are not known or insufficiently defined. Thermal degradation of cellulose, which is represented in Figure 4.1, proceeds through two types of reaction: a gradual degradation, decomposition, and charring on heating at lower temperatures ; and a rapid volatilization accompanied by the formation of levoglucosan on pyrolysis at higher temperatures.[28]

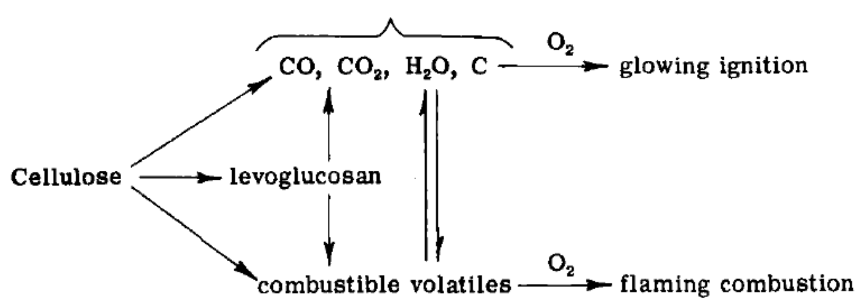

Figure 4.1: General Reactions Involved in Pyrolysis and Combustion of Cellulose[28]

4.1.3 Formation of levoglucosan

Levoglucosan is an organic compound formed from the pyrolysis of cellulose. As a consequence, levoglucosan is often used as a chemical tracer for biomass burning in atmospheric studies.[29] At temperatures above 250 °C, pyrolysis of cellulose provides, a volatile tar which contains mainly levoglucosan. The nature and composition of the volatile products, and the quantity of char, determine the flammability of the cellulosic material and the rate of combustion or propagation of the fire, which is highly sensitive to the effect of the physical and environmental conditions prevailing, as well as to the chemical factors, such as the minor components and inorganic compounds present.[28]

4.1.4 Transformation and carbonization of cellulose

Slow decomposition of cellulose on heating at lower temperatures in air or oxygen produce oxidation and dehydration reactions. Thermal degradation under these conditions generates a loss of strength and deterioration of other physical properties. As the hydroxyl groups are oxidized to carbonyl and carboxyl groups along with the proceeding of degradation reactions, cellulose becomes partially soluble in alkali environment. It passes through a series of color changes, from white to yellow, to reddish-brown and black. After 24 hours of heating at 250 °C in air, a dehydration is produced and the composition of cellulose an change from $(C_{3.6}H_{6.5}O_{3.1})$ to $(C_5.0H_{3.0}O_{2.3})$.[28]

4.1.5 Mechanism of pyrolysis and volatilization of cellulose

The principal reaction involved in the pyrolysis of cellulose at high temperatures is the depolymerization to levoglucosan. This reaction is favored in vacuum to avoid a simultaneous oxidation reactions that may occur by presence of oxygen. As consequence minimize the possibility of further decomposition of the levoglucosan. However, even under these ideal conditions, the fraction containing levoglucosan, which amounts to about 75%, is accompanied by about 18% of lighter volatile products and gases (mainly water, carbon monoxide, and carbon dioxide), while a small charred residue (6-9%) remains. Most of the proposed mechanisms are based on possibilities and circumstantial evidence instead of unequivocal proof. Nevertheless, considering the various alternatives provides an insight into an interesting series of carbohydrate reactions and a basis for further progress in this field.[28]

4.1.6 Charring

Charring is the result of a chemical process of incomplete combustion. The heat removes hydrogen and oxygen from the solid, therefore, remaining char is composed primarily of carbon.[30] When a wood product burns at a constant heat, the boundary between the pyrolyzed material and the intact wood, called the pyrolysis front, proceeds to the wood in a depth direction. Because pyrolyzing wood is potentially char, the charring rate corresponds to the propagation rate of the pyrolysis front. Charring rate is a useful quantity of wooden structures to determine the fire resistance.[28]

4.2 Optics

4.2.1 Lens

A lens is a piece of transmissive optical material with a particular shape to cause light rays to bend in a specific way as they pass through. it. A basic lens consists of a single piece of transparent material. However is possible building complex system using several lenses, arranged along a common axis to improve the . Lenses are made from materials such as glass or plastic shape[31] and the most famous devices that use lens in their system are: microscope[32] and telescope.[33]

4.2.2 Convex lens

A convex lens has a characteristic shape, which causes parallel rays to bent inwards and converging in a point as Figure 4.2 shows. The point at which they converge is known as the principal focus.[34] This point is interesting because concentrates all the energy given by a source of light.

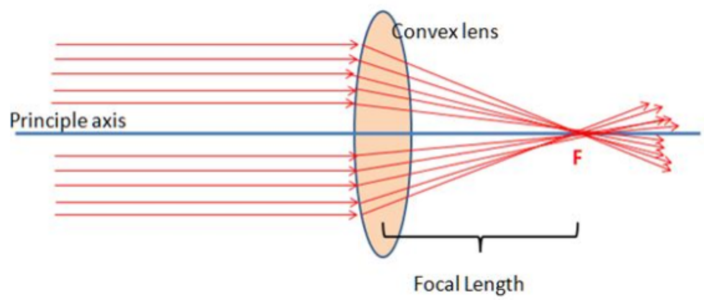

Figure 4.2: Scheme of how convex lens works[34]

4.3 Sun exposure

A very valuable source of energy is sunlight and relative infinite. Earth receives constantly great amounts of solar energy on a surface area. The actual tends is explore and explode all the possibilities to use the free solar energy.

