Hardware Graduation Project
Vacuum Forming Machine
(VFM)

Ibraheem kayed
Hadi N. Jamal

Supervisors:
Dr. Anas Toma
Dr. Mona Demaidi

2021-2022

Contents

1 Acknowledgement

We would like to express our deepest appreciation to our families and friends for their huge support during the project. Our success would not have been possible without the support of Dr. Anas Toma and Dr. Mona Demaidi , thanks will not be enough for their valuable advice and helpful contributions .
Yours sincerely Ibraheem,Hadi.

2 DISCLAIMER

This report was written by student(s) at the Computer Engineering Department, Faculty of Engineering, AnNajah National University. It has not been altered or corrected, other than editorial corrections, as a result of assessment and it may contain language as well as content errors. The views expressed in it along with any outcomes and recommendations are solely those of the student(s). An-Najah National University accepts no responsibility or liability for the consequences of this report being used for a purpose other than the purpose for which it was commissioned.

3 Abstract

This project revolves around the implementation of VFM as a practical hardware graduation project.A vacuum forming machine is a machine that form a various types of plastic panels into any desired shape using molds by first heating the panel to a certain calculated temperature and then vacuum the air between the panel and mold to shape it in the mold shape.

The project development process is divided into many parts that will be discussed later. First, we worked to identify the features that the project needs to meet the requirements, and we also researched and studied the final form of the project. After that, we worked to determine the requirements that the project needs from a mechanical point of view through research and reading articles and topics related to mechanical matters to determine the best and most appropriate way to implement the project. After that we searched for the best parts to implement the project and after deep research we decided to use an ESP32, MLX90614, limit switch, adjustable step down buck converter, a relay, a printed circuit board and Nextion intelligent 7.0 inch display.

4 Introduction

4.1 Overview of Vacuum Forming

Plastic thermoforming has been around since the 1950s, it primarily consists of heating certain thermoplastics at a certain temperature before applying the forming process. The latter consists of creating a pressure difference that draws the heated plastic onto a prepared mold to get the desired shape. Vacuum forming is the simplest type of plastic thermo-forming, which uses one mold and vacuum pressure to obtain the desired part geometry. It is ideal for parts that only need to be precisely formed on one side. It has different applications from automotive parts to household items and grants the opportunity to transform any creative idea into reality with the least cost and acceptable results. The process of vacuum forming has the same principle of functionality as thermoforming with some differences depending on the design of the machine itself, while adjusting the operational steps in which the piece is formed depending on the final part desired, its depth, dimensions and later use. These operations include pneumatic or hydraulic prestretching -if needed-, and uniform or non-uniform heating in order to get the desired plastic distribution for each side of the part.

4.2 Process of Vacuum Forming

Vacuum forming is done by heating a sheet of thermoplastic until it reaches a certain temperature and becomes soft and pliable. A heated plastic sheet is brought down onto a mold and when sealed tightly, a vacuum is applied from beneath and within the mold to draw the thermoplastic into or over the mold -depending on its nature of whether a male or female mold-. The plastic hardens through applying cool air through a fan over the formed part. The mold is then brought down and the piece of plastic is ready for trimming and manufacturing. Manually operated vacuum forming machines can be semi-automated with the right control unit to increase the overall efficiency of the process.

4.3 Applications

Vacuum forming offers a blend of design flexibility at a relatively low cost compared to other manufacturing methods, especially for small to mid-range production quantities due to the lower cost for tooling and prototyping, in comparison to other plastic manufacturing processes i.e. injection molding. Vacuum forming Molds can be made out of wood, aluminum, structural foam, or 3D printed plastics, modification or changes made to the designs can be achieved easily. This gives designers the ability to offer more color options and customization to customers, and enables many businesses the freedom to offer one-of-a-kind designs and produce custom products, at an affordable price point.

The cost-effectiveness of the vacuum forming technique is one of its key advantages, giving it a really accessible alternative for anyone looking to personalize their plastic display. Large numbers of a product can be created in a short period of time compared to other plastic manufacturing techniques, and relatively affordable materials – such as acrylic, polyethylene, and polycarbonate – are commonly used.
Equipment expenses are also significantly lower; nonetheless, despite these cost savings, the finished items are of high quality, sturdy, weather-resistant, and still look great.
Another benefit of vacuum forming is the virtually limitless options it offers, as we discussed in our dedicated blog post. It doesn't matter what size or shape you want the item to be. Whether you need a huge quantity of a basic product or a one-off sophisticated design, the vacuum forming technique can probably handle it.
Thanks to the low cost, light weight, and the ability Common applications of vacuum forming include;

1- Automotive parts.

The interior of any car is mostly made via vacuum forming, from the dashboard to the door panels. Other parts for boats and aeroplanes are vacuum formed as well.

2- Packaging.

The plastics that are used are also excellent for packaging. They are not only cost-effective for huge manufacturing lines, but they are also sturdy, hygienic, and come in a variety of sizes and shapes.
Everything from the food and drink containers that line supermarket shelves to the containers used for medical supplies, cleaning items, health and beauty products, and more is likely to have been created using a vacuum forming technique.

3- Household items.

Vacuum forming plastic is used to make a variety of home objects. Consider your own house: the plastic bathtub in the bathroom, the plastic cutlery and appliances in the kitchen, and the garden equipment stored in the shed. These are all regular items found in the home, items that are used on a daily basis and were made using the vacuum forming method.

4-Retail and marketing displays.

Vacuum forming is now being employed for more creative applications, especially in the retail and marketing industries. It's no surprise that vacuum forming plastic has become a popular technique of generating those amazing displays you see when you're out and about, given their potential beauty and eye-catching capabilities! This specialized fabrication method has an infinite number of applications, and merchants are taking advantage of this by employing it to build promotional displays — displays that are unique, imaginative, and designed to attract the attention of their customers.

5-Signage.

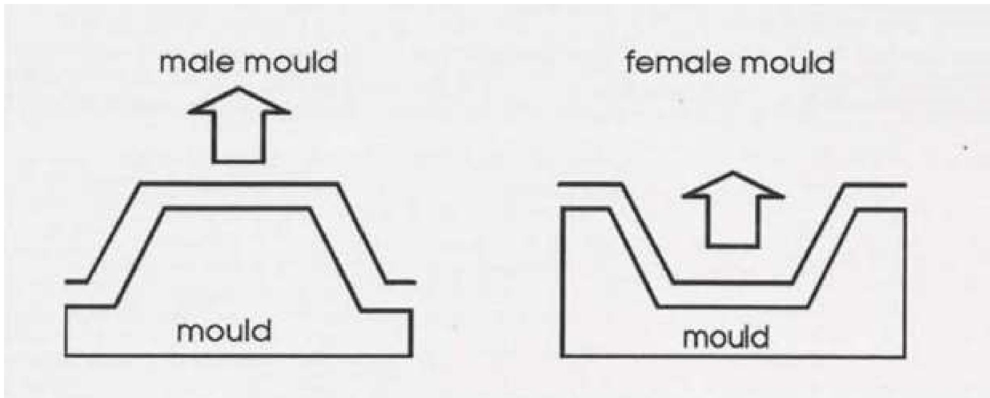
You may advertise your company in a variety of ways. Employing this method of acrylic plastic customization, you may use plastic in a variety of ways, using a combination of colors and styles to create your perfect look, whether it's on a store front, the entrance to your facilities, or anywhere else.

