COMILLAS
UNIVERSIDAD PONTIFICIA
ICAI

GRADO EN INGENIERÍA EN TECNOLOGÍAS INDUSTRIALES

TRABAJO FIN DE GRADO

SOLAR POWERED PORTABLE WATER FILTER

Autor: Alberto Martínez Liñera

Director: Arne Fliflet

Madrid

Julio de 2022

Declaro, bajo mi responsabilidad, que el Proyecto presentado con el título

Solar Powered Portable Water Filter

en la ETS de Ingeniería - ICAI de la Universidad Pontificia Comillas en el

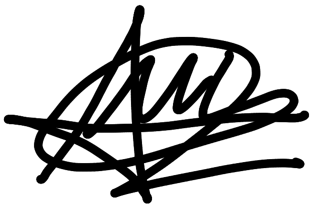
curso académico 2021/22 es de mi autoría, original e inédito y

no ha sido presentado con anterioridad a otros efectos.

El Proyecto no es plagio de otro, ni total ni parcialmente y la información que ha sido

tomada de otros documentos está debidamente referenciada.

Fdo.: Alberto Martínez Liñera Fecha: 17/ 06 / 2022



Autorizada la entrega del proyecto

EL DIRECTOR DEL PROYECTO

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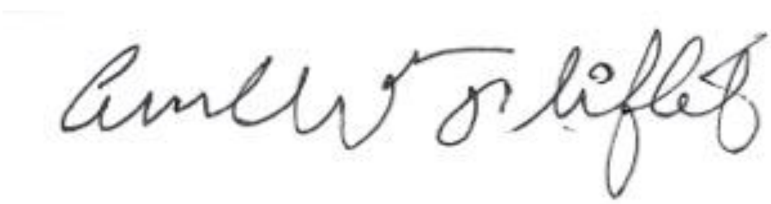

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I would like to thank my family, friends, and academic institutions such as the Universidad Pontificia de Comillas, which have contributed to my educational and personal formation. I would also like to thank the University of Illinois for all the services offered, such as the use of laboratories that have allowed me to develop this work.

FILTRO DE AGUA COMPLETO ALIMENTADO CON ENERGÍA SOLAR

Autor: Martínez Liñera, Alberto.
Director: Fliflet, Arne.
Entidad Colaboradora: University of Illinois

RESUMEN DEL PROYECTO

El proyecto consiste en la elaboración de un sistema completo y portátil de filtrado y desinfección del agua. El proceso de desinfección será completamente automatizado y se indicará al usuario cuando remplazar cada uno de los filtros para minimizar la interacción del usuario en el proceso y posibles riesgos de infección. Adicionalmente el proyecto estará alimentado exclusivamente con energía solar para poder ser usado en lugares sin acceso a la red eléctrica.

Palabras clave: Filtrado de agua, Desinfección del agua, Microfiltro, Filtro de carbono, Desinfección con luz ultravioleta, Energía solar, Proyecto social.

1. *INTRODUCCIÓN*

El consumo de agua es esencial para evitar la deshidratación a lo largo del día, esto es debido a que aproximadamente el 60% del contenido de nuestro cuerpo es agua. El Institute of the National Academies recomienda beber 2,7 litros para una mujer adulta y 3,7 litros para los hombres diarios para mantenerse saludable [1].

Por desgracia, según los últimos datos sobre el acceso de agua publicados en 2019 por la OMS y UNICEF muestran que en 2017, más de 884 millones de personas no tenían agua potable para beber y por tanto se veían obligados al consumo de agua contaminada para sobrevivir [2]. Esto es un gran problema porque el consumo de agua contaminada puede transmitir enfermedades como como la diarrea, la disentería, la fiebre tifoidea y la poliomielitis entre otras. Para ponerlo en perspectiva, se calcula que beber agua contaminada provoca 48.500 muertes exclusivamente por diarrea cada año [3].

