Design of a Control System for an Indirect Solar Dryer

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Bragança 2020

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Dissertation presented to the Escola Superior de Tecnologia e Gestão of the Instituto Politécnico de Bragança, made under the agreement of Double Diploma between the Polytechnic Institute of Bragança and Tunisia Private University (ULT), to obtain the Master's Degree in mechanical Engineering

Bragança 2020

Acknowledgments

I would like to thank the following people who have helped me undertake this dissertation

Firstly, I'd like to express my gratitude to my patient and supportive supervisor, ***Luís Frölén Ribeiro*** *who has supported me throughout this research project. Also, for the kindness and the spontaneity, for all his remarks, his advice so that he helped me to give a good project. I had the great pleasure of working under his direction, his indisputable professional competence as well as his human quality.*

I 'd like to express my big thank to my supervisor ***Yassine Ferchichi*** *for his consistent support and guidance during the running of this project and for the thoughtful comments and recommendations on this dissertation.*

I'm also thankful to the members of the juries who agreed to assess my work.

To conclude, I cannot forget to thank my family and friends for all the unconditional support in this very intense academic year.

Abstract

This dissertation focus on the control system design of a for indirect solar dryer without any difficulty of utilization with low cost and autonomous. The intended interest group of this model is small farmers who don't have the cash-flow to put resources into new drying innovations however need basic and modest machines to contend in the current market for nuts.

In the present work, a multivariable control system using DHT22, BMP280 sensors to measure the drying process parameters of the fig. The Bernoulli equation was established in the Arduino program to calculate the air velocity. The valves designed based on servo motor DS3225. Then, the control of the position of the valve based on the measured sensor parameters and the conditions of the drying process. And for sending the data in real-time to the farmers, the IoT technology was used by the combination of the GSM/GRPS module with the Arduino UNO board. Then, the Blynk application was used to visualize the data, and the ThingSpeak IoT platform for saving the data and analyses the quality of the drying prosses. More than visualization the data in the Blynk application, a notification was added for the farmers in the case of start drying process and overheating condition.

According to the outcomes of the Proteus simulation which have been shown by the Blynk application and the ThingSpeak IoT platform, it can conclude that the design of the control system is successfully done.

Keys words : Indirect solar dryer, Control system, IoT technology, Blynk application, ThingSpeak, Proteus simulation

Résumé

Cette thèse porte sur la conception d'un système de contrôle pour séchoir solaire indirect sans aucune difficulté d'utilisation à faible coût et autonome. Le groupe d'intérêt visé par ce modèle est constitué de petits agriculteurs qui n'ont pas les liquidités nécessaires pour investir des ressources dans de nouvelles innovations de séchage, mais qui ont besoin de machines basiques et modestes pour lutter sur le marché actuel des noix.

Dans le présent travail, un système de contrôle à plusieurs variables utilisant des capteurs DHT22, BMP280 pour mesurer les paramètres du processus de séchage de la fig. L'équation de Bernoulli a été établie dans le programme Arduino pour calculer la vitesse de l'air. Les vannes conçues sur la base d'un servomoteur DS3225. Ensuite, le contrôle de la position de la vanne en fonction des paramètres mesurés du capteur et des conditions du processus de séchage. Et pour envoyer les données en temps réel aux agriculteurs, la technologie IoT a été utilisée par la combinaison du module GSM / GRPS avec la carte Arduino UNO. Ensuite, l'application Blynk a été utilisée pour visualiser les données, et la plate-forme ThingSpeak IoT pour enregistrer les données et analyser la qualité du processus de séchage. Plus que la visualisation des données dans l'application Blynk, une notification a été ajoutée pour les agriculteurs en cas de démarrage du processus de séchage et de surchauffe.

Selon les résultats de la simulation Proteus qui ont été montrés par l'application Blynk et la plate-forme ThingSpeak IoT, il peut conclure que la conception du système de contrôle est réussie.

Mots clés : Sécheur solaire indirect, Système de contrôle, Technologie IoT, Application Blynk, ThingSpeak, Simulation Proteus

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Chapter 1: Introduction

1.1. Objectives

This present project intends to develop a control system for a natural convection solar dryer, which will be low-cost, autonomous and controllable from a distance while allowing for a real-time flow of data to facilitate the decision-making process for the farmers.

Also, to use the communication technology to connect the control system with a WEB browser and/or smartphone application. Also, this control system uses an internal network communication for sending and receiving orders and information.

One of the main aims in this study is to simulate the control system designed in order to test its performance for optimizing the drying process.

1.2.Background and Motivation

Every year and around the world, massive amounts of food are lost due to spoilage and infestations during and after the harvest [1]. Several solutions are proposed to overcome this handicap such as freezing, greenhouse cultivation, and preservation by drying. The latter proves to be a simple, safe, adequate solution for the storage of a large number of products, and facilitates transport, since the food decreases in size due to the high loss of water.

With cultural and industrial development, artificial mechanical drying has started to be practiced more and more in recent years. This process is known to be an energy-consuming and expensive process, and it accounts for 10 to 15% of total global industrial energy consumption [1], which ultimately increases the cost of the product.

The use of free solar energy could reduce the cost of the drying process while producing the same quality of the dried product as mechanical drying. Solar dryers are generally classified as direct, indirect, and mixed-mode. Air circulation through the dryer is ensured either natural or forced (with a fan). Natural convection solar dryers are generally ineffective because the air circulation is quite weak. Some studies have found that using solar chimneys can improve the air flow (flow and speed) through the solar drier. This technique has become the real heat engine in most natural convection solar dryers. the solar drying is basic on four parameters, namely: temperature, humidity, pressure and air flow.

It is therefore natural that the optimal control of these four parameters lead to an optimal drying procedure. Fortunately, the last century of communication technology developments provided us with cheaper ways to achieve automated and distant control.

In fact, over the past ten years, devices have become largely autonomous, operate according to a user-defined profile, and are able to make decisions independently. Therefore, for an automatic solar dryer, the product to be dried must be specified in order to create a profile. Building on earlier work of an indirect sun dryer for figs, the calculation used in the design could make the solar dryer completely autonomous.

1.3.Structure

To reach the objective set it at the beginning of work, a very precise structure will be followed. Therefore, the design and the simulation of the control system for indirect solar dryer will unfold into five chapters:

Firstly, an introduction presents the aims of this project, then, the motivation and the background for the choice of this subject, and this chapter finish with this structure of the report.

Secondly, a theoretical fundamental consists the state-of-the-art portion which presents the major drying processes used in the world, the solar drying modes, the selection and measurement of the important parameters of the solar dryer and the explanation of the control system in the solar dryer.

Thirdly, the chapter of the materials and methods, will describe the methodology of this work and explain the prototype of the solar dryer and its control system.

Fourthly, the chapter of the results and discussion, will illustrate the development of the control system by showing the simulation outcomes and the reach of the objectives.

Finally, a conclusion and the future work chapter will summarize the main points in this work and give an idea about the next step.

Chapter 2: Theoretical fundamentals

2.1.Introduction

Solar drying is a mean of processing certain products. It is used both in the rural and industrial world, through the food and textiles industry. With locally available tools and materials, the solar dryers are easy to build and can operate by natural or forced convection.

Temperature, humidity, solar radiation and wind will affect the performance of the dryer. Nowadays, the drying of wood or agricultural products such as dates, tomatoes, mint, figs etc, of hygroscopic natures, knows an important evolution. A product is said to be hygroscopic when it is likely to lose or regain humidity depending on the characteristics of the air. This hygroscopic nature generates three main vulnerabilities:

- Insect or fungal attacks;
- Defects (shrinkage, cracks, deformation as in the case of wood);
- Processing difficulties and losing nutritional quality for agri-food products;

Drying limits these phenomena and gives the products a certain durability and quality[2].

2.2. History of Solar drying

Drying by exposure to the sun is one of the oldest methods using solar energy, for the preservation of food, such as vegetables, fish, fruits, meat, etc. Since prehistoric times, humanity has used solar radiation as the only source of thermal energy available to dry and conserve all the foodstuffs necessary for the winter, to dry the bricks of the ground for their houses and animal skins for dressage [3].

The first known drying plant was found in the south of France and dated around 8000 BC. It was a surface paved in stone and used for drying crops; natural winds or moderate speeds have been combined with solar radiation to accelerate drying [4]. Various installations around the world have been found between the years 7000 and 3000 BC. There were several combined facilities, natural air circulation, and solar radiation, mainly for drying food. In Mesopotamia have been found sites for solar and air drying of colored textile materials and for solar air drying of written clay plates. The first air-drying facility exclusively for crops was found in the Hindu river valley and is dated to around 2600 BC [4].

The Greek philosopher and the doctor, Aristotle (384-322 BC), who describes in detail the phenomena of drying, gave, for the first time, theoretical explanations of drying. Later, biomass and wood were used to burn primitive ovens to dry building materials, etc., like bricks, but the food was only exposed to direct sunlight [5].

2.3. Drying processes

Several procedures have been developed in our area, namely:

2.3.1. Heat pump drying

Heat pump dryers or dehumidification dryers use only one energy source: electricity. This type of dryer is equipped with a refrigeration unit comprising a cold coil, an evaporator, a hot coil, and a condenser. The heat pump consumes more electrical energy than thermal energy it supplies. There are two processes for heat pump dryers:

- Closed circuit: there is no air exchange with the outside,
- Open circuit: the air exchanger is made with the outside to lower the temperature in the dryer room.

Temperature levels are lower than those of air-conditioned hot air dryers and have longer drying times.

2.3.2. Hot air drying

It is the most commonly used process. It allows, in particular, to work over a wide temperature range reaching 90°C. The humidity is removed from the dryer by air exchange with the outside. The heat contribution can be made directly by a burner or indirectly by heating batteries supplied by hot water, steam, or any other thermal fluid.

2.3.3. Vacuum drying

A vacuum dryer is an airtight enclosure in which the pressure is reduced by a vacuum pump. These are the combined actions of pressure and temperature which will accelerate the circulation of water in the products and intensify evaporation.

Vacuum-drying is, therefore, suitable for heat- and oxygen-sensitive materials. During vacuum-drying, the rate of evaporation increases (at a fixed temperature) since the boiling point of water is reduced. In addition, effective hydraulic conductivity of a material increases under vacuum, so the resistance to mass transfer at the product surface reduces. Vacuum-drying consequently requires less drying time than conventional hot-air-drying and in most cases results in a higher quality dried product [6].

2.3.4. Pre-drying

Pre-drying consists of the start of the artificial drying of the product until the final humidity. Depending on the user's needs, the pre-dried products can be sent to drying cells to reach the desired final humidity level. This technique improves the quality of the products, thanks to a gentle and controlled drying.

2.4. Drying modes

2.4.1. Open-air drying

Drying in the open air or natural drying (so-called traditional) is the oldest method which is carried out by storing the product to be dried, in well-ventilated shelters and sufficiently spaced to allow good air circulation.

This drying method, which does not require any artificial heat source, remains relatively efficient in arid and dry areas. It is suitable for small productions intended for self-consumption or local consumption. Its advantage is that its cost of material is very low, while its disadvantage is that the products remain exposed to the open air, which makes them exposed to dust, insects, and the development of molds due to the recovery of humidity during the night. Also, since the speed of drying depends directly on weather conditions, controlling the duration of drying and the quality of the products to be dried becomes difficult if not impossible.

To remedy these drawbacks, during the night or when it rains, the products can be sheltered under a building or be covered by waterproof fabrics. The evaporation rate can be increased by stirring the products regularly during drying with trays that are not overloaded with products to facilitate air circulation and guarantee uniform drying of the entire product.

2.4.2. Solar drying

Solar drying is an intermediate mode between artificial drying and natural drying. This final drying mode can achieve a lower final humidity than air drying, but relatively higher than artificial drying.

The drying parameters are more controlled than the open air drying but are less accurate than artificial drying. The energy source is the sun which emits solar rays whose wavelengths are essentially between 0.28 µm and 2.5 µm. These rays are then transformed into heat by the absorber which, in turn, transmits radiation in the infrared domain [7].

The table below describes the main advantages and disadvantages of solar and open-air drying [8].

Table 1: Advantages and disadvantages of solar drying and open-air drying (Solar drying - Open air drying)

Solar drying	**Open-air drying**
Advantages	
• Control of the desired final water content • Obtain a quality product • "Free" energy source. • Allows management of the drying process • No risk of attack by insects or fungi • Low to medium cost	• Gentle drying, thanks to the day/night alternation • No qualified personnel required • Low humidity gradient in thickness • Little change in color • No energy expenditure • "Free" energy source
Disadvantages	
• Significant initial investment • Power consumption (if fan) • Operation of the dryer	• Slow drying (penalizing market response time) • Significant losses due to drying defects. • Large occupied area • Risk of attack (insects and fungi) • Difficulty reaching the desired water content

Solar drying systems are generally classified into two major groups, as shown in figure (1):

- Active solar drying systems (often called hybrid solar dryers);
- Passive solar drying systems (conventionally called solar dryers with the natural circulation of drying air).

Depending on the type of dryer and the mode of use of solar energy, four distinct subclasses can be identified for these two active and passive drying systems: direct solar dryers, indirect solar dryers, mixed, and hybrid dryers [9].

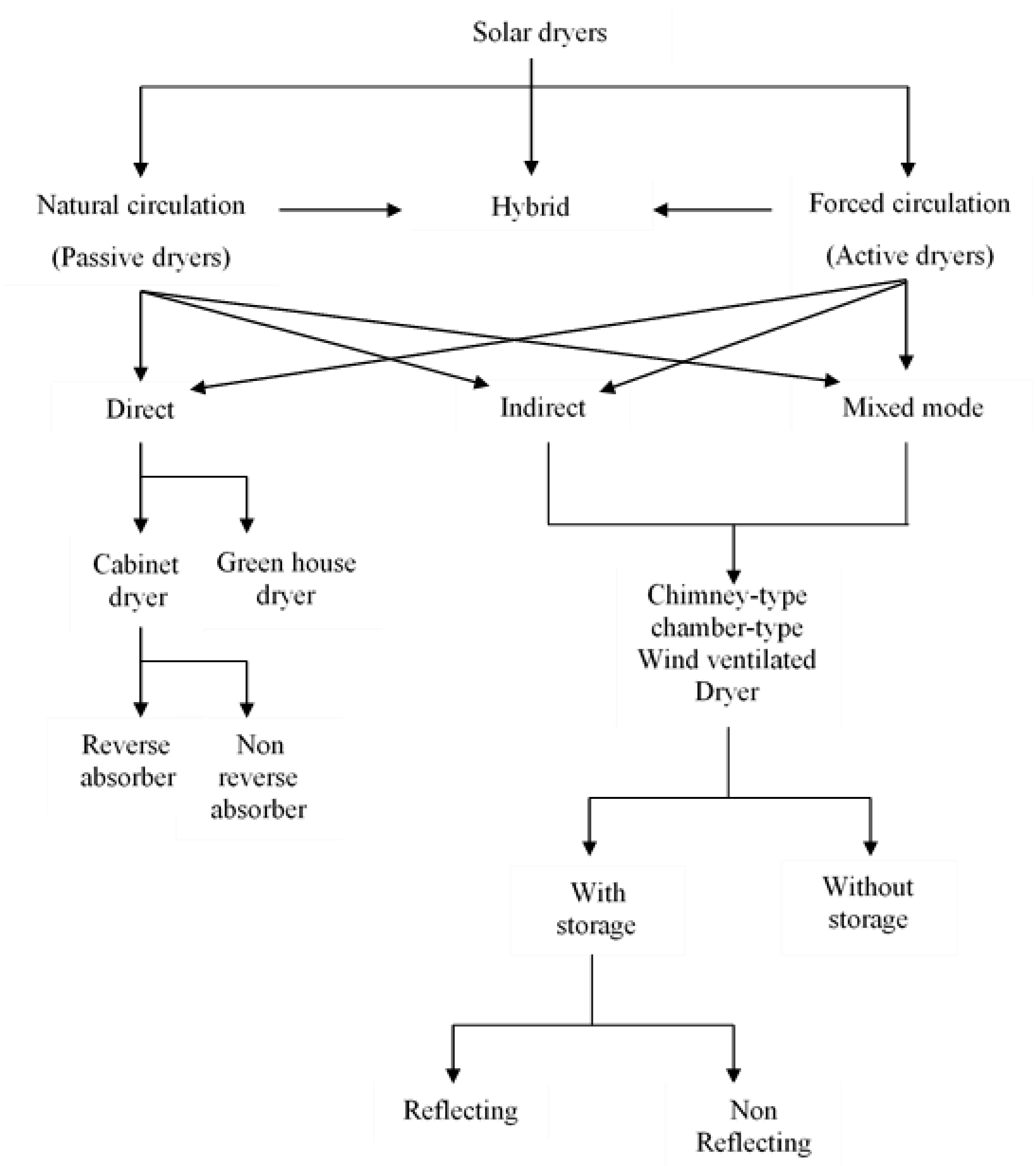


Figure 1: Classification of solar dryers and drying modes (adapted form) [5].

2.4.2.1. Direct solar dryer

Direct solar drying, simple in design, uses direct sunlight to dry products. It is simple to make. They are generally simple and robust constructions of a glazed frame where the glazing is used to increase the greenhouse effect.