4.4 Thermoplastics

Thermoset and thermoplastic according to Wiley [9] are the two primary forms of plastic, with the latter being the softer substance that is ideal for vacuum forming.
Amorphous and crystalline thermoplastics are the two types of thermoplastics. Due to its flexible molecular structure, the first of the two is a much easier vacuum form. Polystyrene is one of the most commonly utilized amorphous thermoplastics in vacuum forming because of its ability to reform quickly at low temperatures. It's also a very quick and cost-effective substance to work with. Toys, displays, and packaging are among the most common uses for polystyrene. Also, crystalline and semi-crystalline materials are employed. Polyethylene, for example, is commonly utilized in automotive parts, while polypropylene is used in luggage and medical purposes. Temperature management is critical during the vacuum forming process to ensure that the product is created appropriately.

4.5 Molds and mold design

The rmoforming is classified as male or female according to Wiley [9]. This refers to how the sheet is draped over the mold. Male moldings are formed sheets that must be pulled off the mold to be removed. Female formings are sheets that are formed in a mold and must be removed when the mold is removed. The part will be created 'on' a male mold or 'in' a female mold, depending on the process utilized.



4.6 Objectives

In this project, we seek to control a vacuum forming machine capable of producing several plastic products that are not required in large quantities. These products will fill the gap between large and small businesses and their ability to grow, allowing small businesses to get their products on the market without having to order large quantities from manufacturers, which is not affordable at this stage of their start-up. It will also target several niche markets that acquire small vacuum forming services.

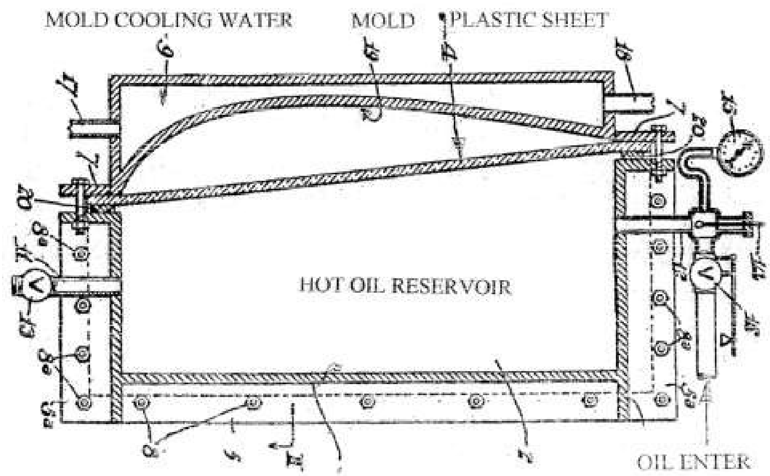
5 Constraints

We faced some constraints due to the fact that we were working with engineers in other departments. Our work was Constrained by theirs most of the time.

6 Literature Review

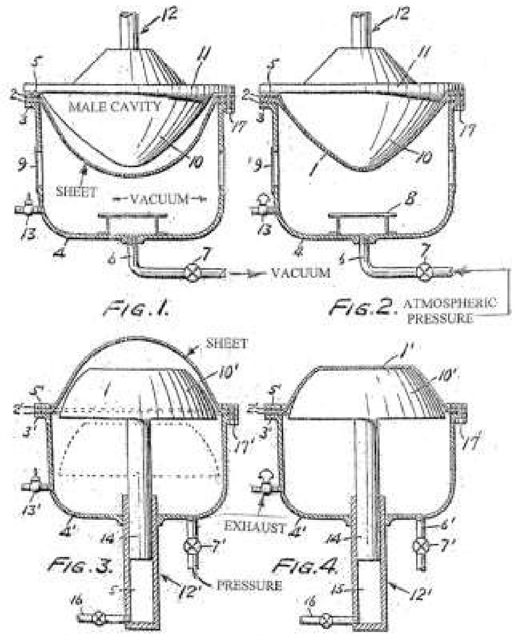
Concepts similar to vacuum forming started appearing in the 1930's-1950's. That the development of sophisticated thermoforming machinery was carried out on the shoulders of foresightful pioneers. Despite the fact that they did not have our modern instruments or hindsight, these experimenters invented many of the techniques we use today.

In 1936, a patent for a vacuum forming machine was filed by H.E. Helwing of Rohm and Haas Corporation. The machine used oil pressure to form a plastic sheet into a mold. As the plastic sheet gets pushed by the oil pressure against the mold as seen in the figure below.

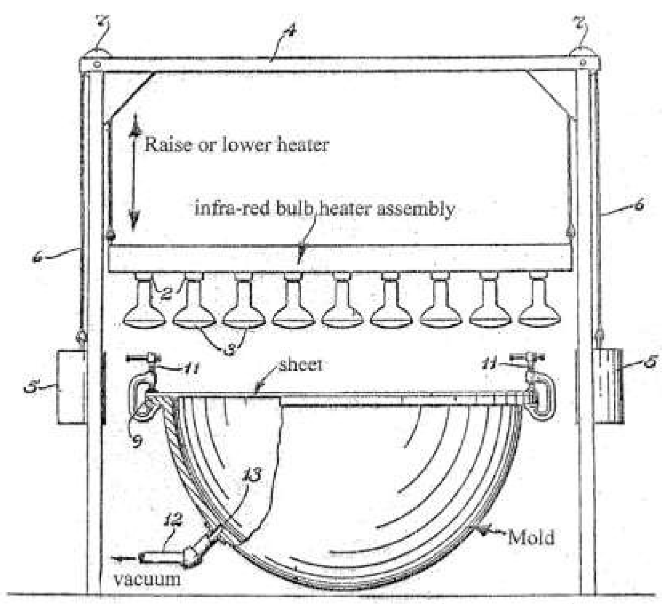


The mold was water cooled to ensure that the sheet surface facing the cavity chilled and hardened sufficiently to avoid being marred against the mold surface. Because it only comes into contact with the hot fluid, the inner surface sheet would be devoid of defects. This procedure is analogous to a modified method currently in use, in which air pressure forms a sheet against a temperature controlled mold, resulting in high-quality parts as in the patent shown in [2]

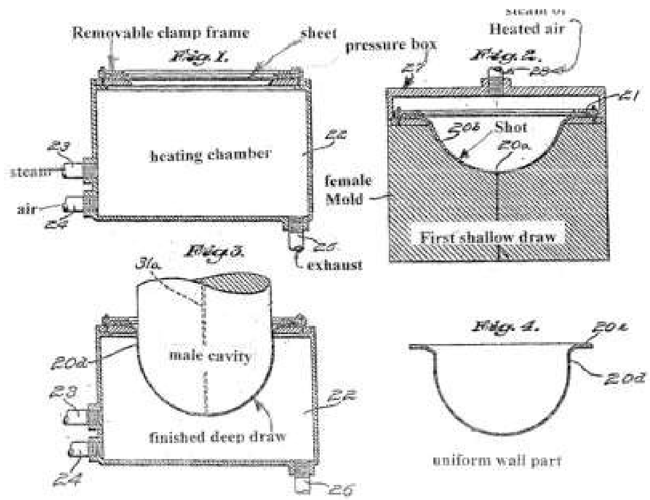
On 28th of august, 1942 Helwing submitted a male snap-back approach using an oven-heated acrylic sheet secured to the device with quick-acting clamps or bolts. This introduced the first and most basic concepts for the stage of prestretching as shown in the figure below:



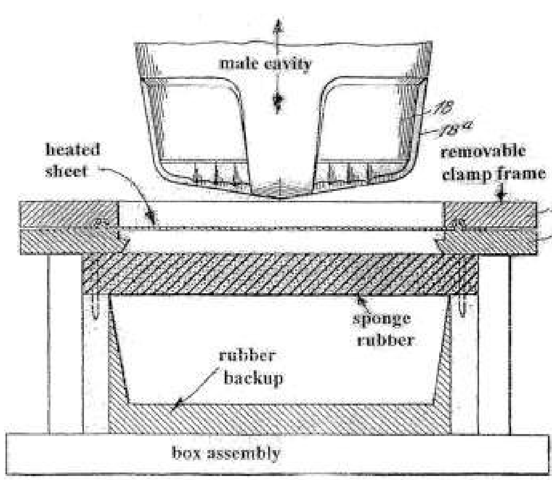
On 27th, December, 1940 R. E. Leary of Dupont Corp filed a patent about vacuum forming employing two techniques of regulating a radiant heat source to obtain a uniform wall thickness as shown in patent [4]