La instalación de un sistema de filtración y purificación del agua es muy costosa, y muchas personas y familias no tienen los recursos necesarios para permitírselo. En los países menos desarrollados el problema es aún mayor debido a tener un contenido más alto de bacterias y virus en el agua que posteriormente son la causa de muchas enfermedades. Además, es habitual que muchos de estos países menos desarrollados tampoco tengan acceso a la red eléctrica viéndose limitadas algunas técnicas de desinfección.

El objetivo del proyecto es crear un sistema portátil de filtrado que permita eliminar las impurezas y bacterias a través de una serie de filtros, para posteriormente desinfectar el agua filtrada con la utilización de luz ultravioleta eliminando así la posible presencia de virus en el agua. Para ser totalmente portátil y no depender de tener acceso a la red eléctrica, el sistema se alimentará exclusivamente de energía solar utilizando un pequeño panel solar y una batería que será cargada durante el día por el panel.

2. *METODOLOGÍA*

Se ha dividido el proyecto en 4 partes que son: el diseño del sistema físico, el diseño del hardware y la PCB, la programación del proyecto y la comprobación del correcto funcionamiento de este.

2.1 Diseño del sistema físico

Se ha decidido utilizar un diseño similar al que posee el producto comercial LifeStraw Home Dispenser [4]. El producto consta de dos grandes depósitos interconectados a través de un microfiltro y un filtro de carbono. Par automatizar el proyecto utiliza dos sensores, un detector de agua y un medidor de flujo. El detector de agua se colocará en el fondo del primer depósito para detectar la presencia de agua que tiene que ser filtrada. El sensor de flujo de agua se colocará a la salida de los filtros para medir la velocidad de filtrado y posteriormente indicar cuando los filtros deben ser remplazados en función de variaciones en la velocidad de filtrado.

La luz ultravioleta se colocará en la parte inferior del segundo depósito que será cubierto de un material que no deje pasar la luz ultravioleta, para no dañar la piel ni la visión del usuario. Todas las conexiones necesarias, la PCB y el panel solar estarán convenientemente situadas en uno de los laterales del sistema.

Se ha elegido este diseño debido a que permite que las conexiones de los sensores estén perfectamente protegidas y se maximiza la exposición de luz ultravioleta en el agua al estar perfectamente distribuidos los LEDs en la base del segundo depósito. Además la PCB con todas las conexiones se encuentran compactas y escondidas mejorando la apariencia del producto final. A continuación se representa una ilustración con las vistas principales del diseño.