Air circulation is through the dryer by natural draft due to heating (chimney effect) or by the action of the wind on the openings or using a fan, due to the simplicity of the models.

This type of drying has two advantages:

- The products are better protected from attack by flies and other insects;
- They are subjected to a greenhouse effect in the same way as a flat sensor absorber, resulting in an improvement in the radiation balance and a rise in the temperature of the product to be dried, which makes it possible to significantly reduce drying times by compared to traditional systems.

2.4.2.2. Indirect solar dryer

Products to be dried are not exposed to direct sunlight. They are arranged on racks inside an enclosure or a room in relation to the importance of the quantities of products to be dried. Fresh air is admitted to the drying chamber after passage through air sensors or another preheater which heats it according to the flow used.

This type of dryer is often more complicated and more expensive to build than the direct dryer. It can be carried out on various scales, and it is mainly used for products very sensitive to solar radiation or whose temperature level must be controlled, such as agricultural products such as fruits and vegetables whose appearance, color, and nutritional and taste quality must be better preserved.

As a principle of operation, this type of dryer generally consists of two parts: a collector which converts solar radiation into heat; and a drying chamber which contains the product to be dried. Air enters the collector which heats up; its temperature increases and, by natural convection, the heated air rises to the drying chamber to dry the product. The drying time remains very variable depending on weather conditions and the ventilation of the dryer.

2.4.2.3. Mixed dryers

In this type of dryer, the heat necessary for drying is supplied by the combined action of solar radiation directly affecting the products and air preheated in collectors.

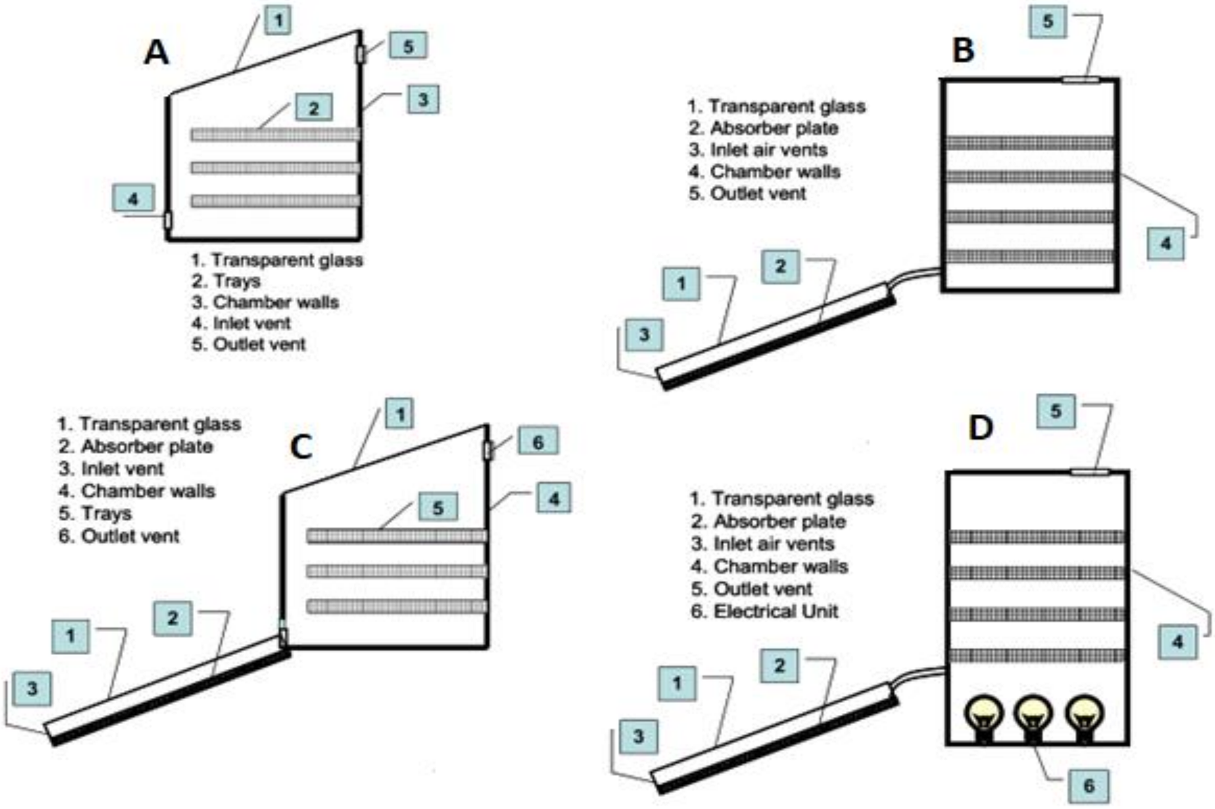


Figure 2: Schematic of (A) Direct solar dryer (B) Indirect solar dryer (C) Mixed solar dryer and (D) Hybrid solar dryer [10].

2.4.2.4. Hybrid dryers

Solar drying shows its limits and disadvantages despite the improvements made. The drying process remains difficult to control since it largely depends on weather and climatological conditions. Also, adding moisture at night leads to prolonging the drying time and exposing products to microbial attack. Hybrid dryers are developed for products requiring large capacities and to overcome these drawbacks by using fuel such as gas, wood or diesel: which are used to maintain a constant temperature inside the dryer whatever climatological conditions, solar energy becomes secondary in this case, the increase in air circulation is done through electric fans. This type of dryer which guarantees an increase in productivity, better control, a continuity of drying during the night and during all seasons; also represents certain disadvantages such as the need for qualified personnel for maintenance and its cost of production and investment which remains high [11].

2.5.Models of indirect solar dryers

In this part, some examples of indirect solar dryers made and tested around the world will be described:

2.5.1. Direct effect dryers

2.5.1.1. Tunnel solar dryer

This model of dryer mainly dedicated to food production is produced in collaboration with Hohenheim University and INNOTECH Engineering Ltd in Germany [12]. It is intended mainly for the tropical and subtropical regions and is in commercial exploitation in one-hundred countries all over the world.

The prototype solar tunnel dryer was modified by the attachment of a supplementary heating unit as shown in figure (3) to facilitate the continuous operation. The Tunnel dryer uses photovoltaic cells to power the fans and thus to circulate the air in the drying area. The fan can significantly reduce the drying time. Air circulates through an area generally painted black (collector area) to absorb heat from the sun and passes through the trays which contain the products intended to be dried. The heating unit was fabricated consisting of a combustion chamber, heat exchanging bottom plate, removable roof and a chimney. This unit was installed between the collector and the drying section of the proto-type solar tunnel dryer. In this design, the width of the bottom plate equals the width of the dryer. The thickness of the bottom plate was taken as 4mm. Design calculation was carried out to select the optimum length of the bottom plate in order to transfer required thermal heat to evaporate the moisture of the product in the drying chamber per unit time.

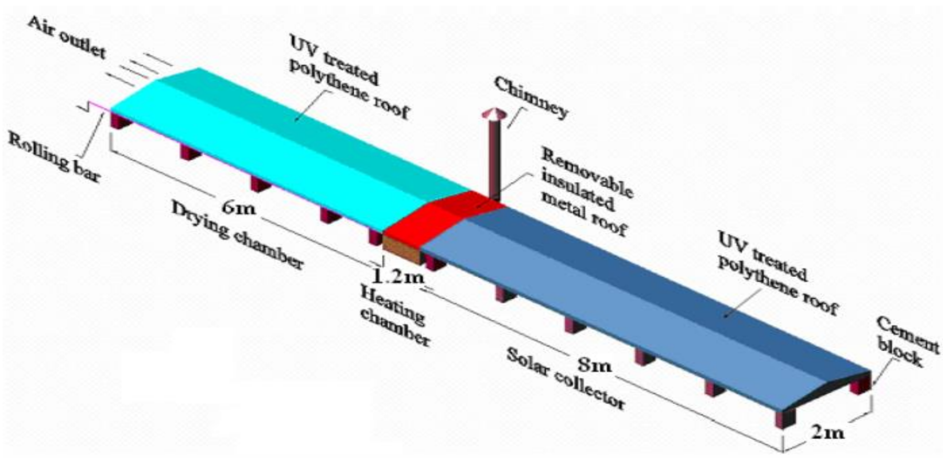


Figure 3: Schematic diagram of the solar tunnel dryer [13].

The technical data of the Tunnel dryer summarized in Table 2:

Table 2: Technical characteristics of the INNOTECH Engineers tunnel dryer company.

Technical characteristics	
Length	18 m
Width	2 m
Area	16 m²
Drying surface	20 m²
Airflow	400 to 1.200 m^3/h
Air temperature	30 to 80°C
Power requirement	20 to 40 W
Fan operation	Photovoltaic solar panel

2.5.1.2. The Twelve Trades dryer

This type of dryer described in figure (4) is designed for food products by an organization based in Holland which invests in the development and information of alternative technical and ecological solutions. The assembly of the dryer is adapted to the climatic conditions of the northern region of Europe, taking into account an angle of inclination of 58°, determined by the average position of the sun in spring, summer, and early autumn. The air is heated by convection and by radiant heat from the aluminum plates painted black, positioned behind the glass which also serves as a support for the racks. A 10 cm opening at the top of the box allowing hot air to enter it. On the back wall opposite the glass, there is a partition with a 10 cm opening to breathe the cool and cool air out of the box using the chimney flue located at the top of the box. The chimney pipe is approximately one meter in length. The Plexiglas tube is isolated from the internal black tube. The box is built-in concrete-plex (plastic multiplex) and is mounted on a mobile table. The largest support located at the bottom is 100 cm x 110 cm, and the smallest support located at the top is 55 cm x 110 cm.

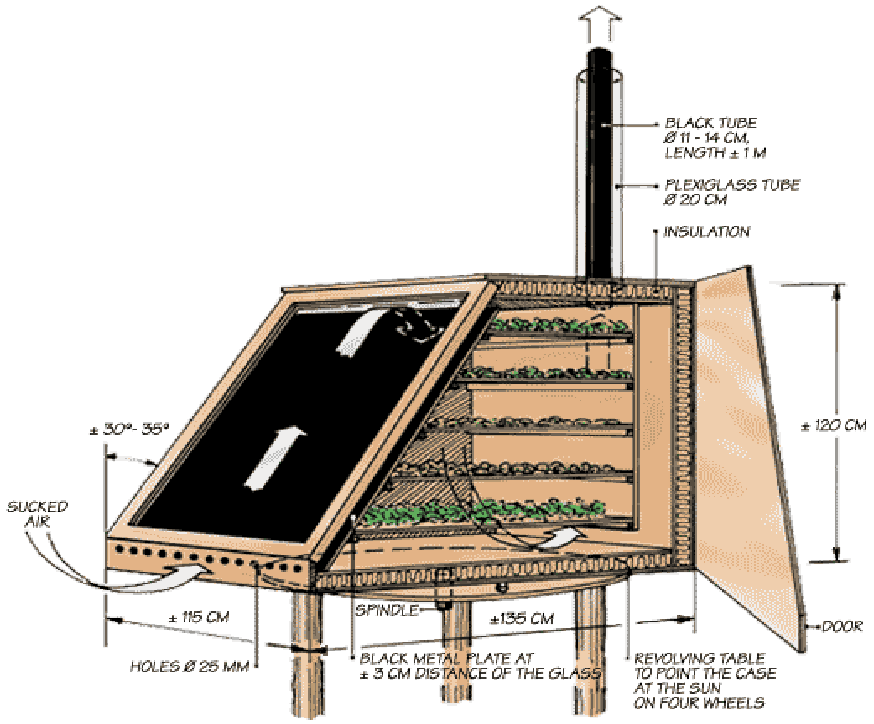


Figure 4: The Twelve Trades dryer [14].

2.5.2. Indirect effect dryers

For this type of dryer, the products are placed in an insulated room as is the case with artificial dryers. The solar collectors are separated from the drying chamber, which makes it possible to optimize the collection surface without being linked to the dimensions of the drying chamber. The heat transfer between the collectors and the drying chamber takes place via the heat-insulated ducts. This category of dryers allows better insulation of the drying chamber thus minimizing heat losses.

2.5.2.1. Mohanraj and Chandrasekar 's dryer

Mohanraj and Chandrasekar designed, manufactured, and tested a forced dryer in indirect mode for drying copra. As indicated in figure (5), It consists of a solar collector, a fan and a solar drying cabinet.

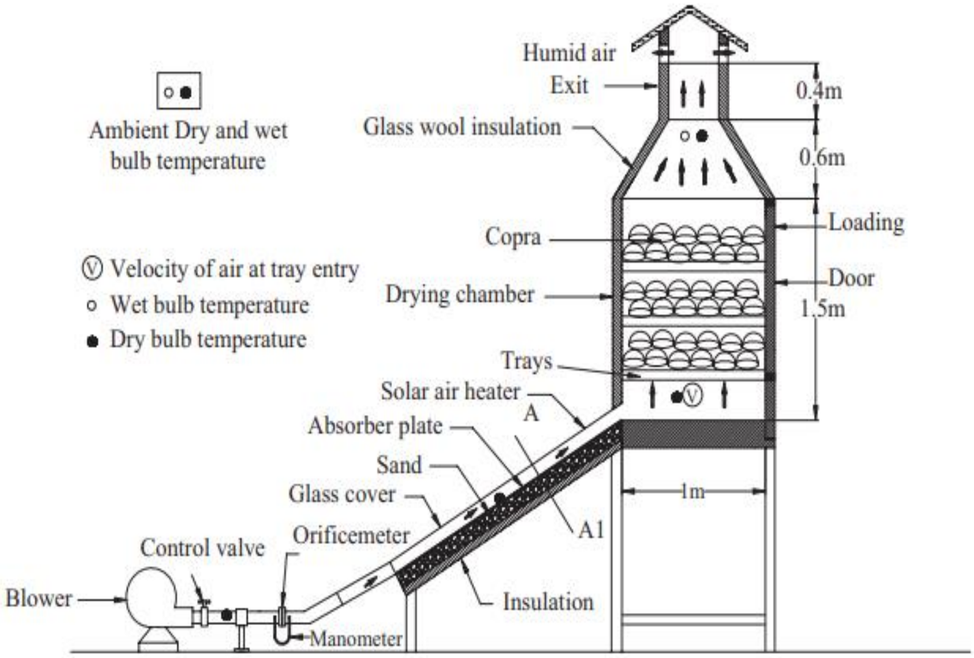


Figure 5: Schematic view of the solar drier used for copra drying [15]

2.5.2.2. ICARO 1.5 dryer

This category of dryers, designed in 2012, is part of the group of solar dryers with indirect light and forced ventilation. These models are characterized by the fact that the forced ventilation energy is supplied by a photovoltaic panel and therefore the unit is therefore completely self-sufficient with regard to energy.

The Icaro 1.5 model is constructed from a 2.44 x 1.22 m sheet. Icaro type dryers have been studied so that they can be made in Africa by craftsmen, taking into account locally available materials, and even a construction technique adapted to moderately equipped metal carpentry workshops figure (6). The products dried by this type of dryer are of an agri-food nature (meat, medicinal herbs, fruit, and vegetables)

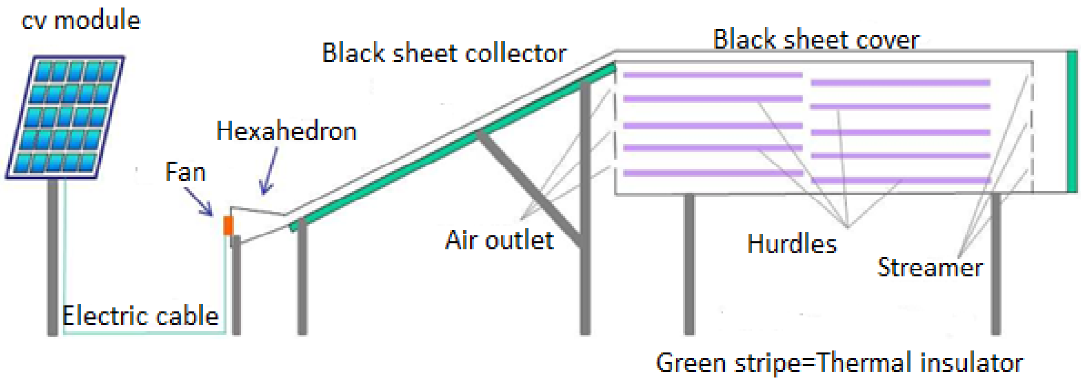


Figure 6: ICARO I.5 dryer model [16]

The Icaro dryer satisfies a number of conditions to guarantee optimal drying:

- Drying out of the sun to have a brighter product color similar to that of the fresh product and high vitamin content
- Complete energy self-sufficiency
- Possibility of moving the unit to the production sites and using them on-site to also avoid loss of product due to heat during transport
- Good drying capacity
- Moderate price

2.6. Relevant state variables influencing solar drying

Solar drying obeys energy and thermal exchanges between the product and the outside environment. Taking these parameters into account makes it possible to produce models describing in a precise manner the behavior of solar dryers and the evolution of water in the product to be dried [8]. These variables are:

2.6.1. Temperature

The drying air temperature is dry temperature. It follows a diurnal oscillation, and its amplitude varies from one place to another according to the seasons: it is greater for continental regions than coastal, it decreases with latitude and increases in the case of a very overcast sky.