4.3.1 Incident angle of sunlight

Because world is rotating constantly, the rays of light are not a constant. The majority of time the sun lights are oblique to the absorbing sufeace, howeve, in specific moments can be perpendicular.The irradiance incident on that surface has the highest possible power density when the rays are absorbed vertically as Figure 4.3 shows .The angle between the sun and the absorbing surface changes through the day, the intensity of light on the surface is reduced. For intermediate angles, the relative power density is $\cos(\theta)$, where θ is the angle between the sun's rays and direct normal or perpendicular to the surface.[35]

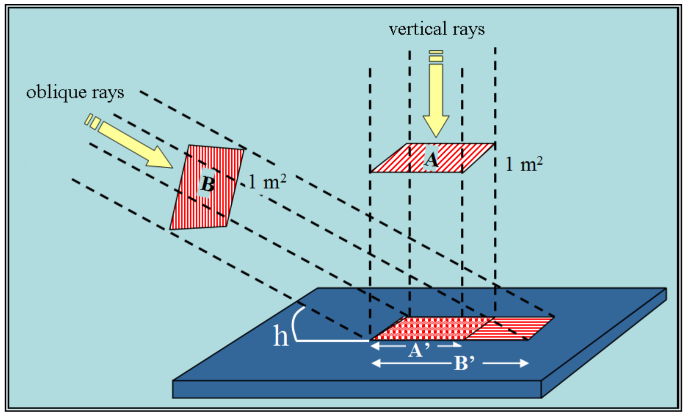

Figure 4.3: Effect of the angle of incidence of solar rays on irradiance[36]

4.3.2 Lux

The lux is the unit of illumination according to the International System. Lux is the amount of illumination determined by lumen over an area of one square meter. .[37] This unit is normally used to determine the the brightness of a place.

4.4 Technology implemented

4.4.1 Arduino

Arduino is an open-source electronics platform based on easy-to-use hardware and software. For example, Arduino boards can read inputs - light on a sensor, a finger on a button or message and turn it into an output activating a motor, turning on a lamp. To do so, use the Arduino programming language and the Arduino Software.[38]

4.4.2 Driver A4998

The A4988 driver is a complete micro-stepping motor driver with a built-in translator for easy operation. The driver has a maximum output capacity of 35 V and ± 2 A. It can operate bipolar stepper motors in full-step, half-step, quarter-step, eighth-step, and sixteenth-step modes.[39] It is used to control the speed and rotation of the stepper motor. Generally, it is used in robotics or toys in order to control their motion.

4.4.3 Shield CNC GRBL v3.0

The CNC Shield was designed by Protoneer.co.nz to take advantage of the demand for a low-cost controller solution for DIY CNC machines. It was designed to be 100% compatible with Grbl, the Opensource G-Code interpreter, and fit onto the popular Arduino Uno. The CNC Shield can be used to control several different types of CNC machines, including CNC milling machines, laser engraving/cutting machines, drawing machines, 3D printers, or any project that requires a precise control of stepper motors. It uses Pololu and compatible stepper drivers, either the A4988 or the higher current DRV8825. There are three main components needed to get the CNC Shield up and running, 1) CNC Shield; 2) Stepper Drivers, and; 3) Arduino UNO. CNC Shield V3 is used as a driving shield for engraving machines, fully compatible with UNO R3. As it was made in this objective, it would be best to stacked it onto the UNO R3 control board when using it. It has a total of 4-way pin slots for stepper motor drive modules to drive 4-channel stepper motors.[40]

4.4.4 Sensor BH1750

BH1750 is a digital ambient light sensor that is used commonly used in mobile phones to detect the incoming light and accommodate the screen brightness based on the environment lighting. This sensor can accurately measure the LUX value of light up to 65535lx.[41]

4.4.5 Step motor Nema 17

Nema 17 is a hybrid stepping motor with a 1.8° step angle (200 steps/revolution). Each phase draws 1.2 A at 4 V, allowing for a holding torque of 3.2 kg-cm.[42] Nema 17 stepper motor is generally used in 3D-printers, CNC´s and laser cutting machines.

4.5 Computer numerical control

A computer numerical control (CNC) machine is a motorized tool controlled by a computer according to specific input instructions. CNC machine receive the instructions in the form of a sequential program such as G-code or M-code.[43] A CNC system requires motor drives to control both the position and the velocity of machine axes. Each axis must be driven separately and must follow the command signal generated by the numerical control. There are two ways to activate the servo drives; the open-loop system and the closed-loop system. In an open-loop CNC system, programmed instructions are fed into the controller through an input device. These instructions are then converted to the controller's electrical signals and sent to the servo amplifier to drive the servo motors. The cumulative number of electrical pulses determines the distance each servo drive would travel, and the signal frequency determines the velocity of movement.[44] These kind of machines are used in professional way or to develop new technologies with a low cost. Arduino users normally build this kind of machine and share the way to do it[45].

4.5.1 Open-loop CNC system

The open-loop system's primary characteristic is that there is no feedback system to check whether the desired position and velocity have been achieved. If system performance has been affected by load, temperature, humidity, or lubrication, the actual output could deviate from that desired. For these reasons, the open-loop CNC system is generally used in point-to-point systems where accuracy is not critical. Very few, if any, continuous-path systems utilize open-loop control. However, it should be noted than an open-loop system is far easier to implement. Figure 4.4 illustrates the control mechanism of an open-loop CNC system.[44]

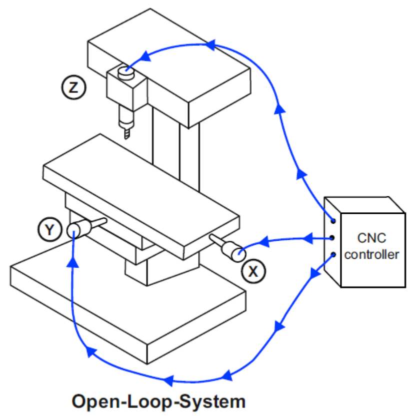

Figure 4.4: Open-loop CNC system[44]

4.6 CNCjs software

It is free software based on a traditional interface for the CNC milling controller. It runs on a laptop computer connected to the Arduino over a serial connection using a USB serial port, a Bluetooth serial module, or a serial-to-wifi module.[46] The software is user-friendly and simple, as figure 4.5 shows.