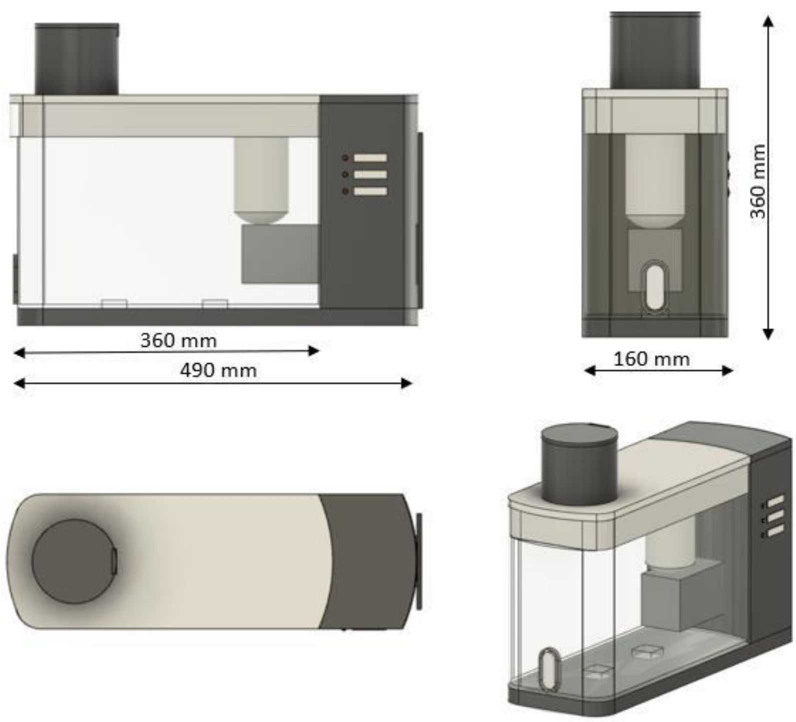

Ilustración 1 – Diseño Físico en CAD del proyecto

2.2 Diseño del hardware y PCB

Para el diseño del hardware y comprobación de su funcionamiento se ha decidido dividir el proyecto en 5 subsistemas que realizan una función especializada cada uno. Estos 5 subsistemas son: alimentación, detección, control, desinfección e interfaz de usuario. Los 5 subsistemas se comunican entre sí según aparece en la ilustración 2 a continuación.

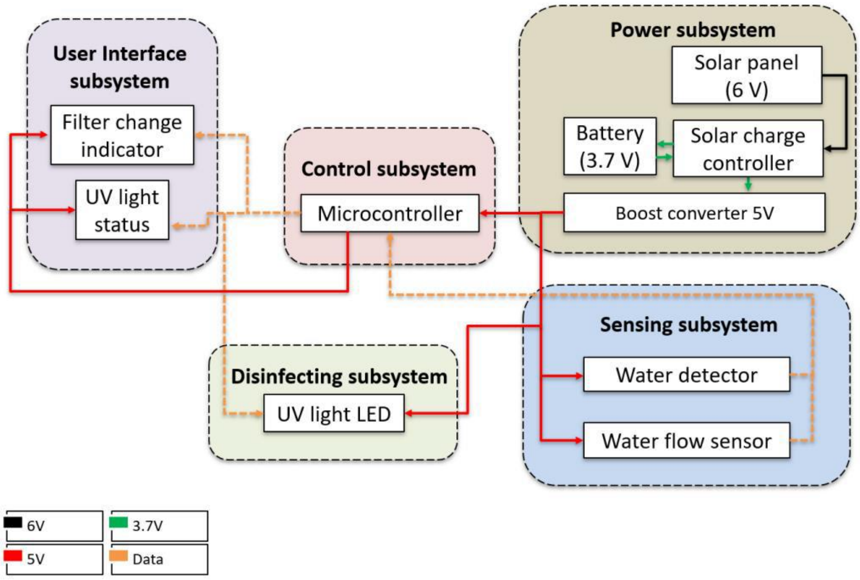

Ilustración 2 – Diagrama de bloques de la interconexión de los subsistemas

Para la elección de los componentes se ha observado la compatibilidad entre ellos, teniendo en cuenta las tensiones y corrientes que necesita cada uno de ellos. Para obtener las tensiones necesitadas se han utilizado dos boost converters (reguladores de tensión que permiten subir la tensión). También se ha realizado un análisis de corriente y tensiones para determinar la potencia mínima que necesita proporcionar el panel solar.

Otros elementos importantes de diseño son la precisión de los sensores, y la eficiencia de los filtros y LEDs de luz ultravioleta. Debido a que el flujo a la salida de los filtros es pequeño, se necesita un sensor muy preciso que no tenga flujo mínimo. La eficiencia de los filtros y de los LEDs de luz ultravioleta son muy importantes debido a que se pretende obtener la mejor calidad de agua posible calidad precio.

Una vez todos los componentes han sido elegidos, y diseñados sus circuitos auxiliares (resistencias, condensadores, diodos…) se ha utilizado el software gratuito KiCad para el diseño de la PCB. Todas las PCBs utilizadas se han pedido a través de PCBWay, un fabricante especializado en su elaboración.

Inicialmente se han diseñado dos PCBs. La primera, es la principal en la cual se encuentran soldadas todas las resistencias, reguladores de tensión, condensadores, el microcontrolador y los conectores de los sensores y LEDs. La segunda PCB, es una pequeña PCB para soldar los LEDs de luz ultravioleta y poder situarlos justo debajo del segundo deposito. No obstante debido a complicaciones con algunos componentes, se ha tenido que rediseñar la PCB principal para reactualizar las conexiones y los pines.