On June 1, 1944, Wiley of Plax Corp. in Hartford, Connecticut, submitted a patent for forming procedures that create a uniform wall thickness on deep drawn pieces shown in patent reference [5]



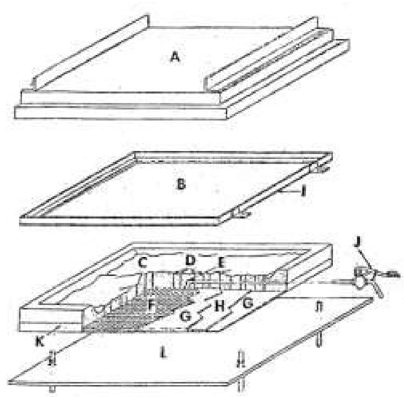
On 2nd Oct, 1941 G. W. Borkland of Borkland Lab, Marion, Indiana filled a patent for forming a plastic lighting diffuser shown in patent reference [4].



On the 8th July 1947, another machine was filed by G. W. Borkland. The machine contained needles protruding upward to attach the sheet of plastic by forcing it to a pivoted platen. The plastic was heated in an oven and brought to a vertical mold to be vacuum formed. Borkland had multiple thermoforming patents issued in the 1940s, and he promoted his procedures in Modern Plastics Magazine to potential licensees.

Two exhibits at the 1950 National Plastics Exhibition (NPE) in Chicago displayed the first public display of thermoformed items. Borkland Laboratories and Regal Plastics of Kansas City both had formed pieces on exhibit. Regal displayed a heavy gauge motion picture machine box built in matching wooden male and female mold holes, while Borkland supplied thin-walled vacuum formed packaging.

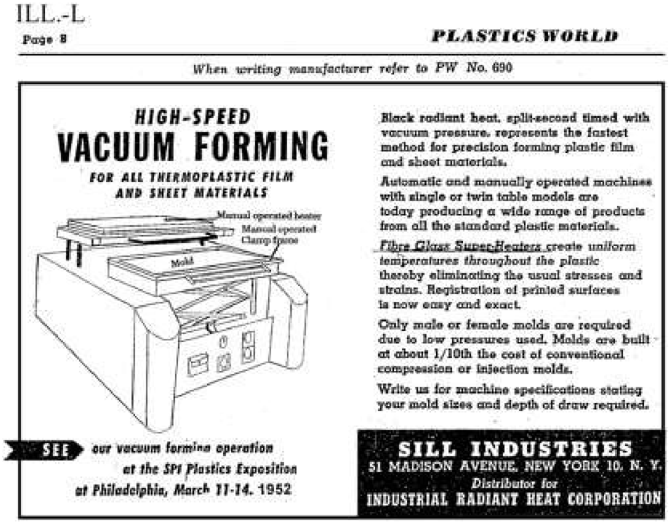
However, not until the 1950's that vacuum forming started gaining a larger reputation and came under the spotlight for many businessmen. That is when pneumatic, mechanical and heating controls were introduced in an enhanced manner. The development of these features were the spark that lit the future of vacuum forming.
Chief of the Relief Map Division, Army Map Service, E. Bowman Stratton, started the production of military relief maps using the equipment shown in the picture. His team developed a machine that included all of the components of a modern vacuum forming as further illustrated in (NPE shows) [5].



This view shows the relationship of the essential components of vacuum-forming equipment as used by the Army Map Service in 1947 to produce three-dimensional maps: (A) superheater; (B) angle-iron frame; (C) mold; (D) vacuum holes; (E) vacuum pipe; (F) wire mesh, 2 layers; (G) aluminum sheet, 0.032"; (H) sponge rubber, 1/4" to 3/8"; (I) sponge rubber gasket; (J) poppet valve; (K) heat-resistant tape; (L) aluminum plate, 1/2". (Courtesy, Relief Map Division, Army Map Service, Corps of Engineers, Washington, D.C.)

Later, in 1950, the Industrial Radiant Heat Corp., NJ, modified and built this vacuum-forming machine, which was offered to commercial clients as shown in the figure:

ILL.-L



Page 8 PLASTICS WORLD

When writing manufacturer refer to PW No. 690

HIGH-SPEED
VACUUM FORMING
FOR ALL THERMOPLASTIC FILM AND SHEET MATERIALS

Manual operated heater
Manual operated Clamp frame
Mold

Black radiant heat, split-second timed with vacuum pressure, represents the fastest method for precision forming plastic film and sheet materials.

Automatic and manually operated machines with single or twin table models are today producing a wide range of products from all the standard plastic materials.

Fibre Glass Super-Heaters create uniform temperatures throughout the plastic thereby eliminating the usual stresses and strains. Registration of printed surfaces is now easy and exact.

Only male or female molds are required due to low pressures used. Molds are built at about 1/10th the cost of conventional compression or injection molds.

Write us for machine specifications stating your mold sizes and depth of draw required.

SEE our vacuum forming operation at the SPI Plastics Exposition at Philadelphia, March 11-14, 1952

SILL INDUSTRIES
51 MADISON AVENUE, NEW YORK 10, N. Y.
Distributor for
INDUSTRIAL RADIANT HEAT CORPORATION

This line of vacuum formers was promoted by Bow Stratton through magazine articles, seminars, trade exhibits, and technical society papers. Many entrepreneurs became very interested in this approach by the end of 1953. Bob Butzko was a seasoned engineer who quickly revised early equipment models to withstand harsh industrial environments. The clamp structure, pneumatics, and mechanical characteristics were all improved, as were the oven and its controls. Within a year of AutoVac's creation, a half-dozen thermoforming machinery manufacturers began competing, providing thermoforming processors with a number of purchase options as in [6].
This led to the rise of the golden age of vacuum forming during 1950 - 1960.

Nowadays vacuum formers vary in size and shape depending on their purpose of use and final product desired. Formech offers great vacuum forming machine that are accurate enough to form the desired shapes fast and easily as illustrated in the figure:

These machines integrate the previous properties within the latest technologies to be used in vacuum forming.

7 Methodology

The purpose of this chapter is to summarize the developments that took place within VFM project and put them in a larger scientific and technological context.