Air temperature greatly influences the drying speed. This influence is due to the addition of heat to the product which increases with the air temperature. It is also due to the temperature of the product which is all the more important as the air temperature is high. Consequently, the diffusion rates of water in the product increase with temperature.

2.6.2. Air humidity

This state variable represents the relationship between the partial pressure Pv and the saturation vapor pressure, Pv-sat. The relative air humidity is 100% when the air is saturated. But unlike relative humidity, absolute humidity corresponds to the mass of water vapor contained by 1 kg of dry air, it is then expressed in kg of water vapor per kg of dry air. During the drying process, it is essential to be able to quantify the humidity contained in the air inside the solar dryer, to follow its evolution, and to know how to regulate its level.

The water content of the air plays an important role in the behavior of the drying kinetics of the products to be dried. As with airspeed, this influence is greater at the start of drying and decreases when the air temperature increases. Experiments show that humidity circulates from a wet region to a dry region perpendicular to surfaces of equal humidity [17].

2.6.3. Pressure

As mentioned, moist air is a mixture of dry air and water vapor. The pressure of the mixture of moist air is only the sum of the partial pressure of dry air Pa and the partial pressure of water vapor Pv. When the air contains a maximum amount of water vapor at a given temperature, the saturation vapor pressure will be used, Pv-sat. The vapor close to the drying surface of the product is at the saturated vapor pressure at the surface temperature (in the first drying phase).

The difference between these two pressures is one of the motor terms promoting the evaporation of water from the product called evaporative power.

2.6.4. Air velocity

Air velocity is characterized by the movement of a mass of air, which is produced by the force of the pressure gradient (high pressures to low pressures). For constant values of temperature and relative humidity, drying is accelerated by increasing the speed of the air on the surface of the product to be dried. Low air velocity causes low evaporation. Indeed, if there is no movement around the product, a layer of saturated air will be created which will stop the exchange of moisture from the product to the air.

Generally, at the start of the drying operation, the airspeed acts very positively when it comes to removing free water, while during the last drying phase the airspeed has a weak influence. Hence the interest in some cases of variable speed fans, with the possibility of high speed at the start of drying and a lower speed towards the end of drying, which results in energy savings with efficient drying.

Having listed the necessary parameters to control the drying process, it is now necessary to choose the suitable materials and methods to achieve an optimal drying process. These will be explored in the next chapter.

2.7. Dried Figs

Dried figs represent an important harvested, with manufacturing between 1.14 million tons. North Africa, Mediterranean Europe and Central Asia are the most important producers of dried figs, whilst Turkey is the biggest producer in the world. Spain exports extra than 4500 tons of dried figs yearly [18].

In Portugal, the region of fig cultivation is approximately 7100 hectares and its total national production is about 2150 tons. The areas of biggest manufacturing are in Algarve, Trás-os-Montes and Torras Novas. Lampos figs are normally produced in less bloodless wintry weather regions, whilst harvested figs are, in general, greater produced in places with colder weather. The region of Mirandela, where the figs used for drying in our control system of the solar dryer, is positioned in the northern place of the country, however harvesting each type of figs [19].

Fruits used for drying are left on the trees until they attain full ripeness. In the traditional technique of drying in the sun, each semi-dried fig is collected and placed in wooden trays. Each fig is periodically becoming from side to aspect till its moisture content reaches 24%. The last product is relatively preferred by means of buyers due to its high-quality dietary value, as it is rich in nutritional vitamins A, B1, B2, fiber, fundamental amino acids and minerals such as iron, calcium and potassium. However, the lengthen in the drying process, relying on local weather changes, can negatively affect the exceptional of the fruit due to the growth and proliferation of microorganisms and nutritional losses. Therefore, the largest trouble in drying figs is the presence of fungi, which are in a position to develop underneath low humidity conditions, and can cause the fruit to deteriorate, such as loss of flavor, discoloration, decomposition and above all, manufacturing of mycotoxins [20]

There are two types of figs produced during the year, the lampos, which are harvested from mid-May to June, and the vintage figs, which are harvested in September and October. The figs that will be dried are the vintage type, as they are smaller and less juicy, less attractive on market shelves. That is why these fruits are dried, which are sold at higher prices and stored for longer and more easily than fresh figs. Currently drying is done in a rudimentary way.

There are many important attributes that determine the quality of dehydrated foods, which cover four groups: physical, chemical, microbial and nutritional characteristics. For dried figs, the most important criteria are high amounts of sugar, low acidity, thick skin for the production of dry figs with a light color, light texture and high concentrations of sugar. Furthermore, for the sale of dried figs, visual appeal, organic characteristics and chemical properties, in addition to food safety, are the key quality parameters as in other dried fruits [18]. The standard indicated for the commercialization of dried figs indicates that the humidity of this food cannot exceed 26% for figs without pretreatment and 26-40% of humidity for figs with pretreatment.

The world market for dried figs is currently dominated by products obtained through solar drying. Evidently, drying parameters such as air speed, temperature and relative humidity, as well as drying time, affect the final quality of the dry product [18]. All fig drying parameters used from the previous work of the design of the indirect solar dryer are shown in table 4, which will be fixed in the studied control system:

Table 3: Dried figs parameters [21]

Parameter	Value
Amount of moisture to be removed from the food (m_w)	18.48 kg
Initial food mass (m_p)	25 kg
Initial food moisture (M_i)	80%
Final moisture of the food (M_f)	24%
Initial drying relative humidity (RH_i)	30%
Final drying relative humidity (ERH)	67.22%
Initial drying temperature (T_{si})	55°C
Final drying temperature (T_{sf})	29°C
Drying time (t_d)	16 hours
Wind speed (v)	2.22 m/s
Air density (ρ)	1.16 kg/m³

Among so many considerations involved in drying figs, perhaps the most important is ensuring that dry food can be stored for 6 to 8 months. The drying process must be done without impairing its ability to be safely consumed after storage. To ensure consumer safety, dry products must be free from chemical contamination and bacterial and fungal infestation [18].

2.8. Control system

The control system has to manage the circulation of air in order to obtain the highest drying rate available at the existing conditions, such as irradiation, ambient temperature and humidity as well as exhaust temperature and humidity [9]. The control system is a system which consist of number of components connected together to perform a specific function, in which the output is controlled by input.

2.8.1. Classification

Control systems can be classified based on some parameters, into the following ways:

- Continuous-time and Discrete-time Control Systems
- SISO (Single Input Single Output) and MIMO (Multiple Input Multiple Output) Control Systems
- Open Loop and Closed Loop Control Systems

The differences between the open loop and the closed loop control systems are mentioned in the following table.

Table 4: The difference between the open loop and the closed loop system.

Open Loop Control Systems	Closed Loop Control Systems
Control action is independent of the desired output	Control action is dependent of the desired output
Feedback path is not present	Feedback path is present
These are also called as non-feedback control systems	These are also called as feedback control systems
Easy to design	Difficult to design
These are economical	These are costlier
Inaccurate	Accurate

2.8.2. Internet of Things (IoT)

Internet of Things (IoT) describes the network of physical objects, is made up of sensors, software and other technologies connected together and exchanging data with other devices and that support one or more common ecosystems, and can be controlled via devices associated with that ecosystem, such as smartphones and smart speakers. The most important utilities that are achieved by the IoT applications are monitoring and consequently immediate decision making for efficient management.

The Internet of things technology has evolved because of the convergence of multiple technologies, real-time analytics, machine learning, and embedded systems such as the wireless sensor networks, control systems, automation [22].

Chapter 3: Materials & methods

3.1.Description of Dryer

In this chapter, the control system of an indirect solar dryer will be designed. The prototype is based in the natural air circulation and it is similar to the principle of the Twelve Trades dryer, which is described in the previous chapter.

This type is composed by three parts, as shown in the figure (7), the first part is the collector which converts solar radiation to heat; the second part is a drying chamber which contains the product to be dried; and the last part is the chimney which facilitating the natural flow of moist air.

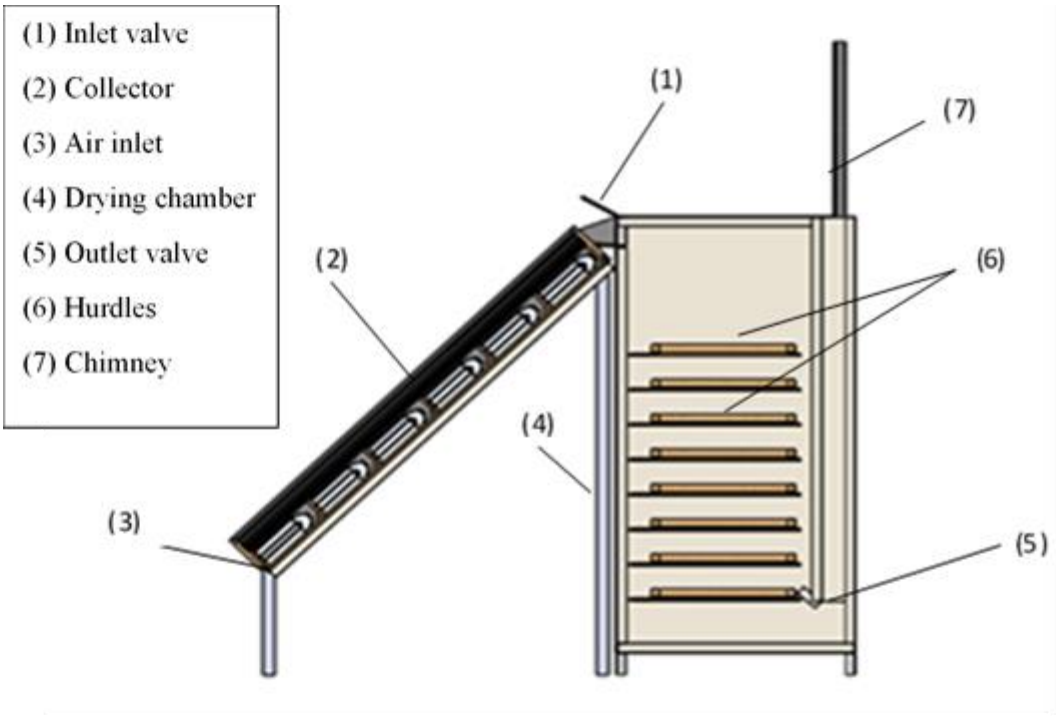


Figure 7: Prototype of the indirect solar dryer [21]

The drying process consists of three steps: the first step, the air enters to the collector, which heats up, its temperature increases by natural convection, the heated air rises to the drying chamber; the second step, the heated air enters to the drying chamber to dry the product through the front opening connected to the collector, then, the already heated air enters and is forced to descend absorbing moisture from the food during the process. The air, which collects a lot of moisture on its descent, is denser and descends to the tunnel below the shelves and trays that are connected to the chimney; in the last step; the colder and humid air tends to rise through the tunnel connected to the chimney due to the decrease in the hydraulic diameter of the air path. To assist in drawing the chimney, it is painted black to absorb more heat, promoting a depression at the top of the chimney, facilitating the natural flow of moist air.

The control of the air temperature entry to the drying chamber is needed to optimize the drying process, there is a valve between the collector and the drying chamber. And, for air flow control, there is a valve at the end of the chimney, it is important to close the chamber and control the air flow needed to improve the drying.

3.2.Measurements and control system

For this prototype, several parameters will be determined to control the drying process and evaluate the moisture of the dried product, namely, the temperature, humidity, pressure and the air velocity.

The temperature is going to be measured in different locations as following: outside air temperature T_{out}, solar collector exit $T_{coll.exit}$ (inlet to drying chamber), and tunnel dryer exit $T_{d.exit}$. In the same locations, the humidity will be measured: outside air humidity H_{out}, solar collector exit $H_{coll.exit}$ and tunnel dryer exit $H_{d.exit}$, also the pressure will be determined in the drying chamber in two points A ($P_{ch.A}$) and B ($P_{ch.B}$) in different altitude to calculate the air velocity.

These parameters will be controlled by the entry of the fresh air from the inlet valve, which exist between the collector and the drying chamber, and the exit of air from the outlet valve, which located in the chimney. For each parameter, a specific sensor will be used, which is related to a microcontroller to treat the data then will be send it to the software by the communication module.

The use of ESP8266 or ESP32 or any other Wi-Fi Modules to send any sensor data to the Internet wirelessly. Hence Wi-Fi comes into action and thus, then needed Wi-Fi Connection for wireless communication with any server. But the disadvantage of using Wi-Fi is that it is not available everywhere. The Wi-Fi signal is limited to certain locations and to a certain range up to a few meters or the solar dryer can be located anywhere and outside the Wi-Fi signal. So, GSM network is the only alternative left as per the present scenario and current technology. GSM/GPRS Module allows to add data to the application. The big advantage of GSM/GPRS connectivity is that it covers a wide area and signal/connectivity is available almost everywhere.

3.3.Hardware

3.3.1. Arduino UNO Board: A Data processing Board

Arduino Uno is an excellent choice for any IoT design. It can except and carve programs according to the needs and able to form interface type circuits to interpret switches and added sensors. Arduino based on microcontrollers tender's flexibility and prevails one board computer that endows with an effective way for coding and circuit interface, creating to comprehend switches and diverse type of sensors. Below Figure (8) shows the Arduino UNO that encloses 'ATmega328' and bestows a serial communication.

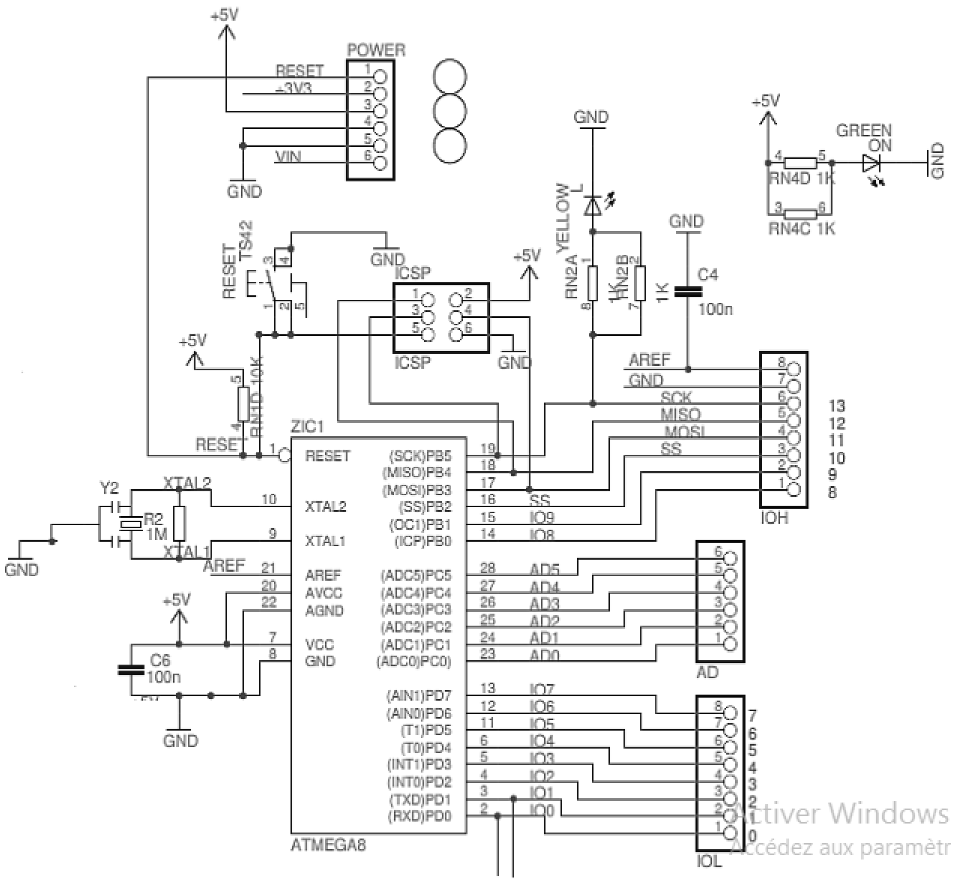


Figure 8: Architecture interne of Arduino UNO Board [23]

Arduino UNO has an internal boot loader that permits uploading of most recent code devoid of using any type of exterior hardware programmer. The coding is done utilizing Arduino programming language (APL) that tenders wiring and the Arduino development environment (IDE) that tenders processing. Users Entail connecting microcontroller to a computer with a USB cable or peripheral AC to DC power adapter or a battery power. Some of the features of Arduino Uno relevant to this project are reported in the below Table (5).

Table 5: Arduino UNO R3 features [23].