2.3 Programación

Para programar el microcontrolador se ha usado un programador ISP (de sus siglas en inglés In-System Programming) debido a que permite la programación del chip una vez instalado en el sistema completo. Debido a la crisis de componentes producida por el Covid-19, no se ha podido utilizar el microcontrolador ATMEGA48-20AU (elegido originalmente en el diseño) y finalmente se ha usado el microcontrolador ATMEGA328 para probar el funcionamiento del sistema.

Se ha utilizado Arduino IDE para escribir el código y programar el microcontrolador debido a ser compatible con el microcontrolador ATMEGA328. Únicamente se ha tenido que asignar los pines del microcontrolador con los asociados a Arduino [5].

Debido a tener únicamente dos entradas (el detector de agua y el sensor de flujo) y que la salida depende del estado anterior, se ha decidido utilizar una máquina de estados para programar el microcontrolador. Inicialmente el programa constaba de 6 estados, pero debido a que el sensor de flujo dejó de funcionar dos semanas antes de la demonstración del proyecto, se tuvo que reducir el programa y realizar algunas suposiciones. Se asumió flujo constante durante todo el proceso de filtrado y se redujeron el número de estados a 5. En la ilustración 3 se muestra el diagrama de estados finalmente utilizado.

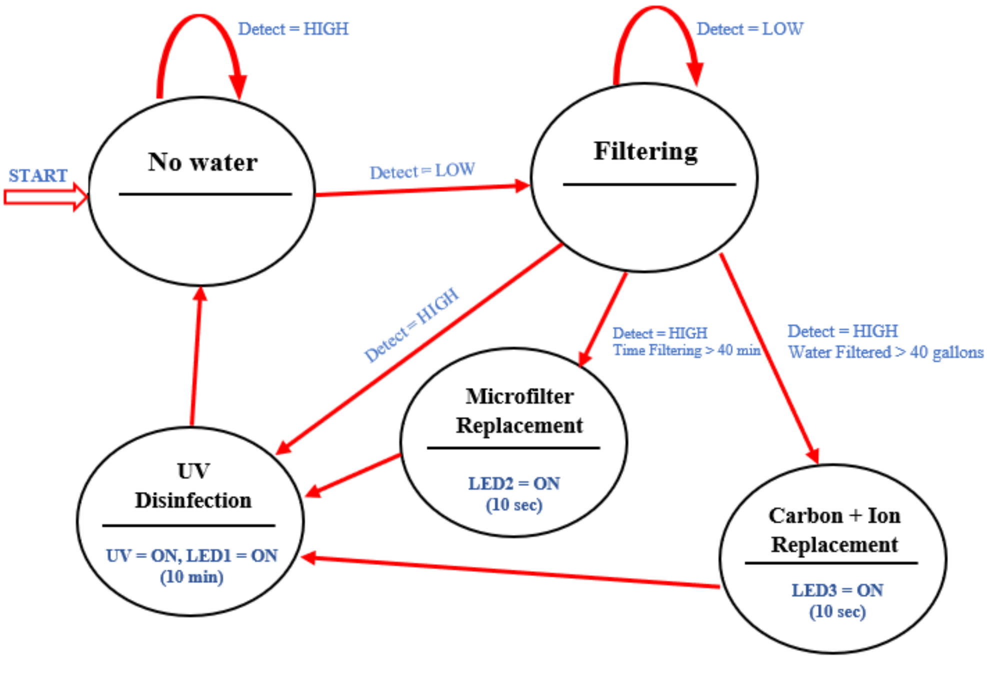

Ilustración 3 – Diagrama de estados

2.4 Comprobación del funcionamiento

Por último se comprobó que el diseño creado funcionaba correctamente. Primero se analizó que el hardware funcionaba correctamente, analizando cada subsistema por separado para evitar que posibles problemas en un subsistema no interfiriesen con otros subsistemas. Cuando todo el hardware funcionaba correctamente, se incluyó el programa y se comprobó que también funcionaba correctamente según diseñado aunque con algunas limitaciones debido a no usar algunos de los componentes del diseño original.