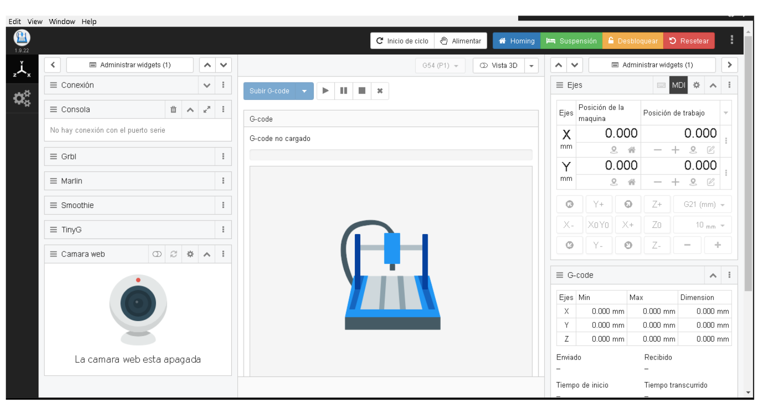

Figure 4.5: CNCjs window

CHAPTER 5

IMPORTANT PARTS AND DESIGN

5.1 Main idea and design

The project consisted of building a prototype of a solar printer and then evaluate how this burns paper. Figure 5.1 shows the scheme of work used to carry out this project. This design process is a repetitive process based on try and failure: If it did not work, then redesign again.

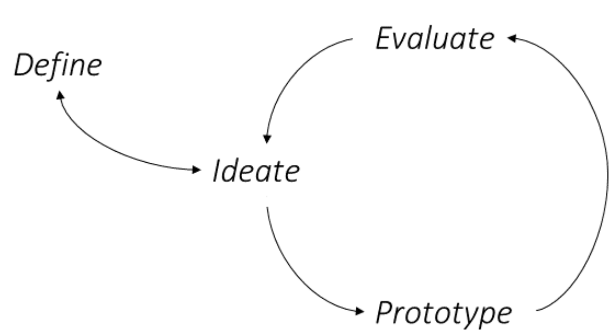

Figure 5.1: General scheme of the strategy used during this work, to design and improve the eco-friendly printer

The general strategy of this work is shown in Figure 5.1, where *Define* is correlated with this project's specific objectives: Designing and developing a prototype of a solar printer and then evaluating how this burns paper. Once *Define* is established, a cyclic process begins. First, *Ideate* is a process, such as a brainstorm, that brings all the ideas and inspirations commonplace to mix them. The brainstorm should be reevaluated as much as possible to approach the specific and possible idea. Therefore, at the beginning of brainstorm, all the ideas are allowed; but each reevaluation should be more strict and realistic. Second, the *Prototype* is the tangible part of the process and is based on the previous process's results. In this part, functionality is above aesthetic or a specific size. Therefore, it is necessary to adopt a strategy of trial-and-error to make a prototype that works. Finally, *Evaluate* is a part that tempts the prototype and verifies if it meets the previous requirements. In the opposite case, failures reasons need to be analyzed to start the cycle with a new brainstorm focused on improving the recent prototype. This process can be theoretically performed infinite times to get better results, in order to make an optimization of the design. However, we should establish a finishing point depending on meeting the requirements and the time available.

5.1.1 The principle idea

Figure 5.2 explains concisely what is the inspiration principle behind the solar printer project. The sunlight passes through a convex lens, and it burns the surface of the paper.

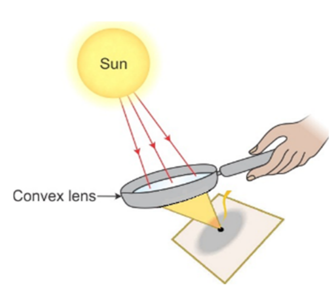

Figure 5.2: Burning paper using a convex lens[47]

5.1.2 Design and development of CNC's controllers

Some ideas were taken into account from an Arduino forum about making a CNC machine.[45] . Every CNC projects have particular characteristics, materials, and design. However, the controllers are based on similar devices: Arduino UNO, CNC shield V3, step motors, and A4998 drivers for each axis that the CNC machine possess. Figure 5.3 shows how all these devices should be connected. Remarkably, the CNC shield V3 needs a 12V power supply to work. Arduino UNO serves as an intermediary between CNC shield V3 and the CNCjs software.

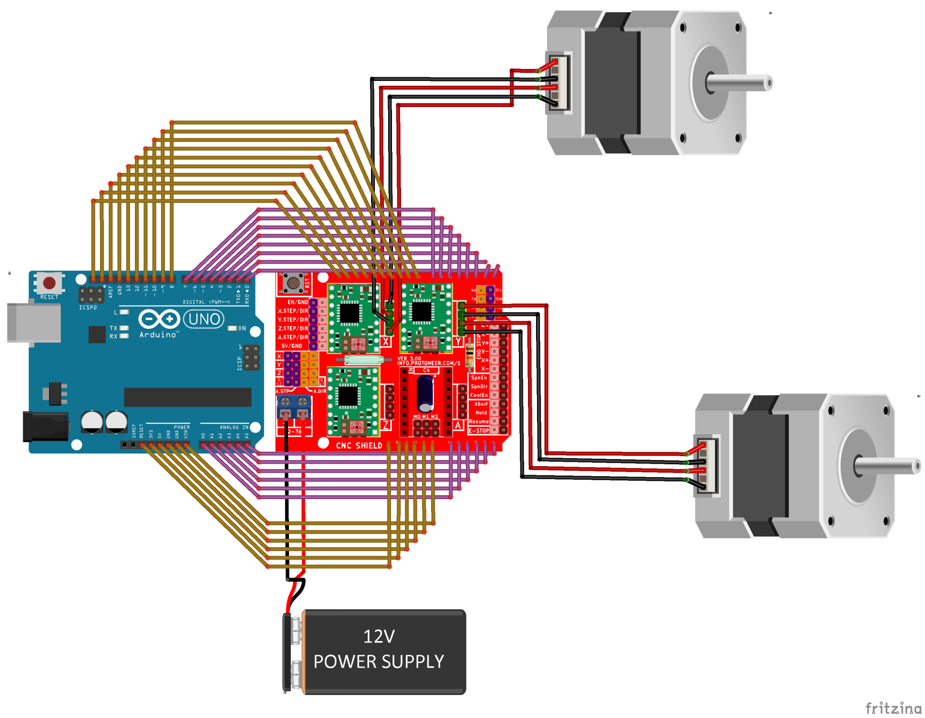

Figure 5.3: Sheme of CNC shield connected to step Nema motors.