Arduino UNO Features	
Microcontroller	ATmega328P
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20 Ma
DC Current for 3.3V Pin	50 Ma
Flash Memory	32 KB (ATmega328P) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328P)
EEPROM	1 KB (ATmega328P)
Clock Speed	16 MHz

3.3.2. Sensors

A sensor is a device whose purpose is to detect and measure a physical parameter and converts into a signal which can be measured electrically, then, it will in turn be translated into binary data that can be used and understood by a system of information. To choose a sensor, there are several criteria can be considered as following [24]:

- Accuracy
- Environmental conditions (usually has limits for temperature/humidity)
- Cost
- Range (measurement limit of sensor)

3.3.2.1. Temperature Sensor and Humidity Sensor

The DHT22 (also known as AM2302) is digital temperature sensor not only measures temperature but also relative humidity, its little brother the DHT11. It contains a chip which has analog to digital conversion capabilities and produces a digital signal with the 2 measurements. This is one of the most popular temperature sensors available due to its high performance and long-term stability.

The DHT22 / AM2302 sensor is capable of measuring temperatures from -40 to + 125°C with an accuracy of +/- 0.5°C and relative humidity levels from 0 to 100% with an accuracy of +/- 2% (+/- 5% at the extremes, at 10% and 90%). A measurement can be performed every 500 milliseconds (i.e. twice per second).

The DHT11 sensor is capable of measuring temperatures from 0 to + 50°C with an accuracy of +/- 2°C and relative humidity levels of 20 to 80% with an accuracy of +/- 5%. A measurement can be made every second.

The DHT22 and the DHT11 are both compatible 3.3 volts and 5 volts (the manufacturer however recommends always supply the sensor with 5 volts to have precise measurements). They also have the same wiring and the same communication protocol. To summarize, here are the characteristics of the two sensors in the form of a comparison table:

Table 6: Comparison between DHT22 (AM2302) and DHT11

	DHT22 / AM2302	**DHT11**
Relative humidity %	0 ~ 100 %	20 ~ 80%
Accuracy (humidity)	+/- 2% (+/- 5% at extremes)	+/- 5%
Temperature	-40 ~ +150°C	0 ~ +50°C
Accuracy (temperature)	+/- 0.5°C	+/- 2°C
Frequency Max measurement	2 Hz (2 measurements per second)	1 Hz (1 measurement per second)
Supply voltage	3 ~ 5 volts	3 ~ 5 volts
Long term stability	+/- 0.5% per year	+/- 1% per year

The DHT22 is clearly much more precise and stable than the DHT11. But it is also twice as expensive. The choice, therefore, comes down to a question of balance between budget, precision, and speed of measurement. In the present study, the DHT22 was chosen because of its precision in the measurement of temperature and humidity to control the drying process. The figure (9) shows the wiring of the DHT22 sensor with the Arduino UNO.

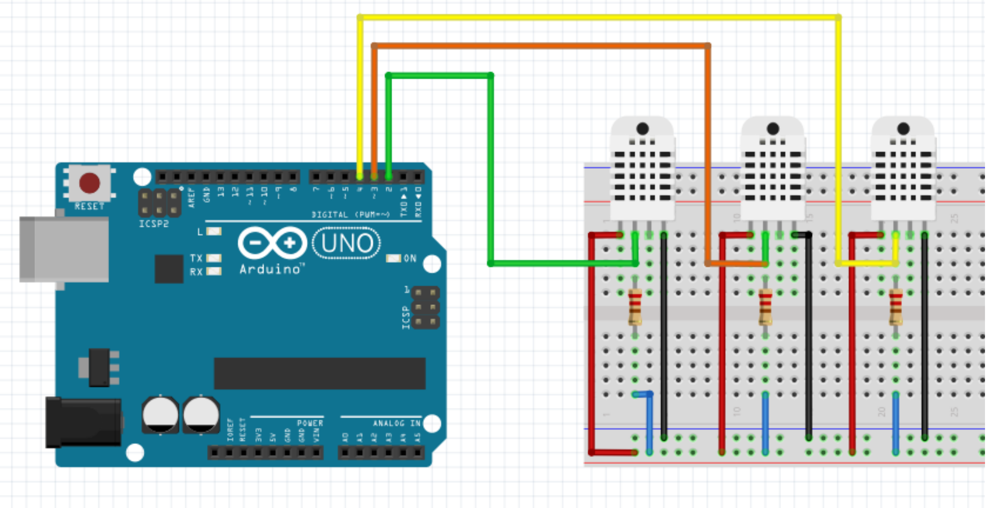


Figure 9: Wiring the DHT22 sensor with the Arduino UNO

3.3.2.2. Pressure sensor (BMP280)

As the successor to the widely adopted BMP180, the BMP280 delivers high performance in all applications that require precise pressure measurement. The BMP280 operates at lower noise, supports new filter modes, and an SPI interface within a footprint 63% smaller than the BMP180.

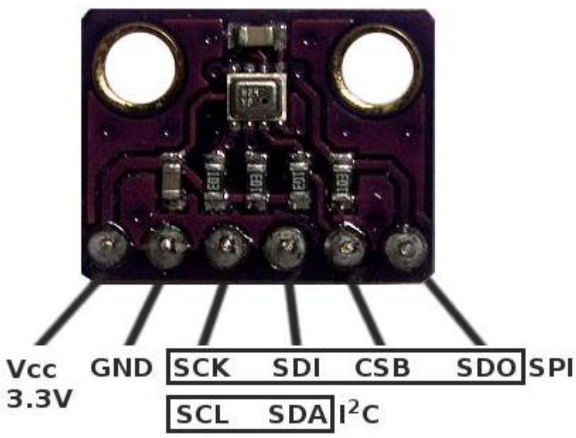


Figure 10: BMP280 Pressure sensor [25].

The BMP280 pressure sensor is the best low-cost detection solution for measuring atmospheric pressure. Because the pressure changes with altitude, also it can be used as an altimeter. It is able to measure pressure from 300 hPa to 1100 hPa with an accuracy of +/-

1hPa and measuring temperature from -40 to +85°C with ±1.0°C accuracy. The BMP280 is compatible 3.3 volts. It can interface with the digital interfaces I²C (up to 3.4 MHz) and SPI (3 and 4 wire, up to 10 MHz) [26].

Table 7: Comparison between BMP180 and BMP280

Parameter	BMP180	BMP280
Footprint	3.6 × 3.8 mm	2.0 × 2.5 mm
Minimum VDD	1.80 V	1.71 V
Current consumption @3 Pa RMS noise	12 µA	2.7 µA
Pressure resolution	1 Pa	0.16 Pa
Temperature resolution	0.1°C	0.01°C
Interfaces	I²C	I²C & SPI (3 and 4 wire, mode '00' and '11')
Measurement modes	Only P or T, forced	P&T, forced or periodic
Measurement rate	up to 120 Hz	up to 157 Hz
Filter options	None	Five bandwidths

To calculate the atmospheric pressure in different point in our solar dryer, two BMP280 sensors were used, then these parameters will be used for the calculation of the air velocity by using the Bernoulli's equation (eq.1). For wiring two BMP280 sensors with the digital interfaces I²C, it's important to use an analogue multiplexer because there is only two wire for read the SDA (Serial Data) and SCL (Serial Clock) in the Arduino UNO.

3.3.2.2.1. 74HC4052 Analogue Multiplexer/demultiplexer

The 74HC4052 is a dual single-pole quad-throw analog switch (2x SP4T) suitable for use in analog or digital 4:1 multiplexer/demultiplexer applications. As present in Functional diagram figure (11), each switch features four independent inputs/outputs (nY0, nY1, nY2 and nY3) and a common input/output (nZ). A digital enable input (E) and two digitals select inputs (S0 and S1) are common to both switches. When E is HIGH, the switches are turned off. Inputs include clamp diodes. This enables the use of current limiting resistors to interface inputs to voltages in excess of VCC.

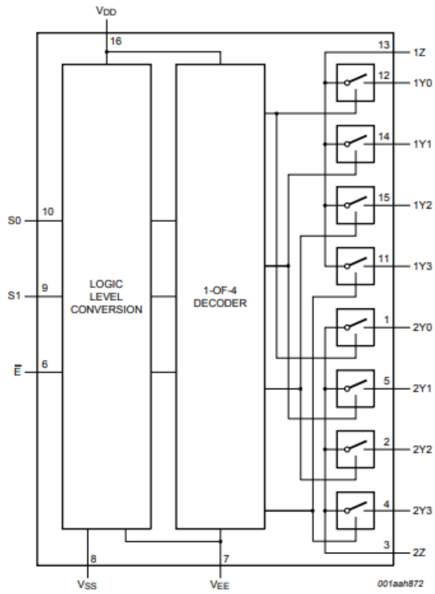


Figure 11: Functional diagram [27]

The table 8 present the functional description for used the input pin of the 74HC4052 multiplexer.

Table 8: Function table of 74HC4052 Multiplexer.

Input			Channel on
E	S1	S0	
L	L	L	nY0 and nZ
L	L	H	nY1 and Nz
L	H	L	nY2 and nZ
L	H	H	nY3 and nZ
H	X	X	None

The figure bellow indicates the wiring of two BMP280 pressure sensor with the Arduino UNO board through the 74HC4052 analogue multiplexer.

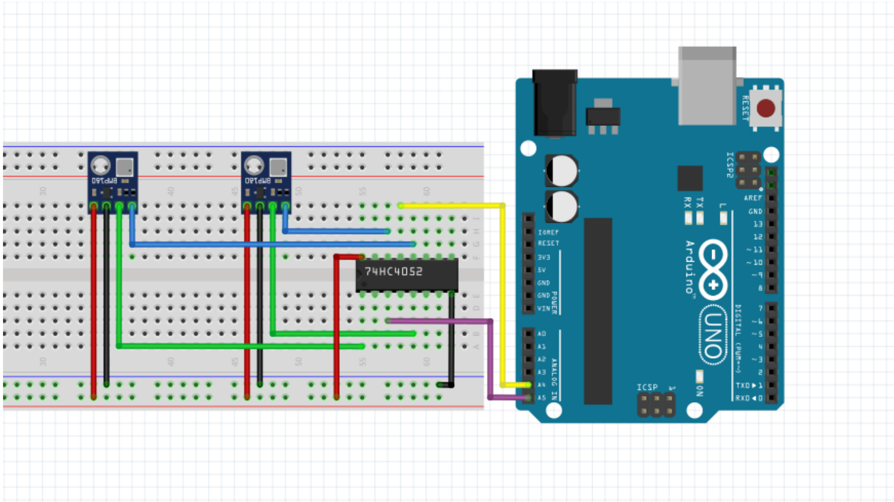


Figure 12: Wiring Two BMP280 pressure sensor with the Arduino UNO

3.3.2.2.2. Air velocity calculation

Bernoulli's equation relates the pressure, speed, and height of any two points (1 and 2) in a steady streamline flowing fluid of density. Bernoulli's equation is usually written as follows in the equation 1.

$$P_1 + \frac{1}{2}\rho V_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho V_2^2 + \rho g h_2 \qquad \text{(eq.1)}$$

The variables P_1, V_1, h_1 refer to the pressure, speed, and height of the fluid at point 1 ,which where the first BMP280 sensor will be fixed, whereas the variables P_2, V_2, h_2 refer to the pressure, speed, and height of the fluid at point 2, which where the second BMP280 sensor will be fixed. The air velocity was calculated using equation 2.

$$(V_1 - V_2) = \sqrt{2 * g * (h_2 - h_1) + \frac{2}{\rho}(P_2 - P_1)} \qquad \text{(eq.2)}$$

3.3.3. Actuator

An actuator is a device that converts energy, which may be electric, pneumatic, hydraulic, etc., to mechanical in such a way that it can be controlled. The quantity and the nature of input depending on the kind of energy to be converted and the function of the actuator. The output is always mechanical energy.

- **Servo Motor**

Servo motors are DC motors with built-in feedback circuits so that the positions of their shaft can be controlled accurately. These motors have three terminals: power, ground, and control. The control terminal is driven with PWM (Pulse Width Modulation) waveform usually with a period of 20 ms (50 Hz). In this project, the small DS32118 servo motor was used, as shown in figure (13).

Figure 13: Servo motor DS3225

Some of the Specification of this servo relevant in this project presented in the table (9).

Table 9: DS3225 Specification

DS3225 Specification	
Operating voltage range	4.8-6.4V
Operating frequency	50-330Hz
Operating speed	0.15 sec/60 degree
Stall torque (5v)	22kg/cm
Pulse width range	500~2500 µsec
Waterproof performance	IP66

3.3.4. GSM/GPRS module

SIM900A Quad-band GSM/GPRS RS232 modem works on frequencies 850 MHz, 900 MHz, 1800 MHz, and 1900 MHz. It is very miniature in size and easy to use it as a plug-in GSM modem. The modem is designed with TTL to RS232 level converter circuitry, which will allow the user to directly interface PC serial port. The baud rate can be configurable from 9600-115200 through AT command [28].

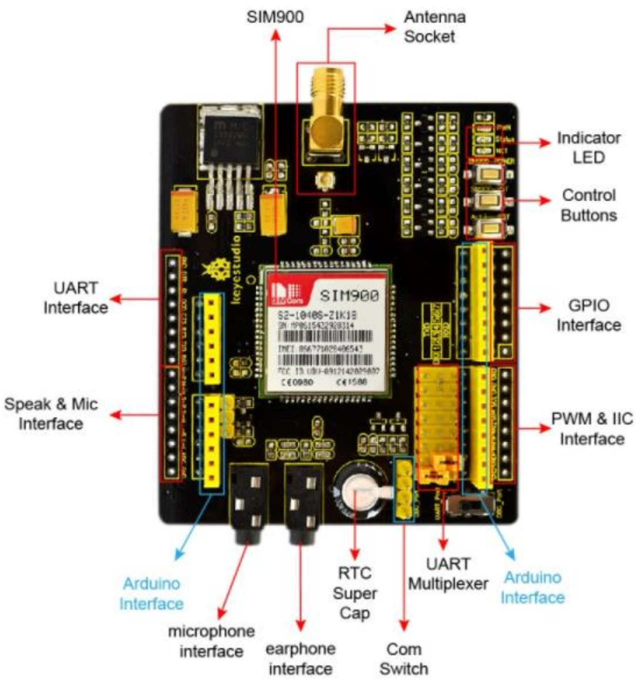


Figure 14: SIM900A GSM/GPRS Module

Initially, Modem is in auto baud rate mode. This GSM/GPRS RS232 modem has an internal TCP/IP stack which will enable the user to connect with internet via GPRS. It will be suitable for sending SMS as well as DATA transfer application in the M2M interface. The modem needed only 3 wires (TX, RX, and GND) except power supply to interface with microcontroller/Host PC. The built-in low dropout linear voltage regulator will allow the user to connect a wide range of unregulated power supply (4.2V -13V). In most cases, 5 V will be used. Sim900a GSM/GPRS module which was used in this project as presented in the figure (14) and the table (10) presents its features.

Table 10: GSM/GPRS Module features and specifications

FEATURES	
• High Quality Product (Not hobby grade) • Quad-Band GSM/GPRS 850/ 900/ 1800/ 1900 MHz • Built in RS232 Level Converter (MAX3232) • Configurable baud rate • SMA connector with GSM L Type Antenna. • Built in SIM Card holder	• Built in Network Status LED • Inbuilt Powerful TCP/IP protocol stack for internet data transfer over GPRS. • Audio interface Connector • Most Status & Controlling Pins are available at Connector • Normal operation temperature: -20°C to +55°C • Input Voltage: 5V-12V DC
SPECIFICATIONS	
• GPRS mobile station class B • Compliant to GSM phase 2/2+ - Class 4 (2 W @850/ 900 MHz) - Class 1 (1 W @800/1900MHz) • Control via AT commands (GSM 07.07 ,07.05 and SIMCOM enhanced AT Commands) • Low power consumption: 1.0mA (sleep mode) • Operation temperature: -40°C to +85°C ➢ Interfaces • Analog audio interface pins at 2mm Pitch RMC • RS232 Serial interface • SMA Antenna Connector ➢ Compatibility • AT cellular command interface	➢ Specifications for Data • GPRS class 10: max. 85.6 kbps (downlink) • PBCCH support • Coding schemes CS 1, 2, 3, 4 • USSD • PPP-stack ➢ Specifications for SMS via GSM/GPRS • Point to point MO and MT • SMS cell broadcast • Text and PDU mode Software features • 0710 MUX protocol • embedded TCP/UDP protocol • FTP/HTTP ➢ Special firmware • MMS • Java (cooperate with Iasolution) • Embedded AT

3.4.Software

3.4.1. Arduino (IDE)

Arduino IDE (Integrated Development Environment) is open-source programming that is predominantly utilized for composing and assembling the code into the Arduino Module. It is an authority Arduino programming, making code assemblage. It is accessible for working frameworks like MAC, Windows, Linux, and runs on the Java platform that accompanies inbuilt capacities and orders that assume an indispensable part in editing, debugging, and compiling the code in the environment.

A range of Arduino modules available including Arduino Uno, Arduino Mega, Arduino Leonardo, Arduino Micro, and many more. Each of them contains a microcontroller on the board that is programmed and accepts the information in the form of code. The main code, also known as a sketch, created on the IDE platform will ultimately generate a Hex File which is then transferred and uploaded in the controller on the board. The IDE environment mainly contains two basic parts:

- Editor: where the former is used for writing the required code.
- Compiler: is used for compiling and uploading the code into the given Arduino Module.