3. *RESULTADOS*

En términos generales, se ha logrado crear un sistema de filtración y purificación de agua portátil y funcional, aunque no funcione exactamente como se diseñó ya que el sensor de flujo dejó de funcionar y no había tiempo para remplazarlo.

Se ha conseguido crear un producto capaz de funcionar exclusivamente con energía solar durante las 24 horas del día gracias a una batería de apoyo que se carga durante el día con el exceso de producción del panel solar. Además, aunque no se ha analizado ninguna muestra en ningún laboratorio, los filtros utilizados ya han sido probados por su fabricante y garantizan una desinfección del 99,99% de la mayoría de las impurezas que pueda contener el agua. En cuanto a la desinfección del agua con luz ultravioleta, la potencia aplicada es superior a la mínima recomendada por los estudios. Por lo tanto, el primer requisito de alto nivel que consiste en garantizar una buena desinfección y filtrado, se cree que se ha logrado completamente.

El segundo requisito de alto nivel que consiste en encender los LEDs del interfaz de usuario correctamente se ha cumplido, ya que los tres LED se encienden cuando se supone que deben hacerlo gracias al microcontrolador. Sin embargo, la sustitución de los filtros sería más precisa si se utilizara el sensor de flujo de agua para no tener que suponer flujos constantes.

Por último, el proyecto se ha diseñado para que sea lo más económico posible, pero debido a la baja velocidad de filtrado y por tanto la necesidad de un sensor de flujo muy preciso y estar alimentado por energía solar, el precio final es bastante elevado. Sin embargo, se reducirá el precio por litro filtrado considerablemente construyendo un producto más grande y con mayor capacidad de filtrado de agua.

4. *CONCLUSIONES*

Aunque se haya conseguido cumplir todos los requisitos de alto nivel y crear por tanto un sistema completo y portátil de filtrado y desinfección del agua, el proyecto es todavía un prototipo. Antes de su posible comercialización o uso global se tiene que probar que funciona correctamente construyendo el diseño físico realizado en CAD, incluyendo el sensor de flujo y la PCB. A continuación, aunque en teoría funciona correctamente debe realizarse un análisis completo de varias muestras en el laboratorio para garantizar que la calidad de agua después de ser tratada por el producto es suficientemente buena para su consumo.

Por último, debido a ser un proyecto solidario con finalidad de acercar el consumo de agua limpia a cuantas más personas mejor, se debe minimizar el precio del producto final lo máximo posible. Para ello se cree conveniente crear grandes depósitos capaces de filtrar más litros de agua y por tanto ayudar a un mayor número de personas De esta forma el coste por cantidad de agua filtrada en litros se reducirá considerablemente debido a que un panel solar grande es menos costoso que la suma de varios paneles pequeños y se puede utilizar únicamente dos sensores por depósito sin importar el número de litros que sea capaz de filtrar.

5. *REFERENCIAS*

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SOLAR POWERED PORTABLE WATER FILTER

Author: Martínez Liñera, Alberto.
Supervisor: Fliflet, Arne.
Collaborating Entity: University of Illinois

ABSTRACT

The project consists of the development of a complete portable water filtration and disinfection system. The disinfection process will be fully automated, and the user will be advised when to replace each of the filters used to minimize the user interaction in the process. In addition, the project will be powered exclusively by solar energy so that it can be used in locations without access to the electrical grid.

Keywords: Water filtration, Water disinfection, Microfilter, Carbon filter, UV disinfection, Solar energy, Social project.

1. *INTRODUCTION*

Water consumption is essential to avoid dehydration throughout the day because approximately 60% of our body content is water. The Institute of the National Academies recommends drinking 2.7 liters for an adult woman and 3.7 liters for men daily to stay healthy [1].

Unfortunately, the latest published data on water access released in 2019 by WHO and UNICEF show that in 2017, more than 884 million people did not have access to safe water to drink and are therefore they are forced to consume contaminated water to survive [2]. This is a big problem because consumption of contaminated water can transmit diseases such as diarrhea, dysentery, typhoid fever, and polio, among others. To put it in perspective, it is estimated that drinking contaminated water causes 48,500 deaths from diarrhea each year [3].