5.1.3 Design and development of CNC's structure

The eco-friendly solar printer consists of two axes (x and y) controlled by an Arduino UNO and Shield. These drive a pair of stepper motors called Nema. This solar printer structure is made of wood, which is simply because it is cheaper, easier to cut and model, but also a more eco-friendly material. All this structure guarantees us replicability and the least amount of random errors. The study focuses on burning paper with a fixed height that coincides with the magnifying glass's focal length to obtain a much faster burning. For this, the continuity of the energy radiated by the sun must also be taken into account.

5.1.4 Design the test

The tests consist in doing a grid of burned-dot on the paper. This process is repeated 10 times using different times. As shown in the figure below, it generates a matrix where the column shows the homogeneity of the dot simultaneously, and the row shows the difference of the dot through time.

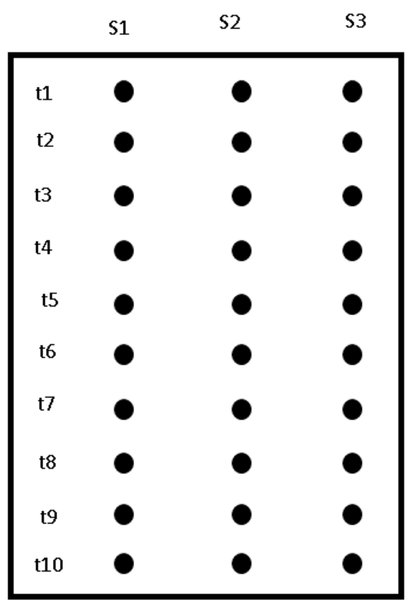

Figure 5.4: Scheme of experimental test.

5.1.5 Design of the light sensor

A light sensor is a way to control the burning process. Its main purpose is to monitor the amount of light reaching the lens: if it would be constant over time during the experiement or not. This light sensor uses an Arduino Mega, BH1750, LCD screen, I2C controller, and wires. Figure 5.5 shows the scheme of the sensor and how it is connected. This light sensor can detect light intensity in a range between 0 lux - 60000 lux. Depending in the conditions, direct sunlight is normally around 32000 - 100000 lux. Consequently, in a fully sunny day our detector can be saturated by very high values but still give us an information about the light source.

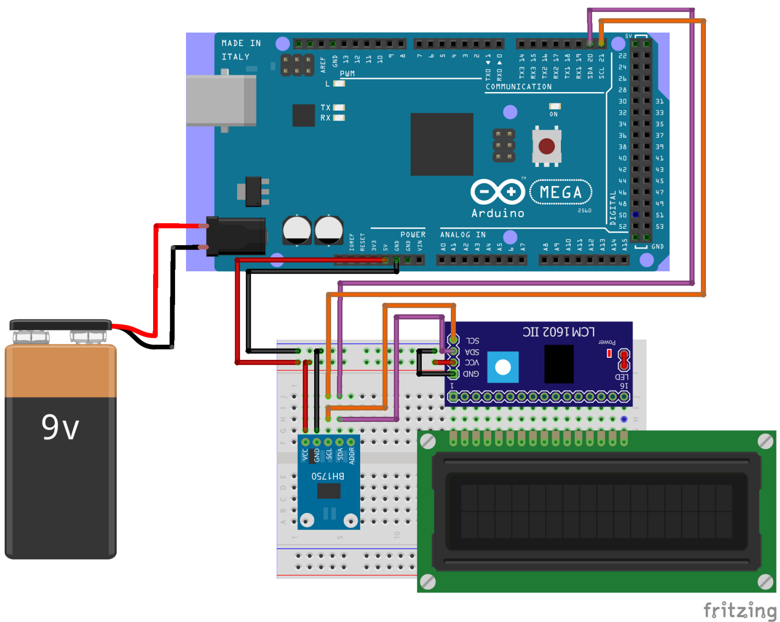

Figure 5.5: Scheme of light sensor.

CHAPTER 6

MACHINE CALIBRATION

This part summarizes the different parts of the machine that should be calibrated before using it. This calibration should be done in two main aspects: calibration of the displacements (between electricity supplied and movement) and calibration of the light source.

6.1 Calibration of A4988 driver

The A4988 stepper driver, made initially by Pololu, would interrupt the current provided to the motor for a little while if it gets too hot. If the motor current is not tuned, the motor does not move correctly and starts pulsating.

6.1.1 Reference voltage

The A4988 allows us to set a target current anywhere between some mA up to a bit less than 2A. This is accomplished by adjusting the reference voltage V_{ref} when turning the potentiometry on a clockwise direction. The V_{ref} voltage will increase and decrease when rotating it counterclockwise.

The actual value of V_{ref} can be calculated using the formula given in the datasheet[39]:

$$I_{max} = V_{ref}/(8 * R_s) \tag{6.1}$$

6.1.2 Sensing resistor

It is necessary to determine the actual value of the current sensing resistor R_s as its exact value depends on the A4988 board manufacturer. As for any resistor, this value can be deduced by looking at the number marked on top of the R_s. For this case, the A4988 brings R200 resistance that means 0.2 Ω and 1.2 A for I_{max} as the datasheet[39] shows. Replacing R_s in the formula allows to calculate V_{ref} using equation 6.1, therefore:

$$V_{ref} = 1.2 * 8 * 0.2 \tag{6.2}$$

Finally, the $V_{ref} = 1.92$ V would be the value used to calibrate the A4988 driver.