3.4.2. Blynk framework

Blynk is an IoT platform for iOS or Android smartphones that are used to control Arduino and GSM/GRPS via the Internet. This application is used to create a graphical interface or human-machine interface (HMI) by compiling and providing the appropriate address on the available widgets.

Blynk was designed for the IoT. It can control hardware remotely, it can display sensor data, it can store data, visualize it, and do many other things. There are three major components in the platform [29]:

Blynk App: – It allows you to create amazing interfaces for your projects using various widgets that are provided.

Blynk Server: – It is responsible for all the communications between the smartphone and hardware. Then can use the Blynk Cloud or run a private Blynk server locally. It’s open-source, could easily handle thousands of devices.

Blynk Libraries: – It enables communication, for all the popular hardware platforms, with the server and process all the incoming and outcoming commands.

The process that occurs when someone presses the Button in the Blynk application is that the data will move to Blynk Cloud, where data magically finds its way to the hardware that has been installed.

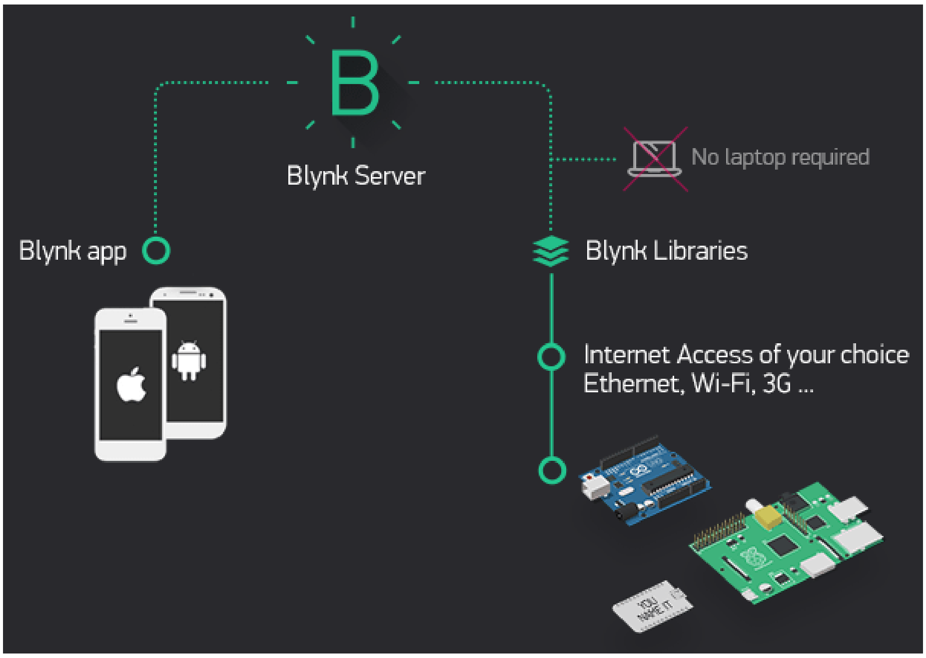


Figure 15: Blynk components [29]

3.4.3. ThingSpeak: IoT Web Service

ThingSpeak is a web-based open API (Application Programming Interface) IoT source information platform that comprehensive in storing the sensor data of varied IoT applications and conspire the sensed data output in graphical form at the web level.

ThingSpeak communicates with the help of internet connection which acts as a data packet carrier between the connected things and the ThingSpeak cloud retrieve, as shown in figure (16). With the ability to execute MATLAB code in ThingSpeak can perform online analysis and processing of the sensed data from the connected sensor to the host microcontroller (such as Arduino, TICC3200 module, Raspberry-pi, etc.). ThingSpeak is often used for prototyping and proof of concept IoT systems that require analytics.

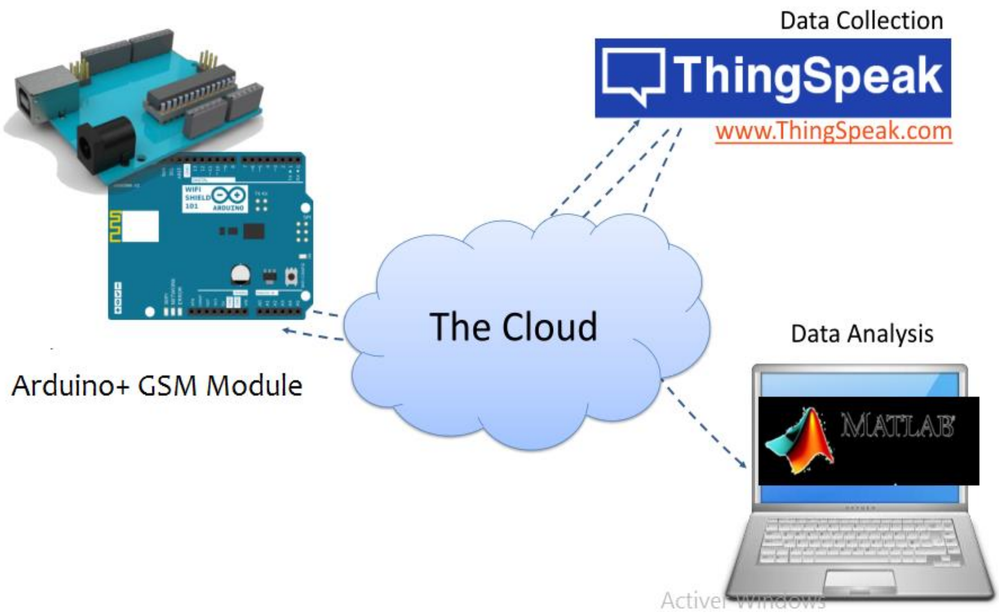


Figure 16: ThingSpeak representing itself as 'cloud'

Once channels were created in the ThingSpeak. The data can be collected in the real-time about the drying process and visualized the information using the MATLAB and responded to the data with tweets and other forms of alerts. A channel ID and API key were used to help for reading and collecting the data from the cloud. The below figure (17) highlights the unique ThingSpeak channel ID and “Write API key” which is used in this project.

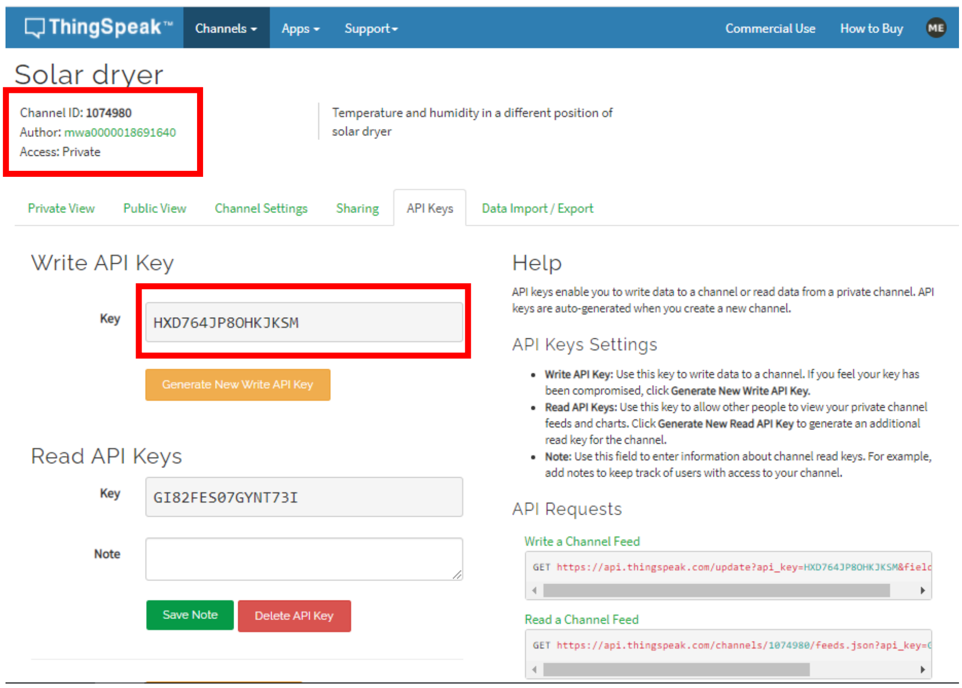


Figure 17: ThingSpeak Channel Parameters

3.5. Costs

The costs of the hardware components were estimated based on surveys in web amazon of France. It can be a good choice to shop because it can provide all supplies with a low cost.

Table 11: The budget of the hardware components

Qte	Materials	Price unit (€)	Total (€)
1	Arduino UNO R3	18,24	18,24
3	DHT22/AM2302	7,00	21.99
2	BMP280	4,99	9,98
2	Servo motor	19,99	39,98
1	GSM/GRPS Module	22,39	22,39
1	74HC4052	2,59	2,59
1	Jumper wire	11,49	11,49
	Total		126,66

It can be concluded that the total budget of the hardware components (126,66 €) is cheaper for a control system based on IoT technology.

3.6. Circuit Simulation Software

Proteus is by far the most popular electronic design and simulation software. Based on this software, the control system can be drawn and simulated on the computer. There are several benefits of simulating the control system proposed for the solar dryer, namely; drawing electronic circuits on the computer is quicker than building them in real life; probability of making mistakes is very low like loose connections because in real-world, it takes hours to find it; even if components are not available physically still can build the circuits and it saves both time and money; there is literally no chance of blowing or braking up a component.

Chapter 4: Results & Discussion

4.1.Proposed System

The design stage is divided into hardware and software design. The hardware design prepares the hardware components that will be utilized such Arduino Uno board, GSM/GRPS module SIM900, sensors and actuators etc. Software design is in the form of designing programs (codes) for Arduino and Android application with the help of the Blynk application, which is all for visualizing the data of the sensors at anytime and anywhere to optimize the drying process.

4.1.1. Hardware design

This part confirmed that the combination of Arduino UNO with GSM/GRPS module is a perfect method for electronic device monitoring wireless, data collection, and data saving. This helps to measure the humidity and temperature values of the particular surroundings using the DHT22 sensor, and to measure the pressure using BMP280. Then, the data will be sent it by the GSM/GRPS module to Blynk application and ThingSpeak platform software to analyze it. The figure (18) shows the proposed system.

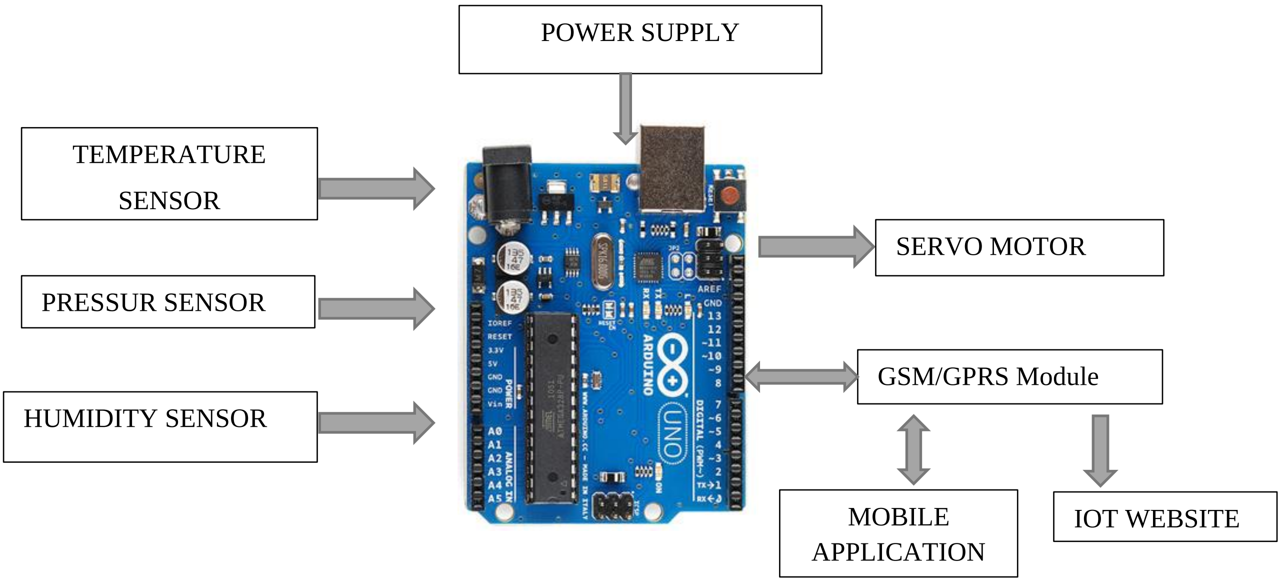


Figure 18: The proposed prototype of control system

In this system, the Arduino UNO is used to collect the data from the sensors. The Arduino UNO microcontroller is the heart of this system. Along with this collecting process, the system is able to control the position of the servo motor based on the measured parameters.

4.1.2. Software design

4.1.2.1. Algorithm

A flow chart of the control system for indirect solar dryer as indicated in figure (19):

- Load sensor libraries in Arduino IDE Software.
- Execute the program and read the data from the sensor.
- Define the Auth Token of the private Blynk server in the Arduino IDE for the communications between the smartphone and the Arduino UNO Board.
- Enter the Network credentials in Arduino IDE.
- Execute the program one more time.
- Visualize the output in Blynk App and in the ThingSpeak cloud.

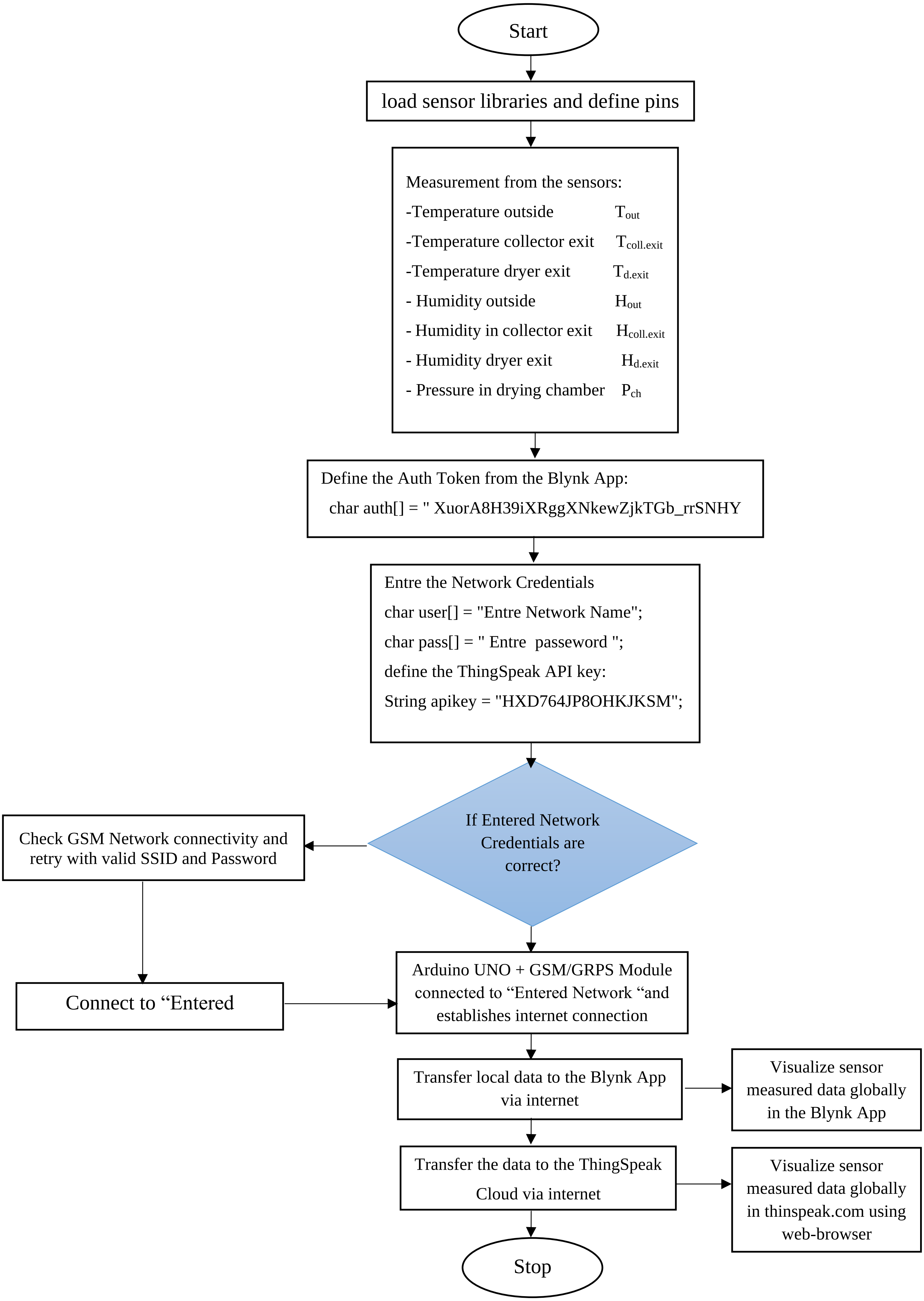


Figure 19: Flow chart of the control system

4.1.2.2. Code Explanation

In the first step of programming, #include , is similar to #define, which is used to include outside libraries in the sketch. This gives the access to a large group of standard C libraries, and also libraries written especially for Arduino. It is necessary to include the library to connect the hardware part with Arduino board. This connection allows to read the physical parameters by the sensor, also to determine the position of the valve. The libraries used in this project are presented in the Code_1:

#Code_1

```
#define BLYNK_PRINT SwSerial
#include <SoftwareSerial.h>
SoftwareSerial SwSerial(10, 11); // RX, TX
#include <BlynkSimpleStream.h>
#include <DHT.h>
#include <Wire.h>
#include <Adafruit_BMP085.h>
#include <Servo.h>
```

After defining the library, it is a prerequisite to define the Auth Token of the Blynk application. Auth Token is a unique identifier needed to make a connection between the control system and the smartphone. The “Write API Key” of the ThingSpeak server marked in the program, is a key for writing data in the solar dryer channel, As explained in the code_2:

#Code_2

```
char auth[]"XuorA8H39iXRggXNkewZjkTGb_rrSNHY";
String apikey = "HXD764JP8OHKJKSM";
const char* server = "api.thingspeak.com";
```

In the Code_3, the global variables were decelerated in order to be used later on the program in the storage of the data acquired from the sensor. In addition, it is important to define the type, name and the initial value of the variable.