7.1 Micro-controller

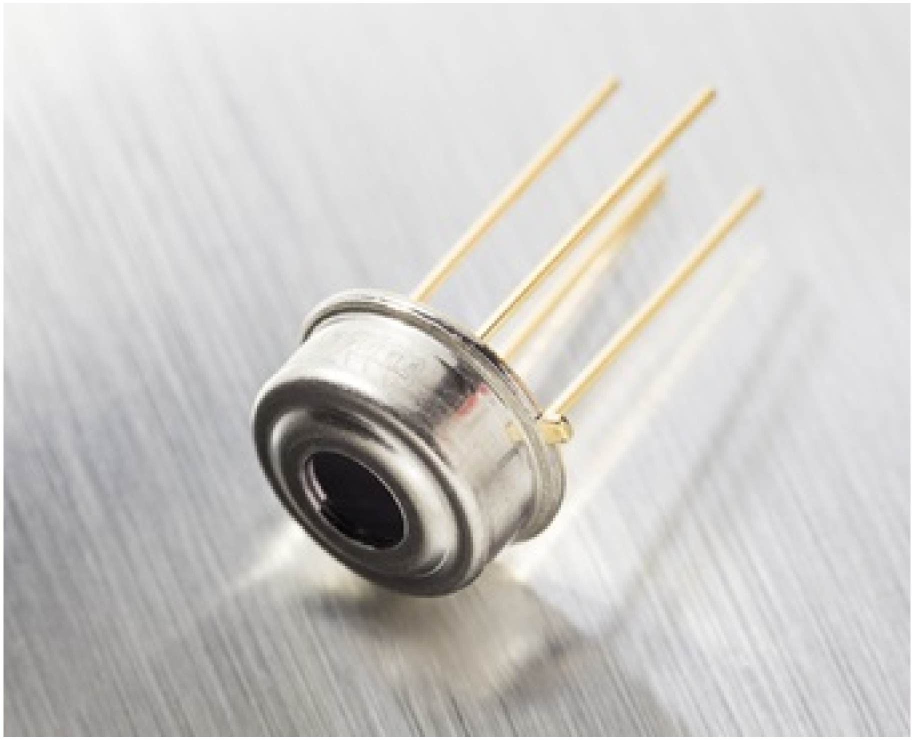
ESP32: It is a series of low-cost, low-power system on a chip microcontrollers with integrated Wi-Fi and dual-mode Bluetooth. The ESP32 series employs either a Tensilica Xtensa LX6 microprocessor in both dual-core and single-core variations, Xtensa LX7 dual-core microprocessor or a single-core RISC-V microprocessor and includes built-in antenna switches, RF balun, power amplifier, low-noise receive amplifier, filters, and power-management modules.
We used the ESP32 instead of arduino because we needed the Wi-Fi to be able to turn off the heater remotely using a mobile application in case of a huge and undesired increase in temperature.

ESP32-Development-Board-ESP-WROOM-32 30pin

7.2 Sensors

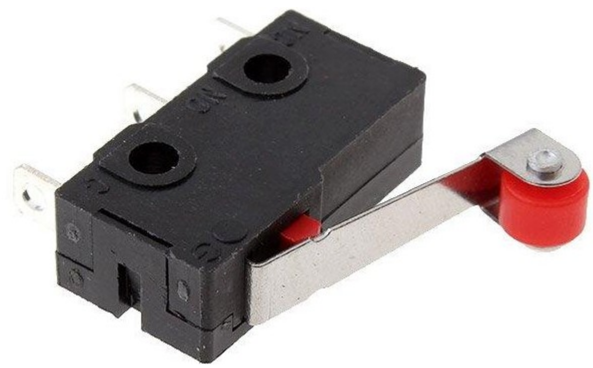
7.2.1 MLX90614

The MLX90614 is an infrared thermometer for non-contact temperature measurements. Both the IR sensitive thermopile detector chip and the signal conditioning ASIC are integrated in the same TO-39 can. Integrated into the MLX90614 are a low noise amplifier, 17-bit ADC and powerful DSP unit thus achieving high accuracy and resolution of the thermometer[3] We used this sensor to measure the plastics temperature.



7.2.2 Limit switch

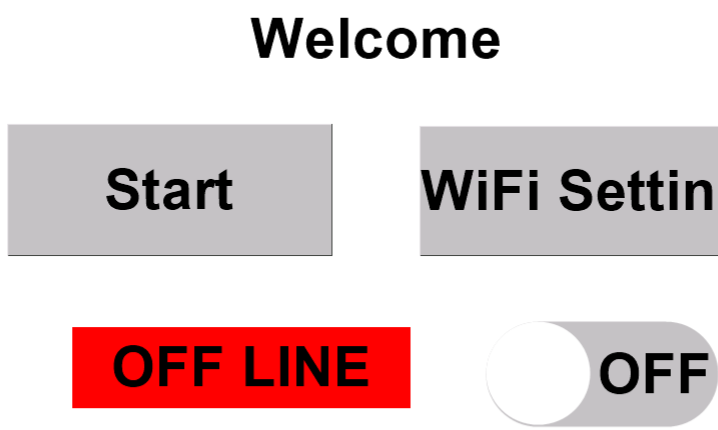
A limit switch is a switch that is actuated by the movement of a part of the machine or the presence of an object. They are used to control machines as part of a control system, such as security locks, or to count objects passing through a point. A limit switch is an electromechanical device consisting of an actuator connected mechanically to a set of contacts. When an object comes into contact with the actuator, the device triggers the contacts to make or break an electrical connection. it was used to detect when the plastic is brought down to activate the vacuum.



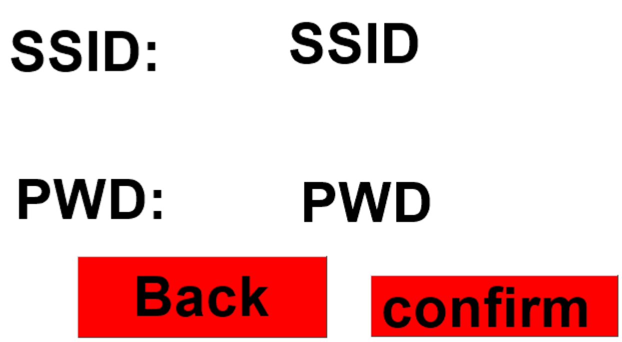
7.3 Nextion Intelligent 7.0 inch Display

Nextion is a Human Machine Interface HMI solution combining an onboard processor and memory touch display with Nextion Editor software for HMI GUI project development. Using the NEXTION Editor software, we were able to develop the HMI GUI by drag-and-drop components (graphics, text, button, slider etc.) and ASCII text based instructions for coding how components interact at display side. Nextion HMI display connects to peripheral MCU via TTL Serial (5V, TX, RX ,GND) to provide event notifications that peripheral MCU can act on, the peripheral MCU can easily update progress and status back to Nextion display utilizing simple ASCII text based instructions.[1]

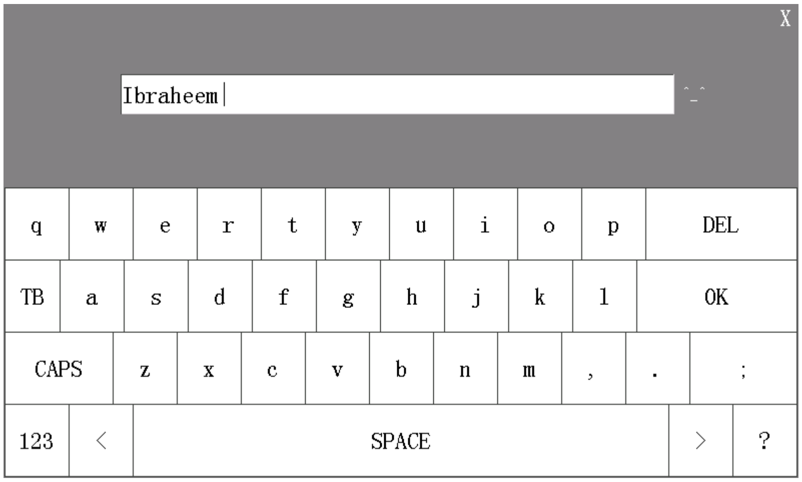
The HMI has an EPROM which we used to save all the data regarding the types of different plastics.
The HMI had several pages and bottoms that the user can easily use, the pages are shown below with a description of each page:



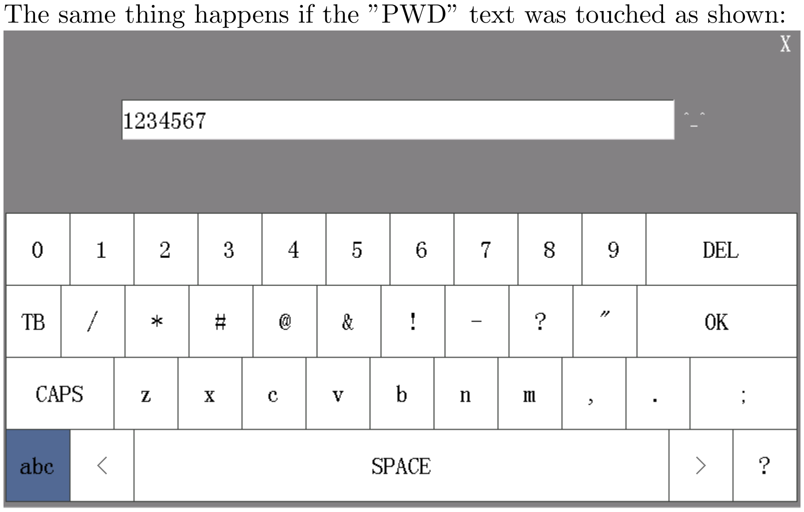
This is the first page that we see when we turn on the HMI. It has a text that says "Welcome", two buttons "Start" and "WiFi Settings", offline/online box which changes according to the connection status to a mobile phone to monitor the heat and turn it off remotely if it increased above the limit that was set.
Now if we press the WiFi Settings button it will take us to the page shown below in the picture:



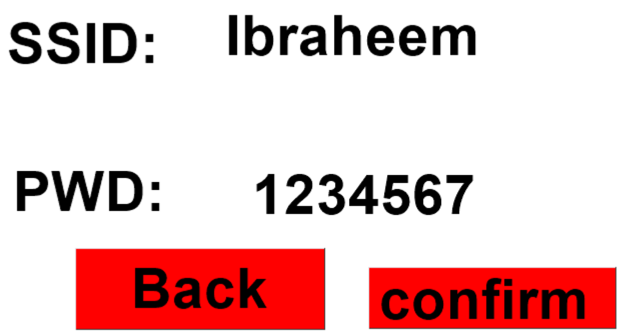
Before any editing the SSID and password are set to "SSID" and "PWD" respectively. if we touch the "SSID" text it will take us to a keyboard that we designed from scratch. The keyboard is shown below:



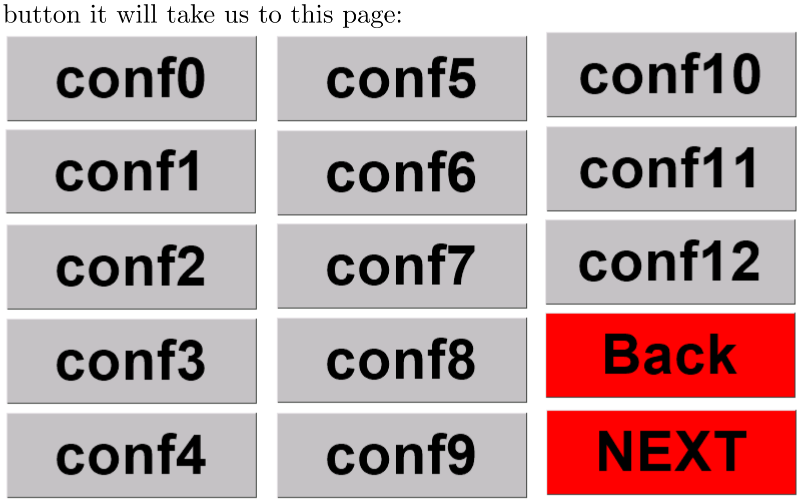
The same thing happens if the ”PWD” text was touched as shown:



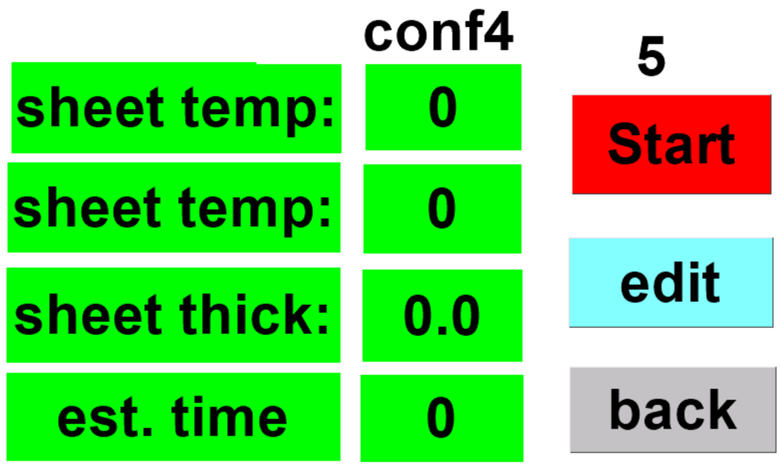
After pressing ”OK”, the SSID and or the password are set as we can see in this picture:



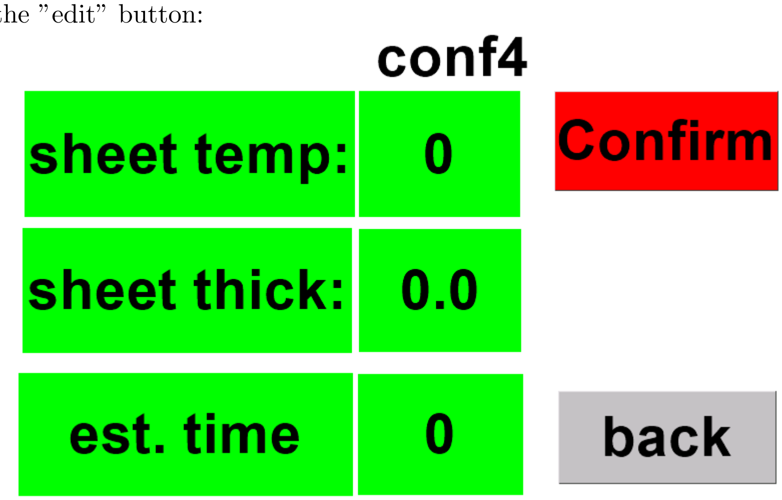
Now pressing confirm will take us back to the first page. If we press the "Start" button it will take us to this page:



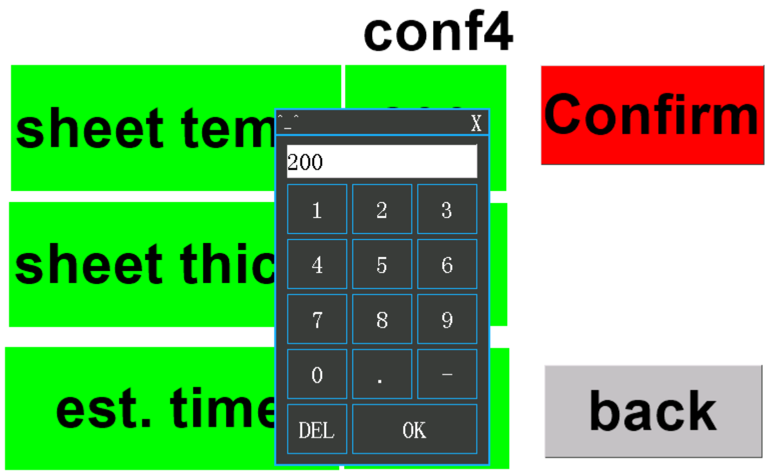
In this page there are 12 buttons that each one represent a type of plastic and each type has different required heat temperature. If we choose any type it will take us to this page:



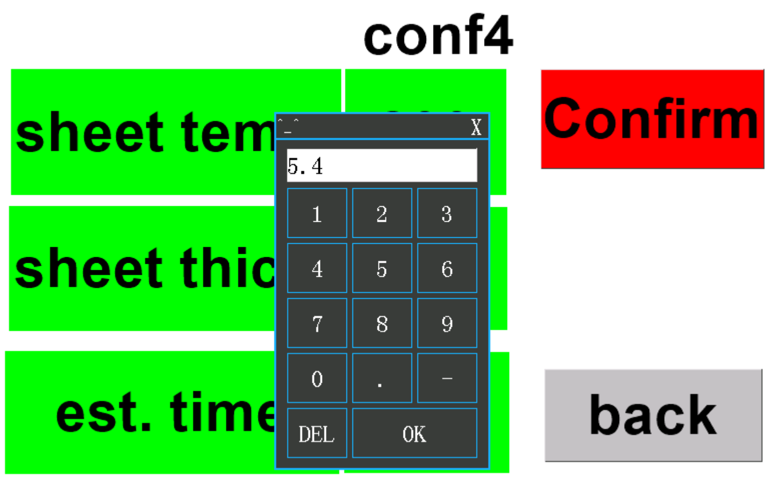
Here we can see a type of plastic and we can set all its parameters by pressing the "edit" button:



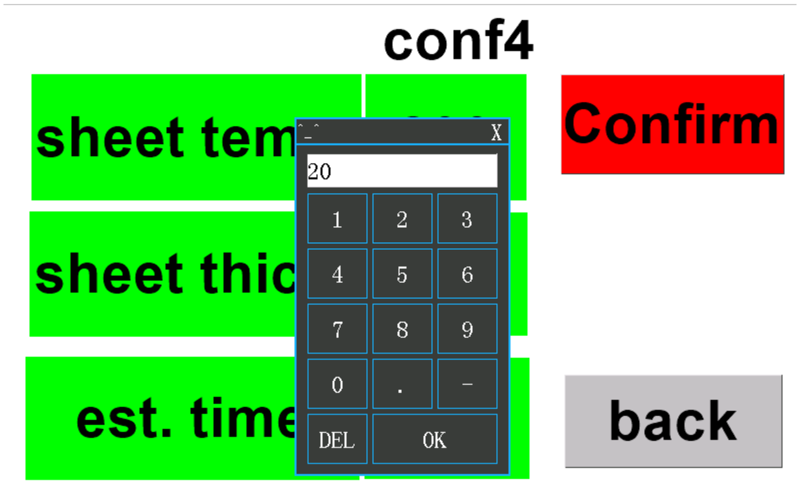
Setting sheet temperature:



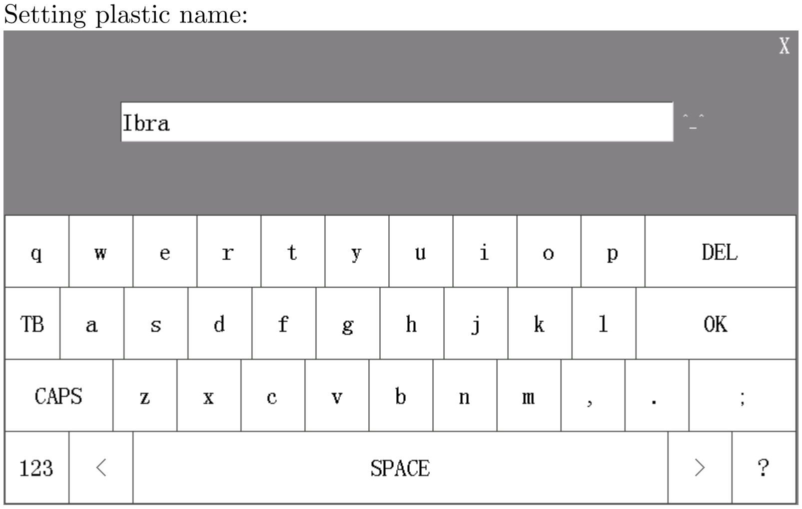
Setting sheet thickness:



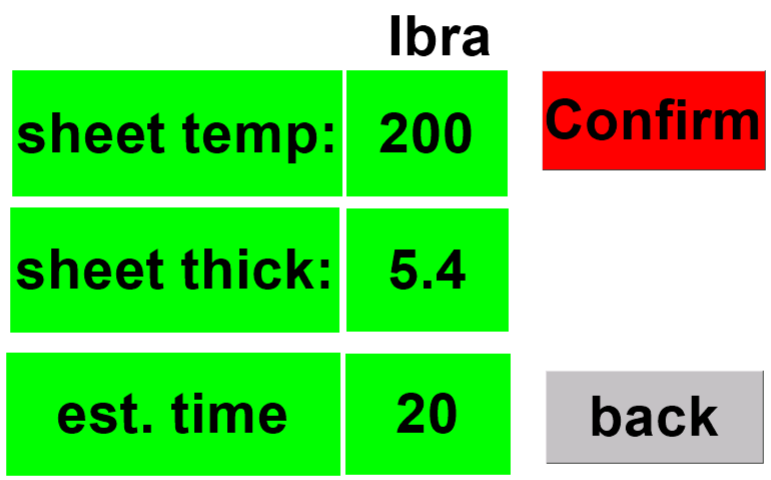
Setting timer:



Setting plastic name:



The Plastic is set:

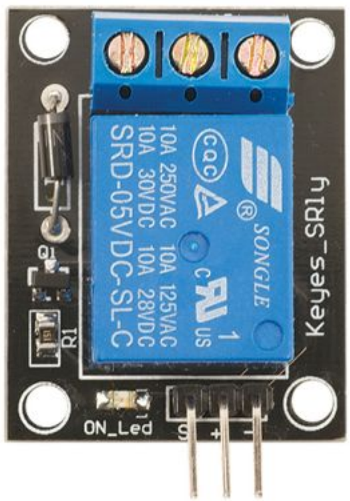


After setting all the parameters and pressing "Confirm", the plastic will be saved in the EPROM and can be used at any time by simply choosing it and pressing start and the timer will start counting and when it reaches "0" the HMI will start a buzzer sound to alert the user that the plastic is ready to the next stage which is the vacuuming stage.

7.4 Adjustable Step Down Buck Converter

We used a step down buck converter because we need 5V voltage and the source voltage was 12V.

7.5 Relay

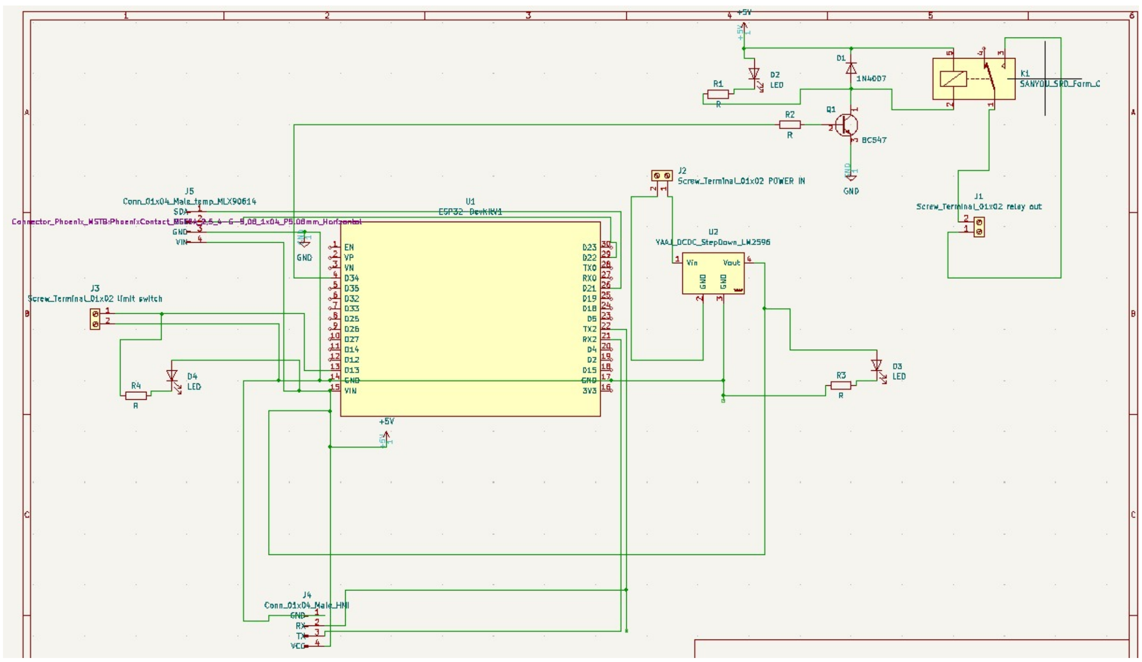


We used a relay between the limit switch and the vacuum to convert the voltage coming from the limit switch from 5V to 220V to turn on the vacuum.