6.1.3 Adjusting the current

A multimeter is used to measure the voltage across the top of the potentiometer head and any ground point on the board. If the motor which the max current is specificated at 2A, it should run at around 70% to 80%. Therefore the motor will run cooler and avoid a overheat.[42] Taking the recommendation so:

$$V_{ref} = 1.92 * 70\% \tag{6.3}$$

Computing, the $V_{ref} = 1.34$ V

6.2 Calibration of step motors

Step motors must be calibrated using a software in order to move synchronously. This process could be manual or automatized, but the automatized version implies using paid software; therefore, the calibration in this work was manual to diminish the costs. There exists a correlation between the steps given by the step motor with the centimeter moved. However, there exist many variables like the current, material, and the sizes of this material. A manual calibration employs CNCjs and trial-and-errors processes to find the ideal parameters. Explicitly, these parameters are a relation between the values, in centimeters, given as input to the CNC controller, and the responses ,in centimeters, actually traveled. Figure 6.1 shows the optimal parameters for this eco-friendly printer, where the motors work synchronously and optimally.

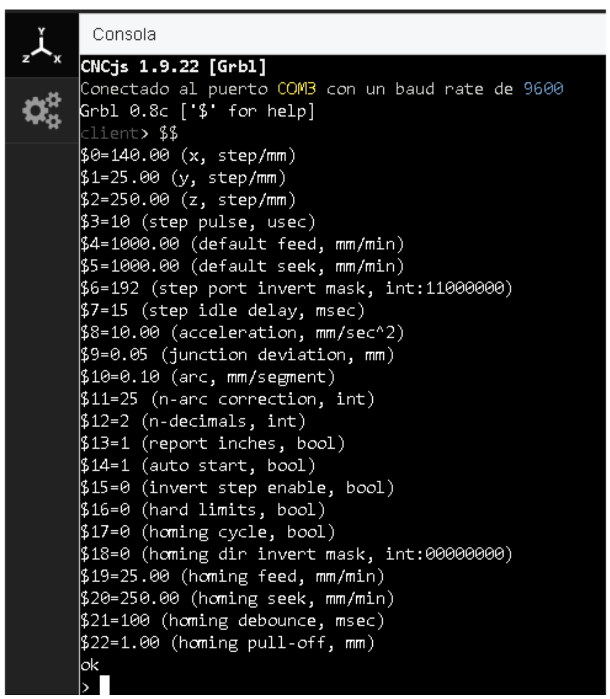

Figure 6.1: Parameters of CNC controller in CNCjs software

6.3 Calibration of lens

The calibration of the lens is highly dependent on the focus of the lens. Despite the focus distance being a constant value characteristic of the lens, some differences can be observed since the source of light, the sun, is continuously slowly moving. However, because losing focus would take a significant amount of time, the tests realized in limited time can be achieved. This calibration is also realized manually through trial-and-error process. It is important to note that it is vital to use protective glasses all the time because being exposed to a concentrated light, even refleted on the paper, can be dangerous for eye health.

CHAPTER 7

RESULTS

This part describes the material necessary to construct the machine, the evolution of different versions, the final prototype and the different tests carried out during this work.

7.1 Prototype construction

The following table summarizes the material used in order to construct our final prototype. All the materials and electronic devices listed in table 7.1 were bought in local stores in Ecuador.

Table 7.1: Materials and devices used during the experimental process

Materials		**Equipment**
Sheet of paper	Lens 2 diopter	Nema step motor 17
Screws	Bolts	Arduino UNO
Bearings	Threaded rods	Arduino Mega
5x8mm Flexible couplers cnc motor	Reinforcement angles	Arduino CNC shield V3
Wood sheets	Wires	Driver A4988
Protoboard	9V battery	12V charger
LCD Display 16x02	I2C adapter	Digital multimeter
		Professional laser protective glasses
		BH1750 sensor

Finally, inspired by CNC technics, the design proposed in chapter 5 is carried on. Also, prior to machine tests, we realized the calibration of the different parts as mentioned in chapter 6.

7.2 Prototype evolution

Through the time when this work was developed several attempts were realized to make the best structure for the eco-friendly printer. The strategy shown in chapter 5 (Fig 5.1) was key to the generation and improvement of the prototypes. Figure 7.1 shows the first attempt better-called prototype 1.0. This prototype is simple and consists of a lens gripped to a metallic tube. The big problem with this prototype is the support that covers the lens and finding the best focus with this structure is hard.

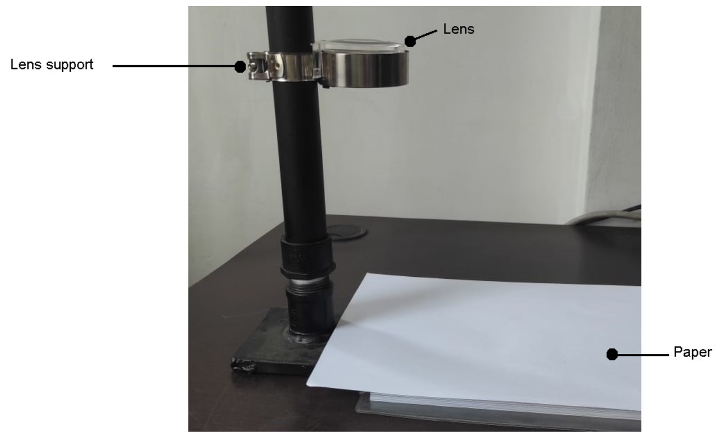

Figure 7.1: Prototype 1.0

Figure 7.2 shows prototype 2.0, which improves the support system. Now consisting of a little metallic structure which allows the lens more flexibility and movement in order to find the best focus. The purpose of this prototype was to determine at which height the best focus is found. For the lens used, the focus is found approximately at distance of 10 - 13 cm between paper and lens. The disadvantage of this system lies in the weight of the lens that moves the gripers of the metallic support.