#Code_3

```
float g = 9.81;
int f= 1000 ;
float z=1.5 ;
float Temp01,Pressure01;
float Temp02,Pressure02;
float Humid1,Temp1;
float Humid2,Temp2;
float Humid3,Temp3;
float Velocity;
```

The second step consists to configure the specified pin mode as either input for the sensors and an output for the servo motor. Moreover, the creation of the DHT object leads to define the type of the sensor. As presented in Code_4:

#Code_4

```
  servo1.attach(9);
  servo2.attach(10);
DHT dht1(2, DHT22);
DHT dht2(3, DHT22);
DHT dht3(4, DHT22);
  pinMode(7, OUTPUT);
  pinMode(5, OUTPUT);
int pos1 = 0;
int pos2 = 0;
```

The Webhook function was adopted in order to send data from the Blynk application in the smartphone to ThingSpeak, also, it is necessary to declare it in the program as shown in the Code_5.

#Code_5

```
BLYNK_WRITE(V0)
{
  Serial.println("WebHook data:");
  Serial.println(param.asStr());
}
Blynk.virtualWrite(V0,  Temp2, Temp3, Humid1 Humid2,
Velocity);
```

The Code_6 is the "void setup ()" function, this function defines the initial state of the Arduino upon boot, it initializes libraries and runs only once.

#Code_6

```
void setup()
{
  SwSerial.begin(9600);
  delay(2000);
  Serial.begin(9600);
  Blynk.begin(Serial, auth);
  bmp.begin();
  dht1.begin();
  dht2.begin();
  dht3.begin();
```

In the “ReadSensor (void)” function as shown in the Code_7, it was used to read the data from the DHT22 and BMP280 sensors, it takes sensors data from pin number then write the value readied to virtual pin of the Blynk application.

#Code_7

```
void ReadSensor(void)
{
  digitalWrite(7,LOW);
  digitalWrite(5,LOW);
  delay(500);

  Pressure01 = bmp.readPressure();
    Blynk.virtualWrite(V1, Pressure01);
      delay(300);
  Temp01 = bmp.readTemperature();
    Blynk.virtualWrite(V2, Temp01);
      delay(500);

  digitalWrite(7,LOW);
  digitalWrite(5,HIGH);
  delay(500);

  Pressure02 = bmp.readPressure();
    Blynk.virtualWrite(V3,Pressure02);
      delay(200);
  Temp02 = bmp.readTemperature();
    Blynk.virtualWrite(V4, Temp02);
      delay(200);
  Velocity = sqrt((2/1.2)*(Pressure01+Pressure02)-(2*g*z));
    Blynk.virtualWrite(V11, flow);
      delay(200);
  Temp1 = dht1.readTemperature();
    Blynk.virtualWrite(V5, Temp1);
      delay(100);
  Humid1 = dht1.readHumidity();
    Blynk.virtualWrite(V6, Humid1);
      delay(100);
  Temp2 = dht2.readTemperature();
    Blynk.virtualWrite(V7, Temp2);
      delay(100);
  Humid2 = dht2.readHumidity();
    Blynk.virtualWrite(V8, Humid2);
      delay(100);
  Temp3 = dht3.readTemperature();
    Blynk.virtualWrite(V9, Temp3);
      delay(100);
  Humid3 = dht3.readHumidity();
    Blynk.virtualWrite(V10, Humid3);
      delay(100);
}
```

According to the table (3) in the chapter (2), the conditions of the drying process of the fig were optimized and set in the "void loop ()" function as described in Code_8, to automatize the control system.

#Code_8

```
void loop()
{
  if (millis()-cp >= 30000)
  {
   cp=millis();
   ReadSensor ();
 if(((Temp2<55) && (Temp2>29) &&(Humid2>30) &&
(Humid2<67.22)))
  {
    servo2.write(0);
    servo1.write(0);
      }
  else if ((Temp2 <= 29) && (Humid2<67.22))
  {
      servo2.write(70);
      delay (100);
      servo1.write(0);
    }
  else if ((Temp2 >= 55) && (Humid2<67.22))
 {
  Blynk.notify("Over-heating");
    servo1.write(70);
    delay(100);
    servo2.write(0);
  }
else if ((Velocity < 2.22) && (Temp2>=29))
 {
    servo1.write(0);
    delay(100);
    servo2.write(70);
  }
  }
 Blynk.run();
 timer.run();
}
```

4.2.Proteus Simulation

As can be observed in figure (20), Proteus tool allows to simulate the control system of the solar dryer, which is equipped by the Arduino UNO, sensors, servo motor, and GSM/GRPS model, as this compound cannot be used in the Proteus simulation, it will be replaced by the COMPIM. Therefore, the performance obtained will be similar to the performance of the real experience. One of the aims of this simulation is to acquire and supervise the temperature, humidity, pressure and air velocity of the studied solar dryer.

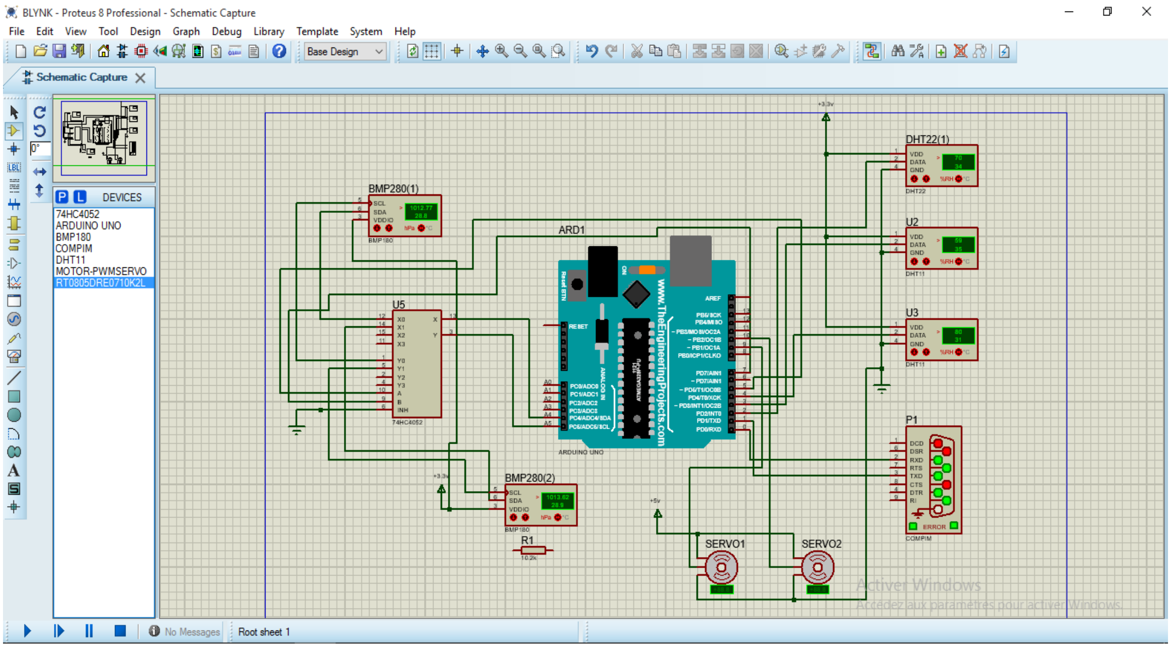


Figure 20: The electronic circuit model of solar dryer under Proteus

4.2.1. Connecting Proteus to computer

The UART (Universal asynchronous receiver-transmitter) communication protocol was followed to connect the Proteus simulation with the Blynk application. The Arduino UNO receives data transmitted from the sensor. After processing the data, the Arduino UNO sends it to the Blynk applications, thus, it is essential to make a connection between the Proteus circuit and the serial port of the computer using the COMPIM, which is presented in the figure (21).

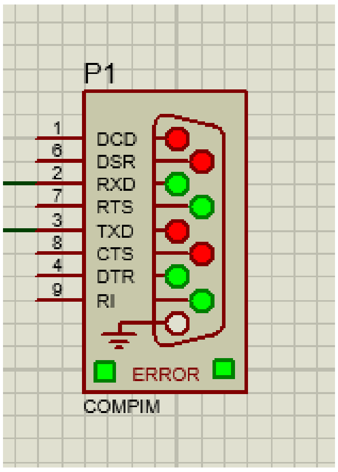


Figure 21: COMPIM

The COMPIM is the component useful to connect the physical port of the computer with the virtual port. This component need to fixe the parameters to be compatible with the physical port, as shown in figure (22). The port COM3 was selected with the Baud Rat 9600, so the virtual port need the same Baud Rat selected.

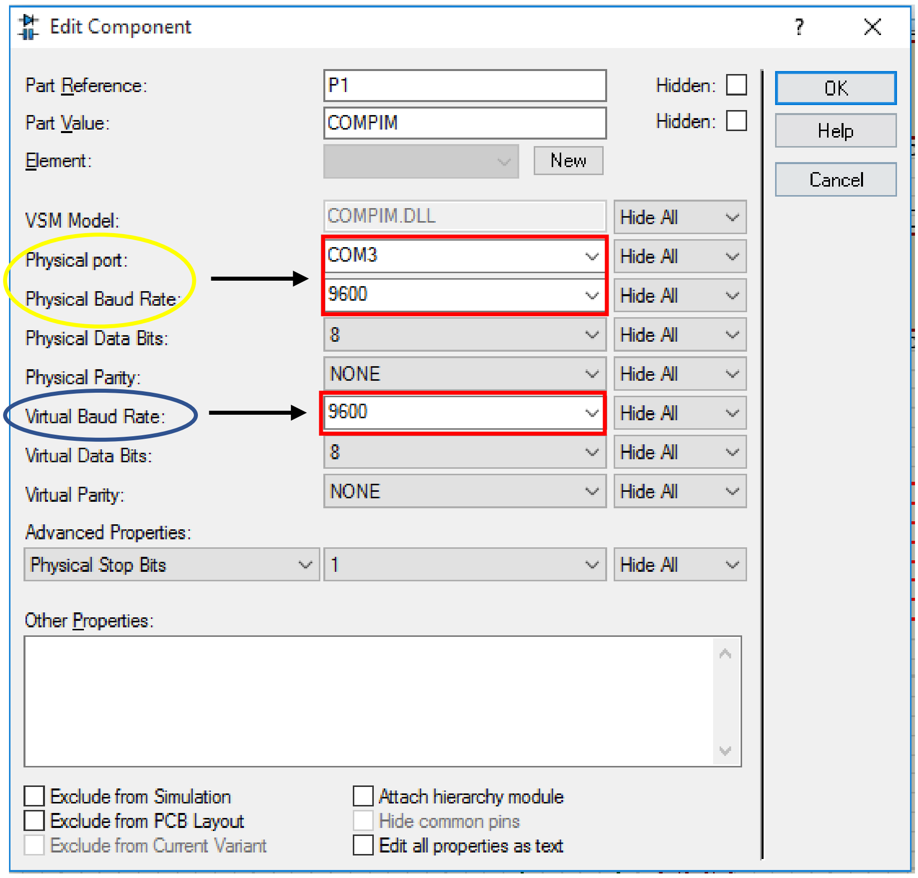


Figure 22: COMPIM parameters

4.2.2. Connecting Proteus to Blynk application

In the first step, The VSPE (Virtual Serial Ports Emulator) software application share the physical serial port data for the Blynk application in the smartphone, as follows: Launch the application and create new devise. Then, specify the type of the devise, the pair device consists of two logically connected virtual port, as shown in figure (23).

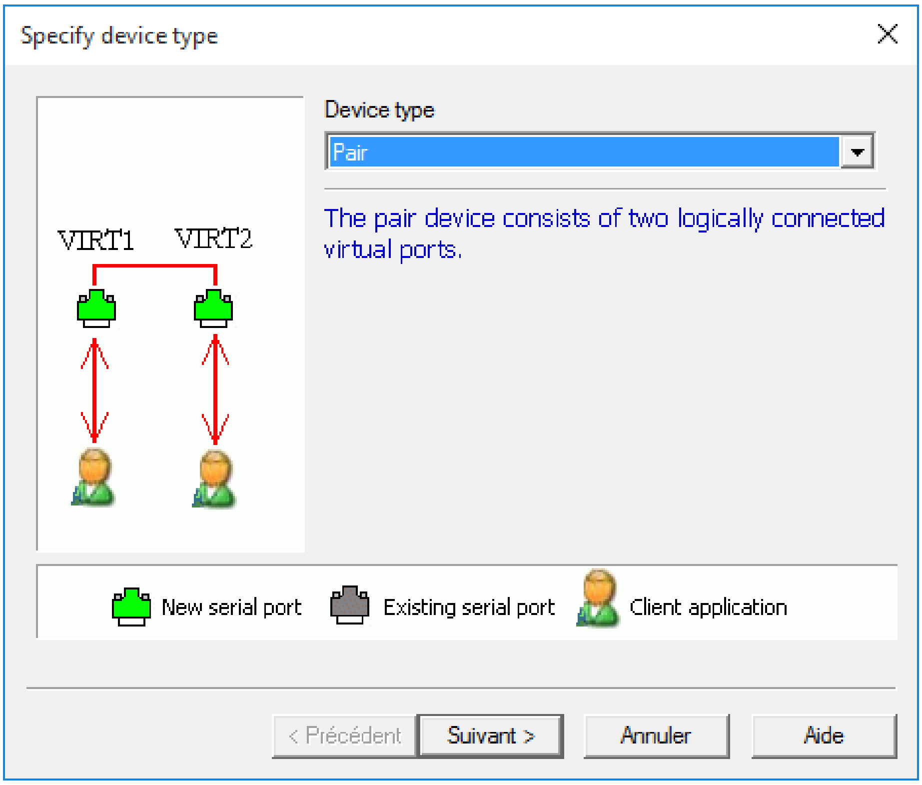


Figure 23: Specify devise type

Next, link the physical port of computer COM3 considered as a virtual serial port 1 with COM4 considered as a virtual serial port 2, as can be seen from figure (24).

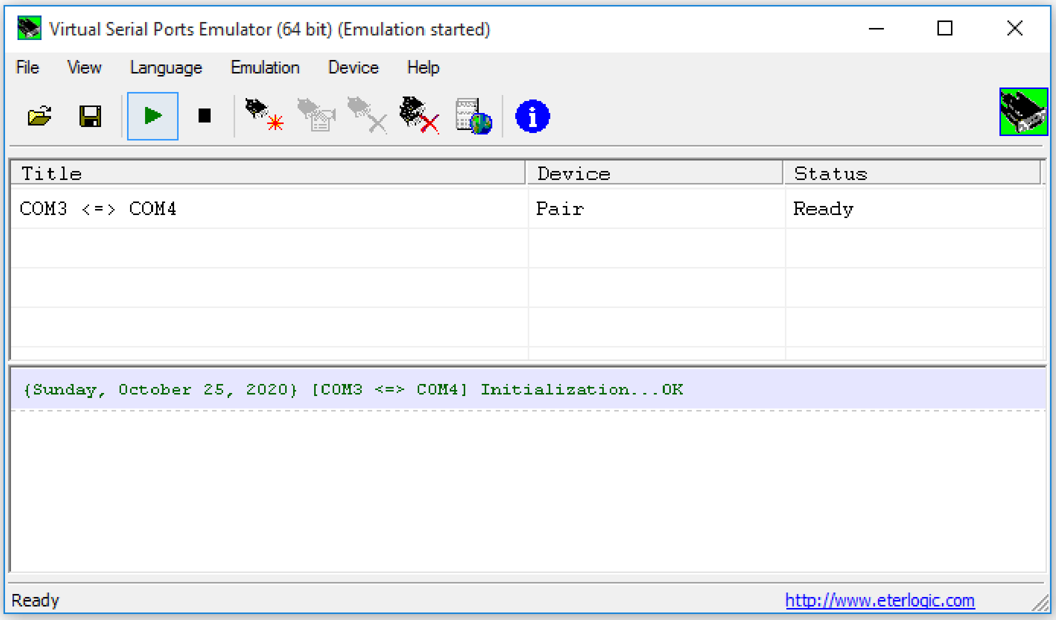


Figure 24: Virtual Serial Ports Emulation

Secondly, run the script located in “scripts” folder of the Arduino library root (“->Blynk-> scripts->blynk-ser.bat”), to redirect the traffic to Blynk cloud, as presented in figure (25).