Installing a water filtration and purification system is expensive, and many people do not have the resources to afford it. In less developed countries the problem is even greater because they typically have a higher content of bacteria and viruses in the water that subsequently cause diseases. In addition, it is common that many of these less developed countries also do not have access to the electricity grid and therefore some disinfection techniques are limited.

The objective of the project is to create a portable filtering system that allows the removal of impurities and bacteria through a series of filters, and then disinfect the filtered water with the use of ultraviolet light to eliminate the possible presence of viruses in the water. To be portable and not depend on having access to the electrical grid, the system will be powered exclusively by solar energy.

2. *METHODOLOGY*

The project has been divided into four parts: physical system design, hardware and PCB design, project programming, and functional testing.

2.1 Physical system design

It was decided to use a design similar to the commercial product LifeStraw Home Dispenser [4]. The product consists of two large tanks interconnected through a microfilter and a carbon filter. Two sensors have been used to automate the filtering process: a water detector and a flow sensor. The water detector will be placed at the bottom of the first tank to detect when there is water that needs to be filtered. The water flow sensor will be placed at the outlet of the filters to measure the filtration rate.

The ultraviolet light will be placed at the bottom of the second tank which will be covered with a material that does not allow the ultraviolet light to pass through, avoiding damage to the skin or vision of the user. All connections including the PCB and solar panel are conveniently located on one side of the system.

This design has been chosen because it allows the sensor connections to be perfectly protected and maximizes the exposure of ultraviolet light in the water as the LEDs are perfectly distributed at the base of the second tank. In addition, the PCB with all the connections is compact and hidden, improving the appearance of the final product. Below is an illustration of the main views of the design.

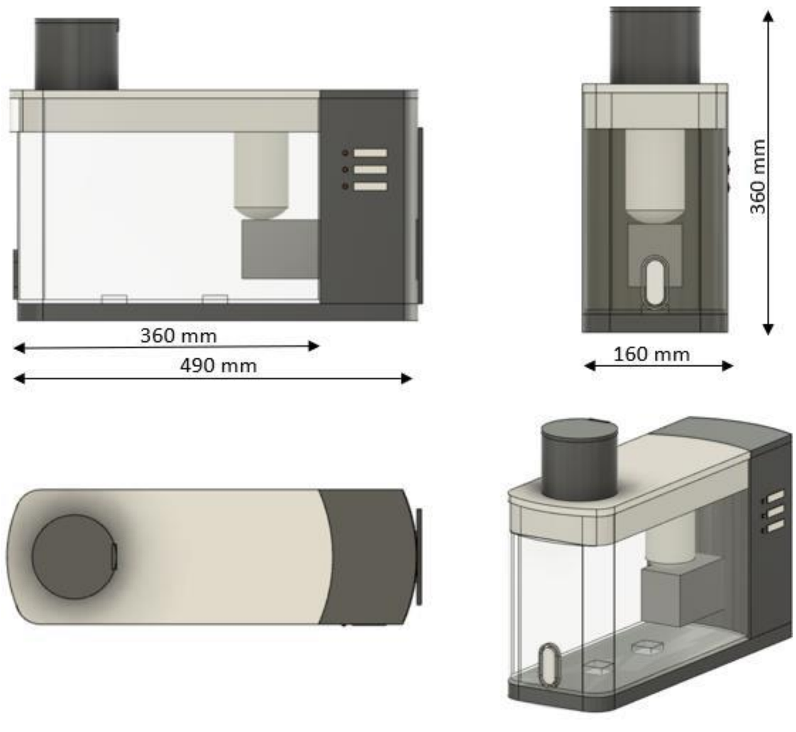

Illustration 1 – CAD Design of the project

2.2 Hardware and PCB design

For the design of the hardware and the testing of its operation, it has been decided to divide the project into five different subsystems, each of which performs a specialized function. These five subsystems are: power subsystem, sensing subsystem, control subsystem, disinfecting subsystem, and user interface subsystem. The five subsystems communicate with each other as shown in illustration two below.