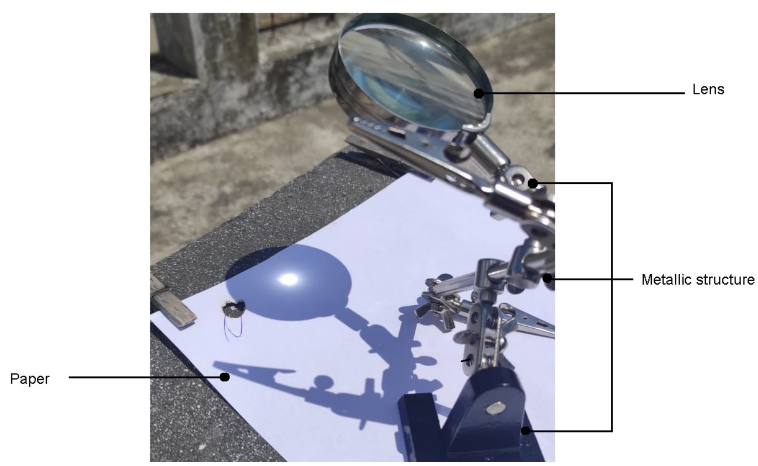

Figure 7.2: Prototype 2.0

Prototype 3.0 (Fig. 7.3) shows a structure based on metal and wood pieces. The lens is fixed to a aluminium tube giving more stability. Furthermore, a plate to support the paper was implemented, with the purpose to fix the paper with grips.

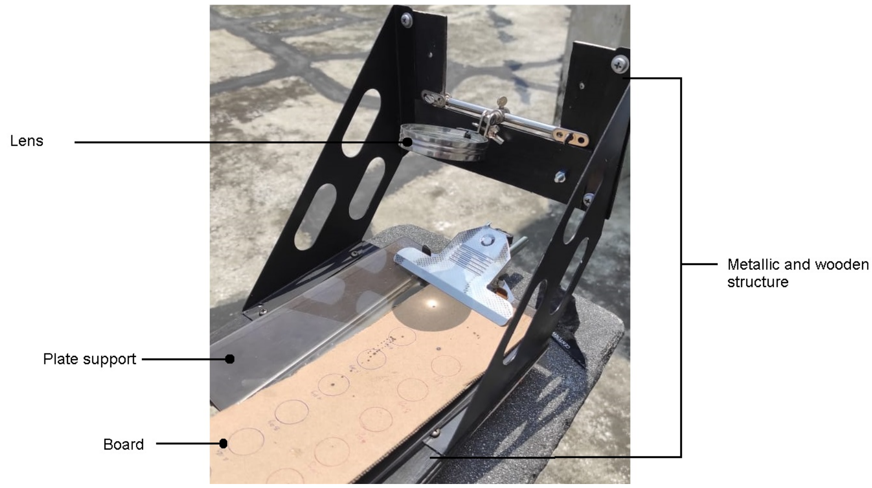

Figure 7.3: Prototype 3.0

A more complex prototype can be seen (Fig. 7.4). This device consisted of a metallic support combined with wooden pieces to form a rectangle to put the Y axis and the support of the lens was the X axis. The axis consisted of motors attached to large screws that move pieces of wood that are linked to desktop rack rails to improve the movement. The lens is found at approximately the focus distance and the CNC Shield V3.0 was connected to the Nema motors. This system worked nicely, however, it needed more stability and be fixed because some parts "danced" when the motors began to move.

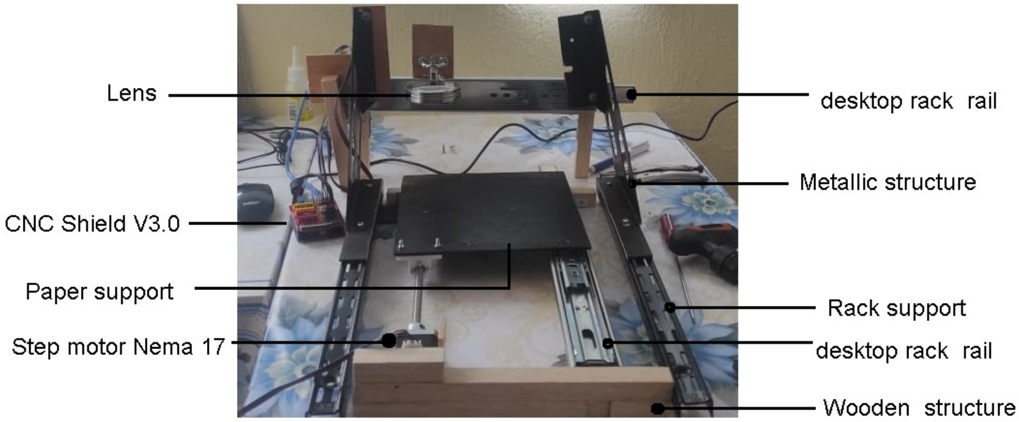

Figure 7.4: Prototype 4.0

7.3 Final prototype: Eco-friendly printer

Figure 7.5 shows the CNC controller assembled and ready to work. It is connected to a serial-usb cable (blue) and 12 V supply power (black), and two-step motors (colours).

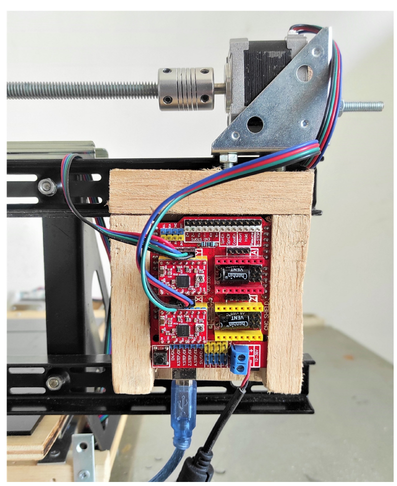

Figure 7.5: CNC Shield controller

After some prototypes were proposed and redesigned, Figures 7.6 - 7.10 show several angles of the final prototype resulting from many modifications and sophistication. The eco-friendly printer has a wooden structure for Y and a metallic structure for X axis. CNC controller is attached to two-step motors fed by 12V charger.