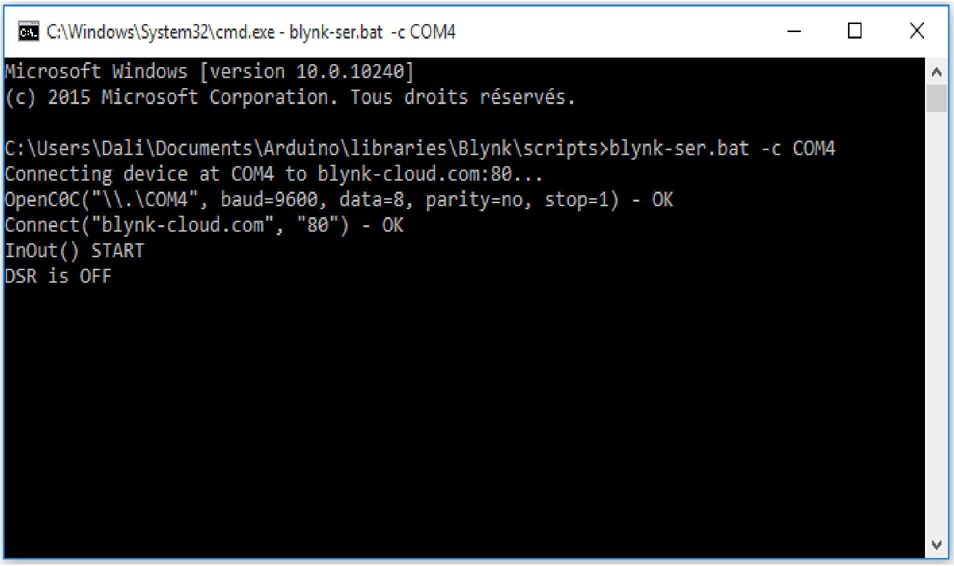


Figure 25: connecting device at COM4 to Blynk-cloud

Finally, the Proteus simulation was connected with the Blynk application.

4.3. Blynk interface

To create the interface with Blynk application, first of all, create an account and log in to the application, next, choose the type of the hardware model used in the Proteus simulation. Then, select the connection type.

As mentioned in the previous chapter, the parameters to be measured are selected, so it needs to prepare the interface for visualization the result of the measured parameters. In the Blynk application, there is many types for visualizing the data of sensors. For analyzing the measured parameters, these results will be saved in a temperature and humidity chart, as indicated in figure (26).

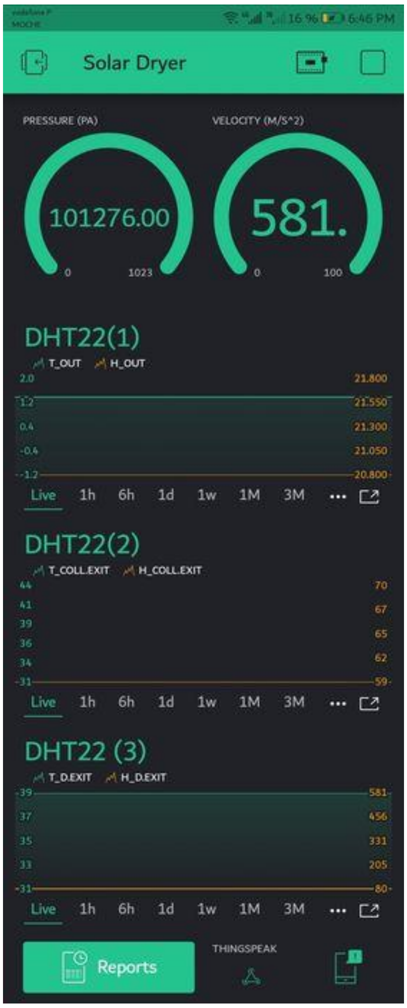


Figure 26: Solar dryer interface

To improve the control system, an addition of notification was carried out allowing the farmer to know when the drying prosses start, and also to protect the figs from the overheating as indicated in the figure (27).

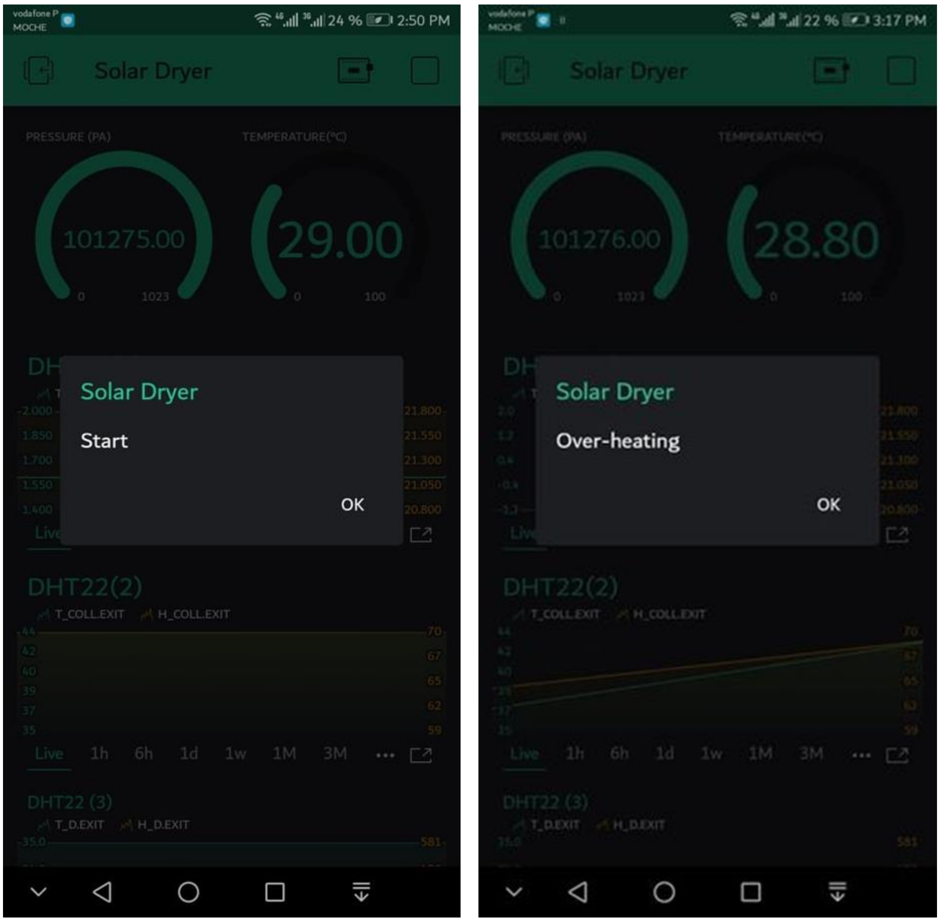


Figure 27: Solar dryer notification

- **ThingSpeak interface**

The data was sent from the Blynk application to the web browser ThingSpeak through the WebHook widget. The virtual pin selected in "WebHook Setting" is V0, which was defined in the program with the data value contents. Applying the URL syntax indicated in figure (28) allows to specify the ThingSpeak channel as well as the field of each data.

https://api.thingspeak.com/update?api_key=LHVYS1M00UEJ5POT&field1=/pin[0]/&field2=/pin[1]/&field3=/pin[2]/&field5=/pin[3]/&field6=/pin[4]/

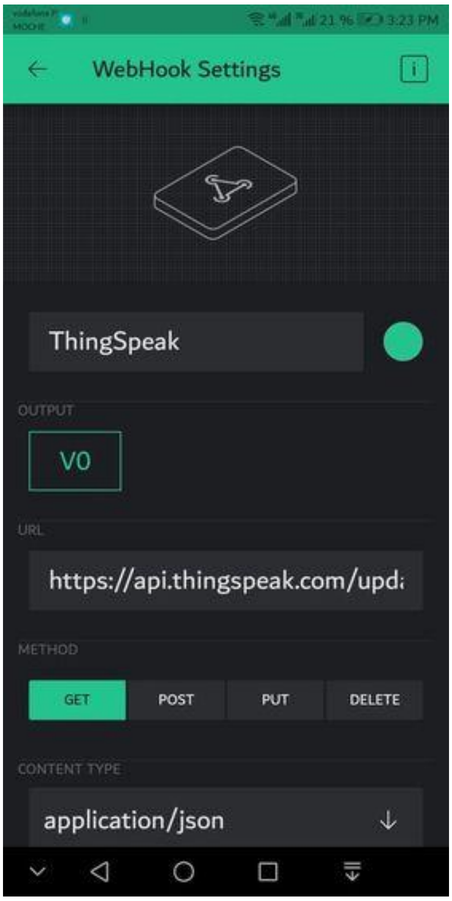


Figure 28: WebHook Setting

The all humidity and temperature values were uploaded on the ThingSpeak platform. After that, one can see its graphical representation of both humidity and temperature values in a separate view window, as can be observed in figure (29).

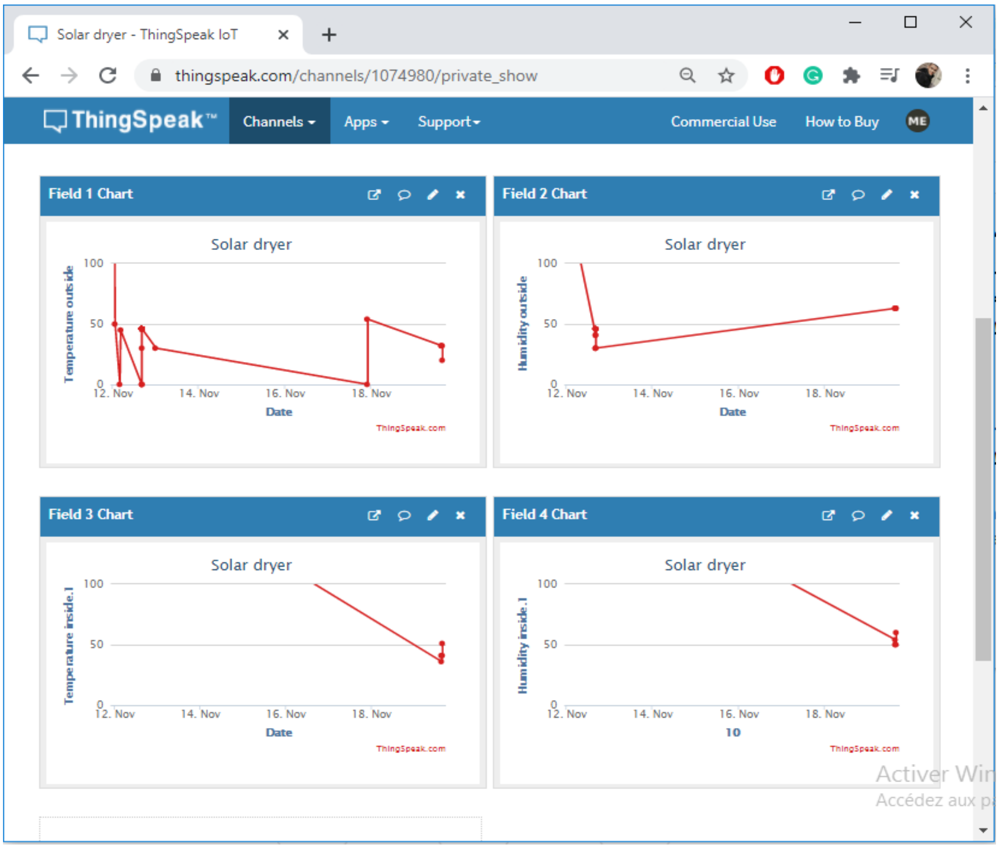


Figure 29: Thingspeak IoT Cloud Output results

4.4.Valve design

This part presents the design of the valves on SolidWorks. The control of the valves is based on servo DS3225 position. The servo DS3225 can control the position of the valve with high accuracy, according to the input data of the drying process.

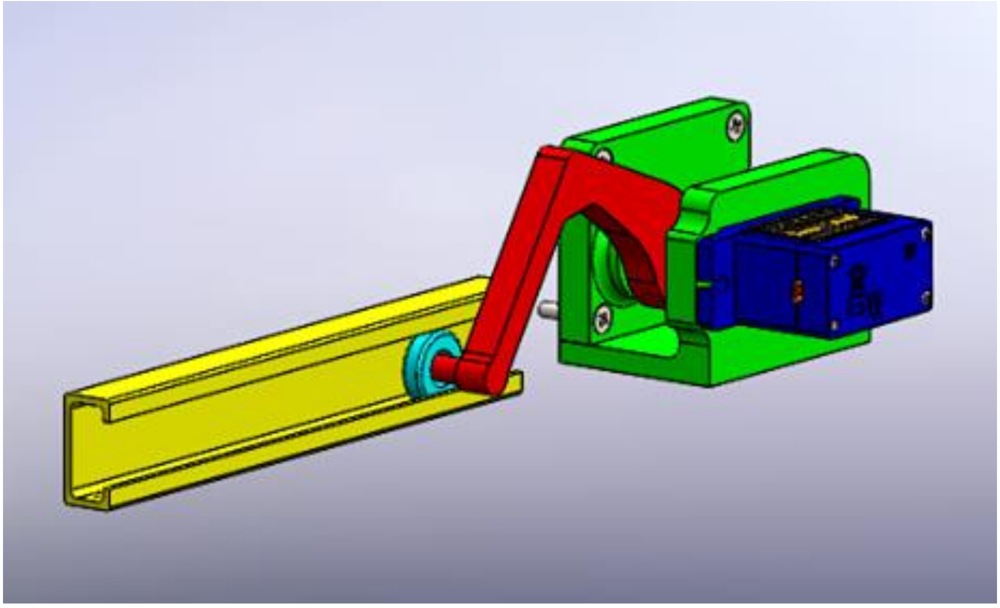
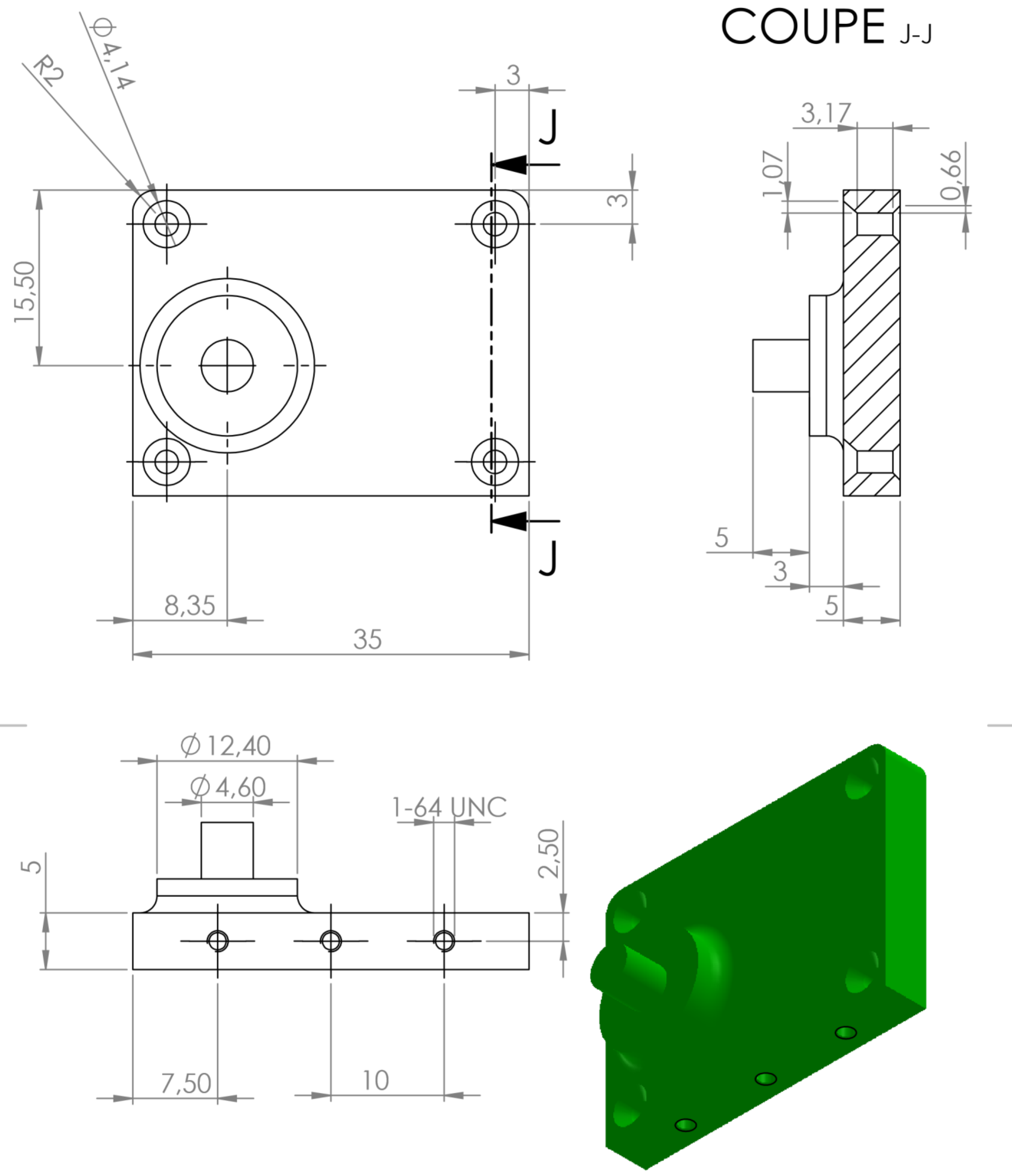
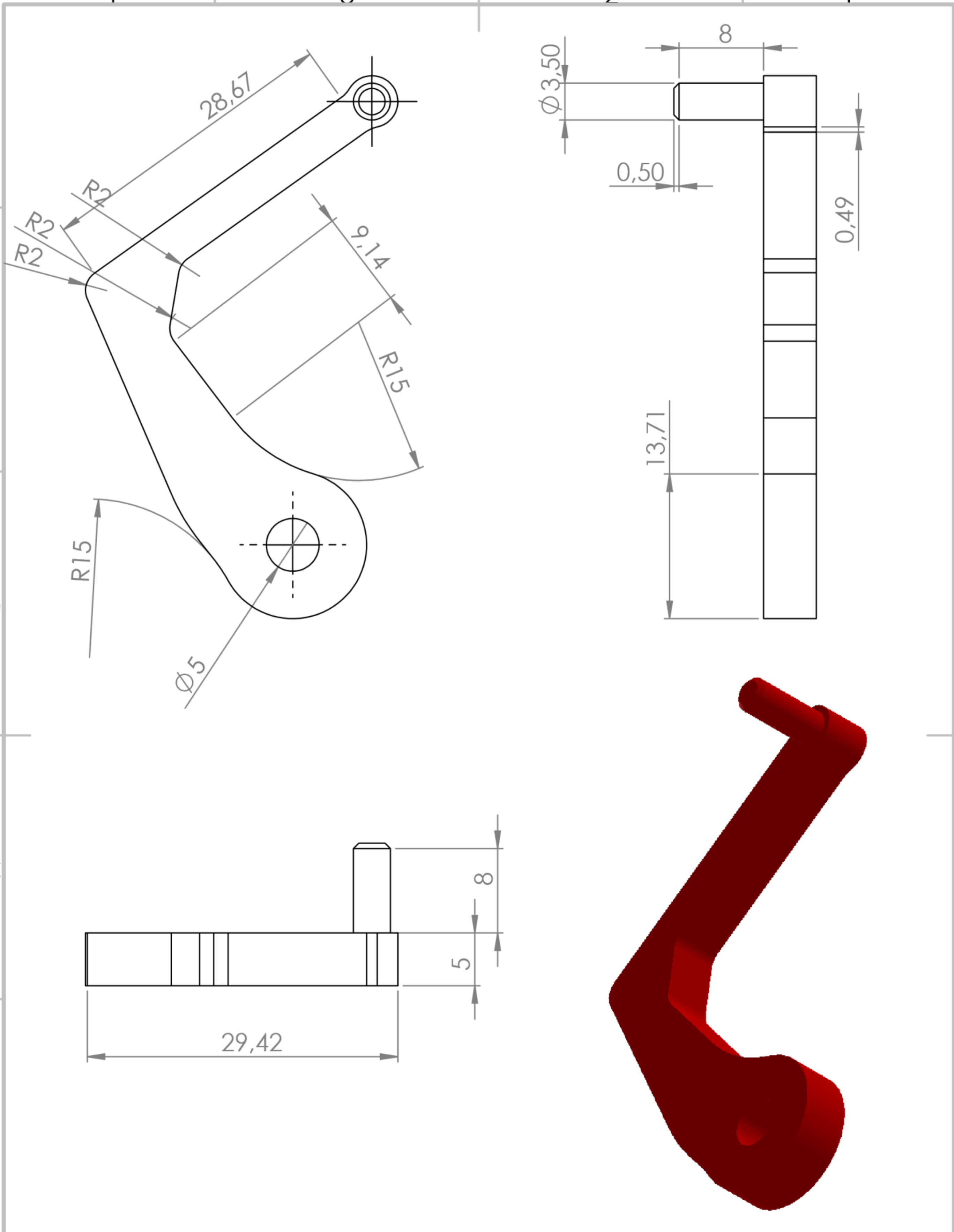