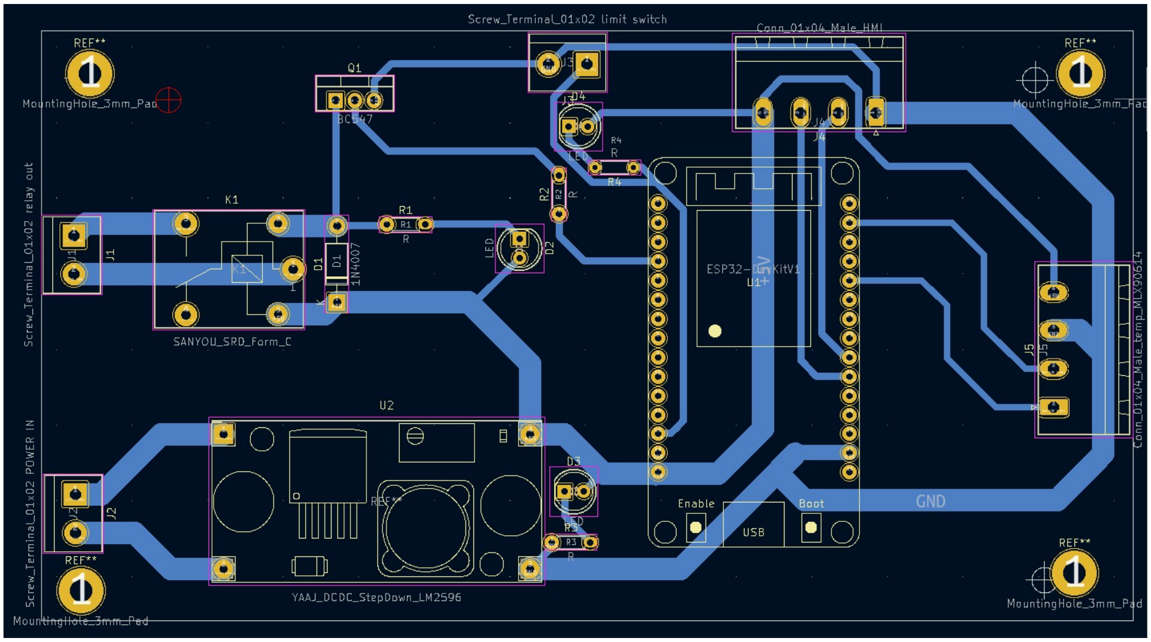
7.6 Printed Circuit Board (PCB)

We designed a PCB to make the installation of our work to the work of the mechatronics students easier, more professional and with higher durability.

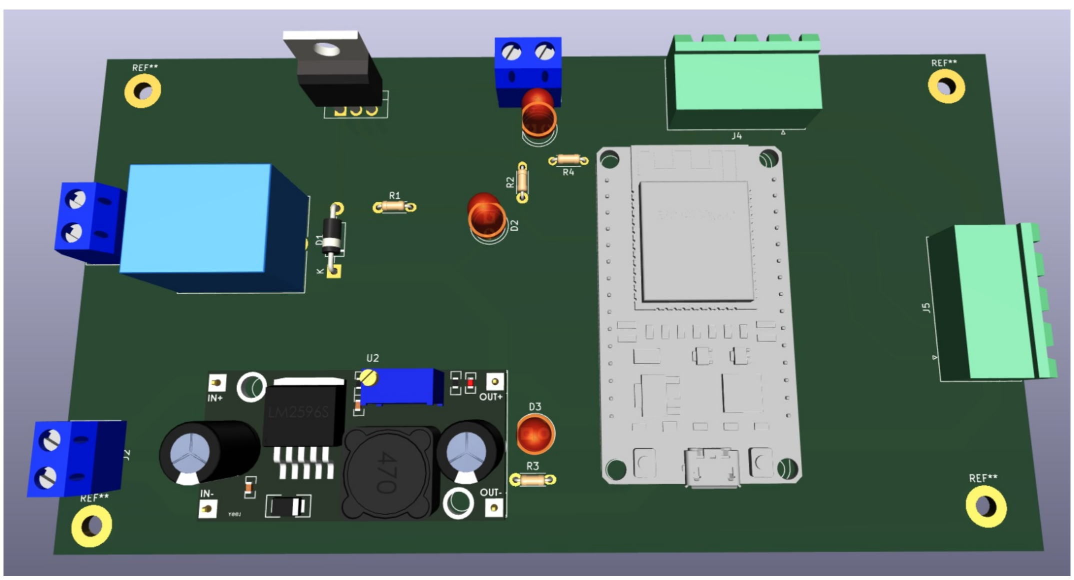
First, we created the schematics file were we established the connections between all the pieces and the schematic file looked like this:



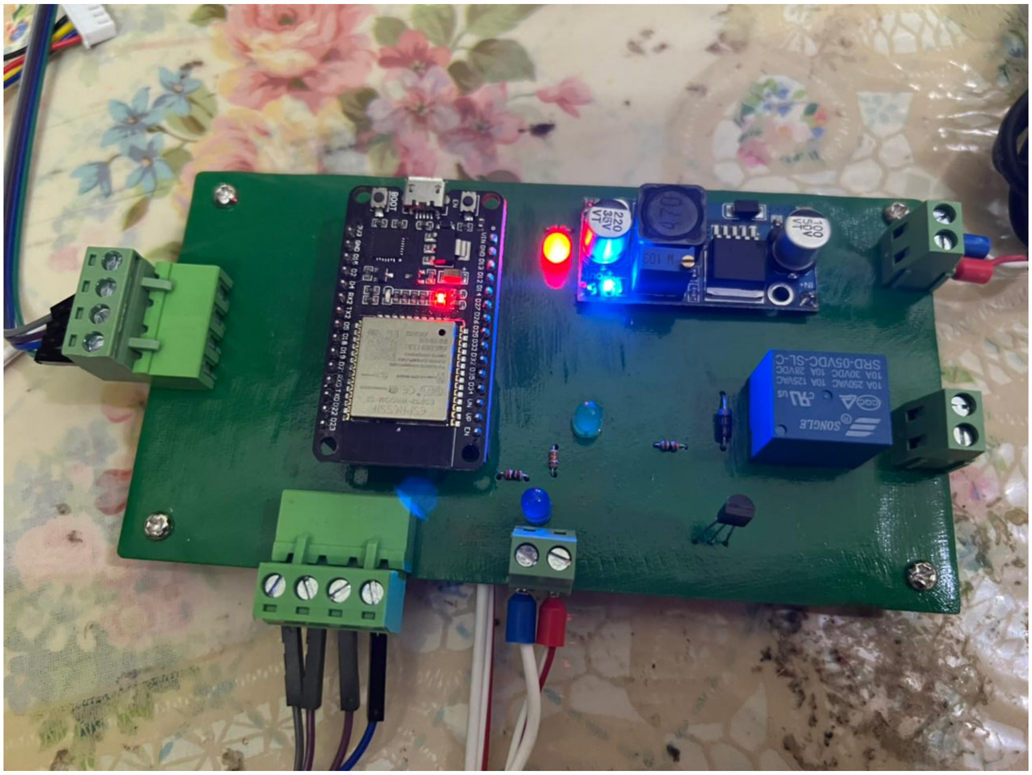
After finishing the schematics file we started the wiring process to show the connections from the schematics file on the board. The connections were shown as in this picture:



After that we created a 3D view to be able to see a virtual outcome of the PCB and it looked like this:

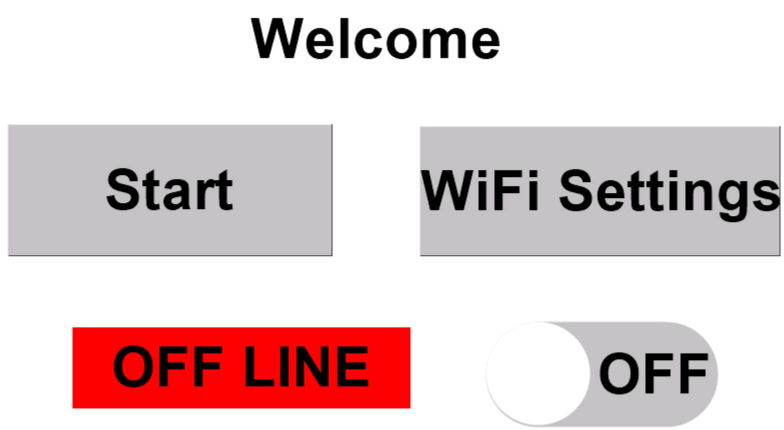


Finally, the PCB was created and the this was the final output:



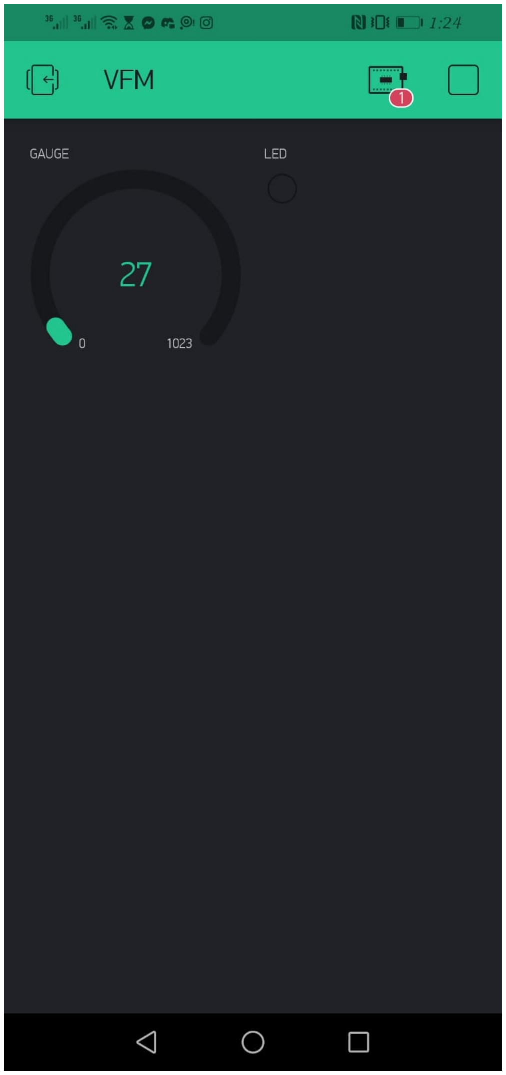
7.7 Blynk

We connected the HMI to a mobile phone via WiFi and by using Blynk app we showed the temperature measured by the sensor on the phone to be able to monitor the heating process remotely and we also showed the limit switch status and whether it's open or close.

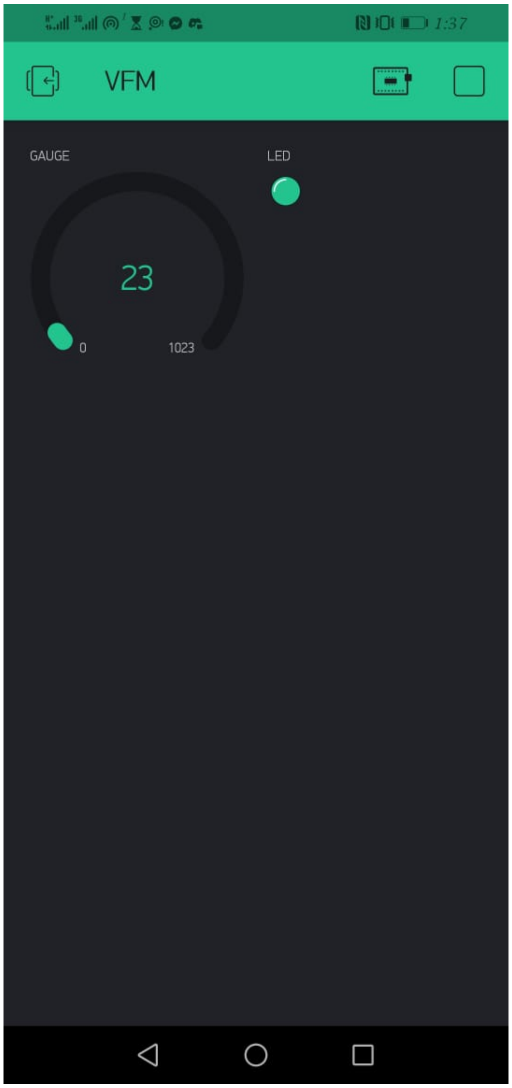


This is the start page in the HMI when it's not connected to the mobile phone.

And this is the start page after the connection is set.



This is the mobile application and it's showing the temperature of the sheet and that the limit switch is open(the vacuum is turned off).



And here it's showing that the limit switch is closed(the vacuum is turned on)

7.8 Frameworks

We used the Arduino IDE to program the ESP32, KiCAD to design the PCB and Nextion editor to program the HMI.
We used the Blynk app to connect the HMI with a mobile phone and show the temperature measured by the sensor and to the the status of the limit switch whether it's open or closed.

8 Conclusions and Recommendation

In this section , were going to show the most important results we have achieved in our project .

8.1 Summary

Based on what was explained before we can conclude that our project is viable, easy to use by anyone and conclusive. We recommend using a human machine interface in projects of this kind due to the fact that these machines are most likely not going to be operated by engineers.

8.2 Future Work

For the short-term period, we aim to continue working on our project until we achieve the best result we can. We aim to increase the number of plastics types that can be added, improve the GUI, adding more sensors to lower the power usage by controlling the heater and finally adding a fan to cool down the plastic after the vacuuming process.

9 References

References

[1] Antonio Carlos Bento. Nextion tft development an experimental survey for internet of things projects. *International Journal*, 8(11):1–9, 2020.

[2] Edward L Helwig. Method of shaping thermoplastic sheets, January 3 1939. US Patent 2,142,445.

[3] Gang Jin, Xiangyu Zhang, Wenqiang Fan, Yunxue Liu, and Pengfei He. Design of non-contact infra-red thermometer based on the sensor of mlx90614. *The Open Automation and Control Systems Journal*, 7(1), 2015.

[4] Richard E Leary. Method of and apparatus for shaping thermoplastic sheets, June 12 1945. US Patent 2,377,946.

[5] Fred E Wiley. Method of deep drawing organic plastic sheets, April 26 1949. US Patent 2,468,697.