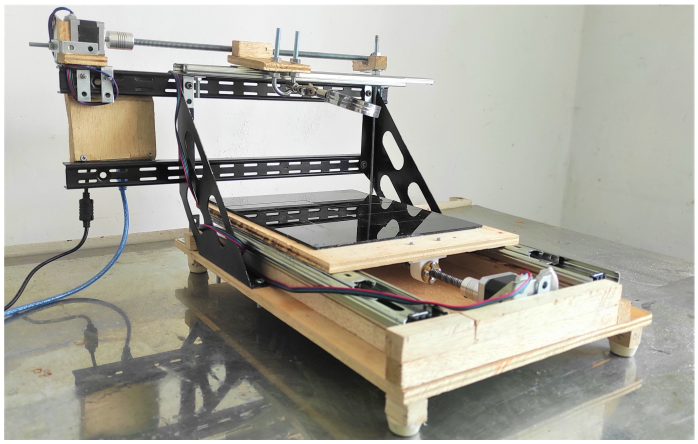

Figure 7.6: Eco-friendly printer.

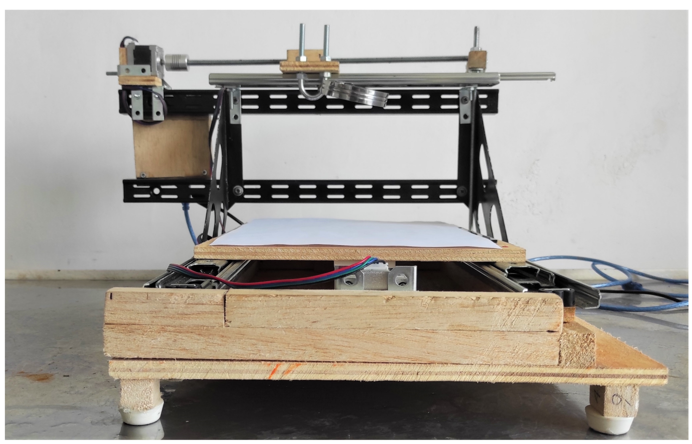

Figure 7.7: Eco-friendly printer frontal face.

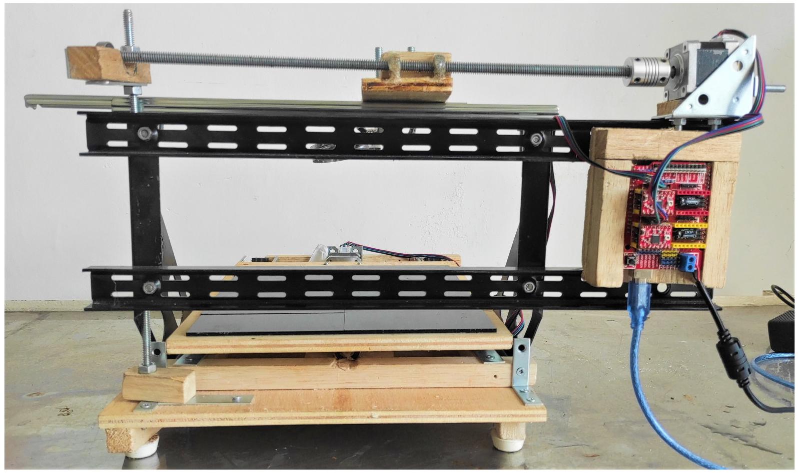

Figure 7.8: Eco-friendly printer back face.

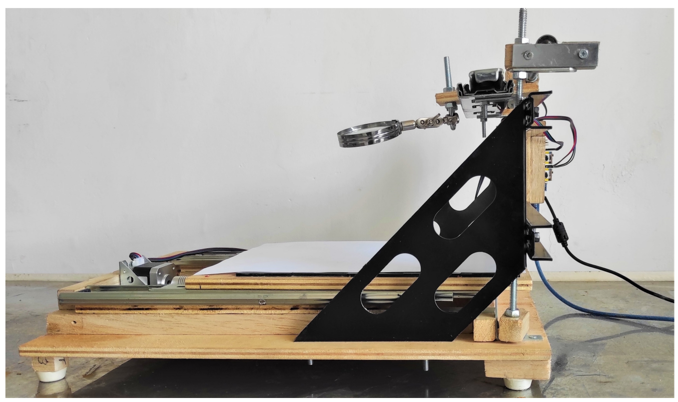

Figure 7.9: Eco-friendly printer side face.

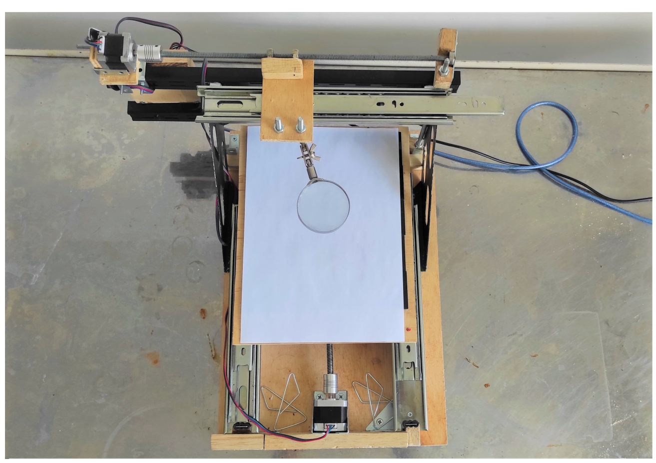

Figure 7.10: Eco-friendly printer transversal face.

7.4 Burning paper

Test 1

The first test was done directly with the machine, without taking into account any other parameters. The results are shown in the figure below.