Figure 30: Valve design

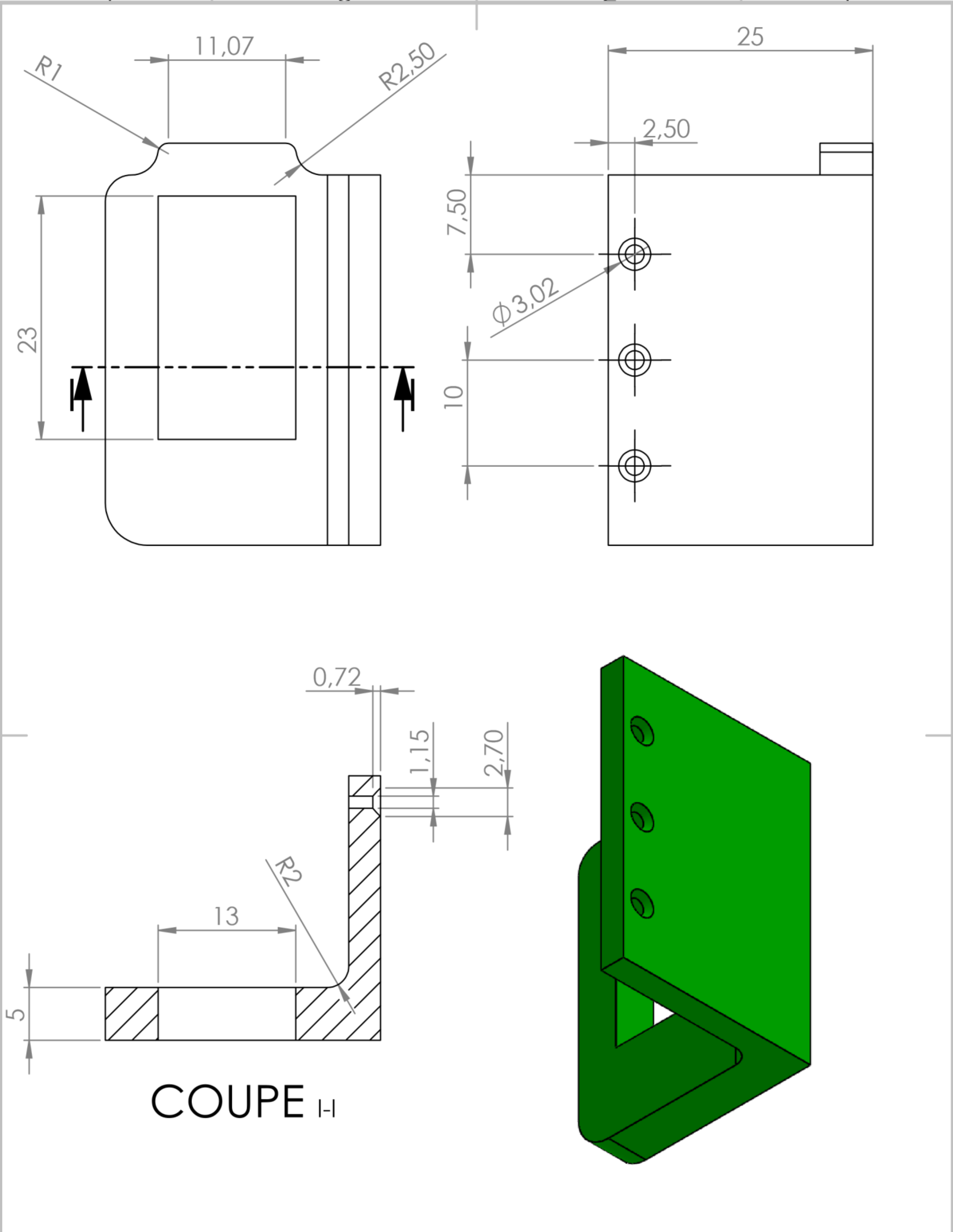
In this part, the support of the servo motor was designed, which consists of two pieces; the first piece is the top support of the servo motor; the second part is the base support, then assemble the two pieces together by three screw. To connect the servo shaft with the valve, the connecting rod was designed, this one connects to the servo shaft by the internal splines.



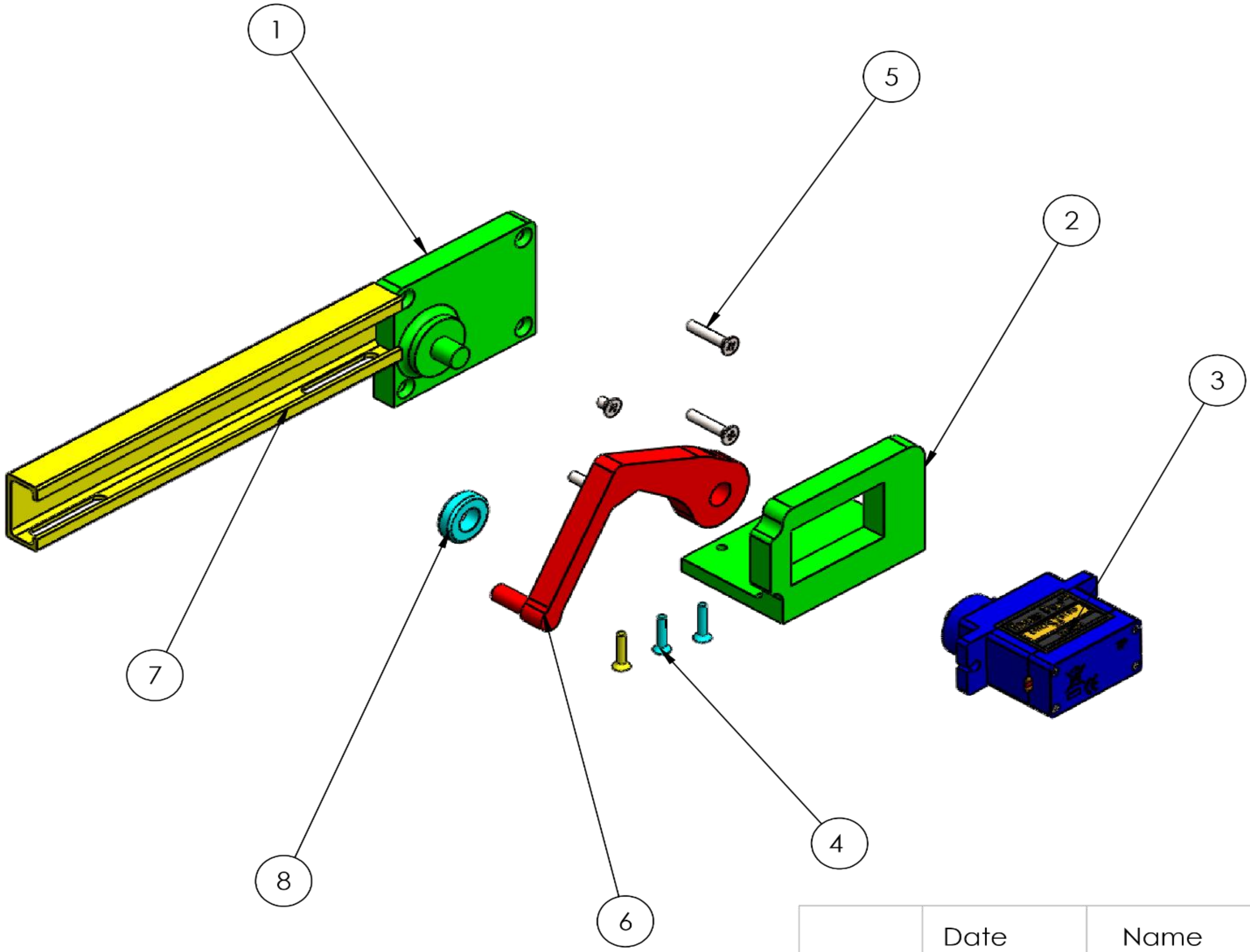
	Date	Name	Design of an Control System for Indirect Solar Dryer	ESTIG-IPB ULT
Draw.	22/11/2020	Mohamed Ali Elmehri		
Verif.	25/11/2020	Luís Frölén Yassine Ferchichi		
Scale 2:1	Part-1		Base-Support	Material:
	Tolerance			Number: 1

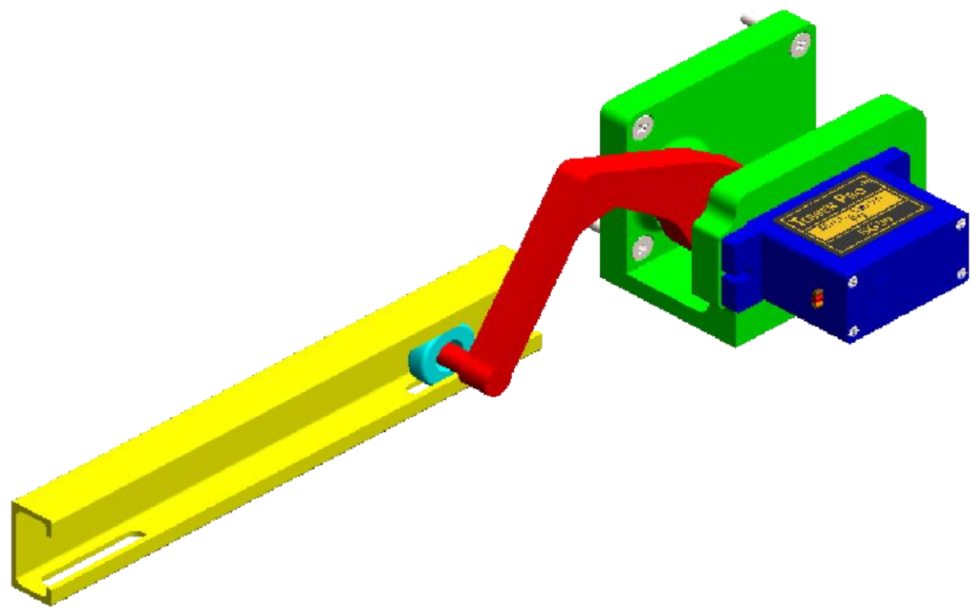


	Date	Name	Design of an Control System for Indirect Solar Dryer	ESTIG-IPB ULT
Draw.	22/11/2020	Mohamed Ali Elmehri		
Verif.	25/11/2020	Luís Frölén Yassine Ferchichi		
Scale 2:1	Part-1		Connecting Rod	Material:
	Tolerance			Number: 1



	Date	Name	Design of an Control System for Indirect Solar Dryer	ESTIG-IPB ULT
Draw.	22/11/2020	Mohamed Ali Elmehri		
Verif.	25/11/2020	Luís Frölén Yassine Ferchichi		
Scale 2:1	Part-1	Support Servo-Motor		Material:
	Tolerance			Number: 1





No. ARTICLE	QTE	DESCRIPTION
1	1	Base Support
2	1	Support Servo
3	1	Servo motor
4	3	SCHCSCREW 0.06-80x0.3125x0.3125-HX-N
5	4	ISO 7046-1 - M2 x 10 - Z - 10N
6	1	Connecting Rod
7	1	Rail
8	1	Tensioner

	Date	Name	Desigin of an Control System for Indirect Solar Dryer	ESTIG-IPB ULT
Draw.	22/11/2020	Mohamed Ali Elmehri		
Verif.	25/11/2020	Luís Frölén Ribeiro Yassine Ferchichi		
Scale 1:1		Exploded View		Material:
	Tolerance			55

Chapter 5: Conclusions & Future work

5.1.Conclusion

This study presents, the design and the simulation of a low-cost and autonomous control system for indirect solar dryer. This control system adopts the IoT technology, which is based on the combination of the GSM/GRPS module (replaced by COMPIM component in the Proteus simulation) with Arduino UNO board to collect and send data in real-time. The proteus simulation findings proved that this combination provides an efficient for electronic monitoring wireless of the drying process parameters

The drying parameters (temperature, humidity and air velocity) were selected to choose the DHT22 and BMP280 sensors. These sensors read the data used in the Arduino program to automize the control system which is based on the figs dried conditions. According to the execution of the Arduino program, it can be confirmed that the automatization of the solar dryer was succussed.

Based on the outcomes showed by the Blynk application, it can conclude that the connection between the Blynk application and the Proteus simulation is done, which can assist the farmers monitoring the drying process. To enhance the project, the visualization of the data was added in the ThingSpeak IoT platform to analyze.

The design of the valve was carried out using the SolidWork. The control of the valve position is based on the servo motor with connecting rod.

The estimation of the budget of the hardware components pointed out that it is cheaper compared to the other IoT technology which encourage the farmer to make this control system.

5.2.Future work

The future work in the project is to fix the control system proposed in the dryer machine, verifying the theory study and prove the efficiency of the control system design.

Update the program to be capable of adding another choice of product for the farmer to select using the BLYNK application.

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