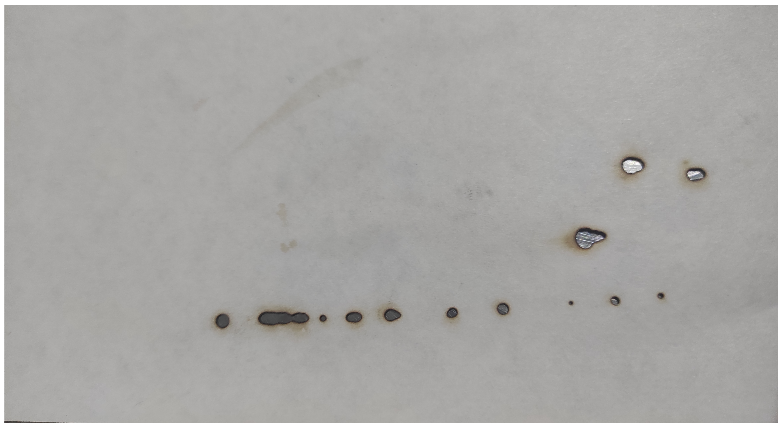

Figure 7.11: Points made by the eco-friendly printer

It can be observed that the size of holes made does not depend explicitly on time: some spots are large and totally burnt while others are much more smaller, but no progressive trend is observed. During these we actually realized that clouds were sometimes passing during the test, influencing directly the quantity of light arriving onto the paper. For this reason no regular trend is observed as clouds can pass randomly during the test if we are not attentive to the sky .

Test 2

The second test was made while looking at the sky in order to assure that no clouds were present at this time. Figure 7.12 shows the results corresponding to this experiment. In that case, a clear trend can be observed where bigger spots correspond to longer burning time while smaller spots correspond to shorter time (on the left side). On the other hand, this trend does not seem to be linear: the 2 bigger spots are clearly much larger than all the others. These results indicate that, even though there was no clouds in the sky, there could be slight variations of the incident light falling onto the paper. At this point, we

Figure 7.12: Points made by the eco-friendly printer

have a control over the spots made but not a total control. In terms of printing it could result in bad printing quality.

Test 3

In the third test, we tried to make a variation of the material used, passing from normal white paper to paper board. Figure 7.13 shows the results on the paper board material.

Figure 7.13: Points made by the eco-friendly printer.

The first observation is that the spots are formed much more faster, in approximately 1-3 seconds. These much shorter times are probably due to the composition of the board comparing to the white paper. Indeed, this kind of sheets are less treated, with a higher content of lignin, suggesting that less paper treatment is actually better to use our machine. This very short burning time could seem problematic but, as it can be seen in the results, we actually obtain a substantive better control over spots sizes when using different burning times.

CHAPTER 8

MAIN FACTORS OF THE PRINTING PROCESS

From the different printing tests conducted, different influences were identified as key factors affecting the efficiency of our printer. These are particularly important as it shows orientations of how to improve this prototype in the future.

8.1 The influence of burning time

Time has a particularly important influence on the tests. Indeed, the paper needs to reach a specific temperature to burn. Brightness of the paper and moisture are factors that can delay combustion. Pyrolysis is a fast reaction where the reagents are consumed rapidly and the majority of products are gases. Therefore, there are two steps to make a nice point. The first step is waiting to reach a sufficient temperature to start the pyrolisis, and then, the second cut the reaction as soon as possible in order to generate an incomplete combustion. As deduced from the different test, on a sunny day, the first step can take between 10-15 seconds, and the second step takes less than 1 second.

8.2 The influence of the material

Each material possess specific heat transfer properties, therefore, different temperatures to burn each material would be required. However, the material's color also plays a role. In order to make a comparison, white paper takes between 10-20 seconds to burn. Instead, a board of brownish color, in the same conditions, takes 2-4 seconds to burn. The color of a paper product is normally given by 2 different factors: the manufacturing process, and, the principal difference, the specific chemical composition of the material. In contrast to sheets of office paper which passes through the bleaching process, board is composed of a significant quantity of lignin, adopting a brown color similar to a tree.

8.3 The influence of weather

It is an essential part of the experiment. Sun was taken into account like a light source. However, the principal problem that needs to be considered is a cloudy day, including just a few clouds. Although the light sensor can not take the exact amount of lux necessary to burn, it can detect a cloudy day. When clouds cover the sun, the light sensor shows around 34000-40000 lux. The influence of the day is a bigger problem because the tiny cloud can delay the print process.

8.4 The influence of time in the day

Not only the weather but also the time in the day influences the intensity of incident light received from the sun, and thus the efficiency of our printer. In fact, the angle of the incident light received, due to the position of the sun in the sky, clearly affect the printing process. For realizing efficient tests, these should be made at the middle of the day as the lux received during sunset or sunrise would be significantly lower. The experiments where perform at 11:00 a.m. to 13:00 p.m., local hour.

CHAPTER 9

CONCLUSION AND RECOMMENDATION

9.1 Conclusions

This work explores a crazy possibility to redesign the printer industry without ink. Therefore, it is an interesting project for eco-friendly technologies, and can be included in a circular economy system. Moreover, it is a highly multi-disciplinar project where very different areas of knowledge are required.

- Through several trial-and-errors steps we could reach a usable design, implemented finally on a working prototype. The approach used is inspired by CNC machine where different axes need to move using stepped motors, while the burning part is highly specific of our prototype.

- The preliminary tests conducted in this work show that this prototype is already working reasonably well on white paper if care is taken about the weather.

- The results also show that board material can be a better idea than white paper for printing using our prototype, as it is an easier material to burn. This suggests that a better material would be a less treated paper with a higher content of lignin. This aspect could also be interesting from an ecological point-of-view because whitening paper is a process requiring potentially toxic chemical products.

- The principal concept was to use the sun as a printing source through its light and it was realized successfully. However, some problems persist in order to obtain a perfect control over the burning time and is dependent on the material. In addition, the influence of the weather is a bigger problem because even tiny cloud can largely delay the printing process.

9.2 Recommendations

From the experience gained, we could identify the key limits of our ecological printer. While having clear benefits, the lack of control on solar light can be problematic. As is currently the prototype, it is possible to recommend to use the printer only when there is a blue sky as a complementary technology. Still, it would be impossible in the rainy season for example.
As shown during this work, there could be too much light or a lack of light, resulting in over-burning or not burning the paper at all. The first matter is easy to solve: we could use a filter between the sunlight and the lens. This could be coupled with the light detector easily to prevent too much light from passing. For the second matter, we could replace the lens with a lens with better focusing properties.
As it is currently, our prototype is working but should be improved in different aspects in order to be usable by anyone at any time.

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