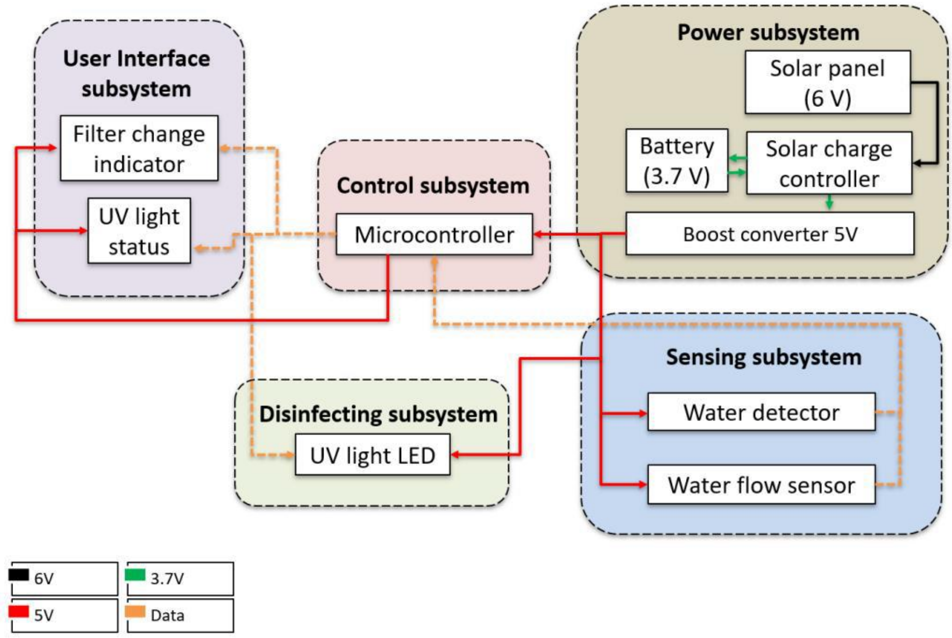

Illustration 2 – Block diagram of the interconnection of the subsystems

For the choice of the components, the compatibility between them has been analysed, considering the voltages and currents required by each one of them. To obtain the required voltages, two boost converters (voltage regulators that allow increasing the voltage) were used. A current and voltage analysis was also carried out to determine the minimum power that the solar panel should provide.

Other important design elements are the accuracy of the sensors and the efficiency of the UV filters and LEDs. Because the water flow at the output of the filters is small, a very accurate sensor with no minimum flow is needed. The efficiency of the filters and UV LEDs is very important because the aim of the project is to obtain the best possible water quality for the best possible price/performance ratio.

Once all the components have been chosen, and their auxiliary circuits (resistors, capacitors, diodes...) have been designed, the free software KiCad has been used to design the PCB. All the PCBs used have been ordered through PCBWay, a manufacturer that is specialized in their production.

Initially, two PCBs have been designed. The first one is the main PCB on which all the resistors, voltage regulators, capacitors, microcontroller, sensors, and LED connectors are soldered. The second PCB is a small PCB to solder the ultraviolet light LEDs to place them under the second tank. However, due to complications with some components, the main PCB had to be redesigned to update the connections and pins of some components.

2.3 Programming

An ISP (In System Programming) programmer was used to program the microcontroller because it allows the programming of the chip once it is installed in the complete system. Due to the component crisis produced by the Covid-19, the ATMEGA48-20AU microcontroller (originally chosen in the design) could not be used and finally, the ATMEGA328 microcontroller was used.

Arduino IDE has been used to write the code and program the microcontroller because of being compatible with the ATMEGA328. The pins of the microcontroller had to be assigned with those associated with Arduino [5].

Due to having only two inputs (the water detector and the flow sensor) and because the output depends on the previous state, it was decided to use a state machine to program the microcontroller. Initially, the program consisted of six states, but because the flow sensor stopped working two weeks before the demonstration of the project, the program had to be reduced and some assumptions had to be made. Constant flow was assumed throughout the entire filtering process and the number of states was reduced to five.

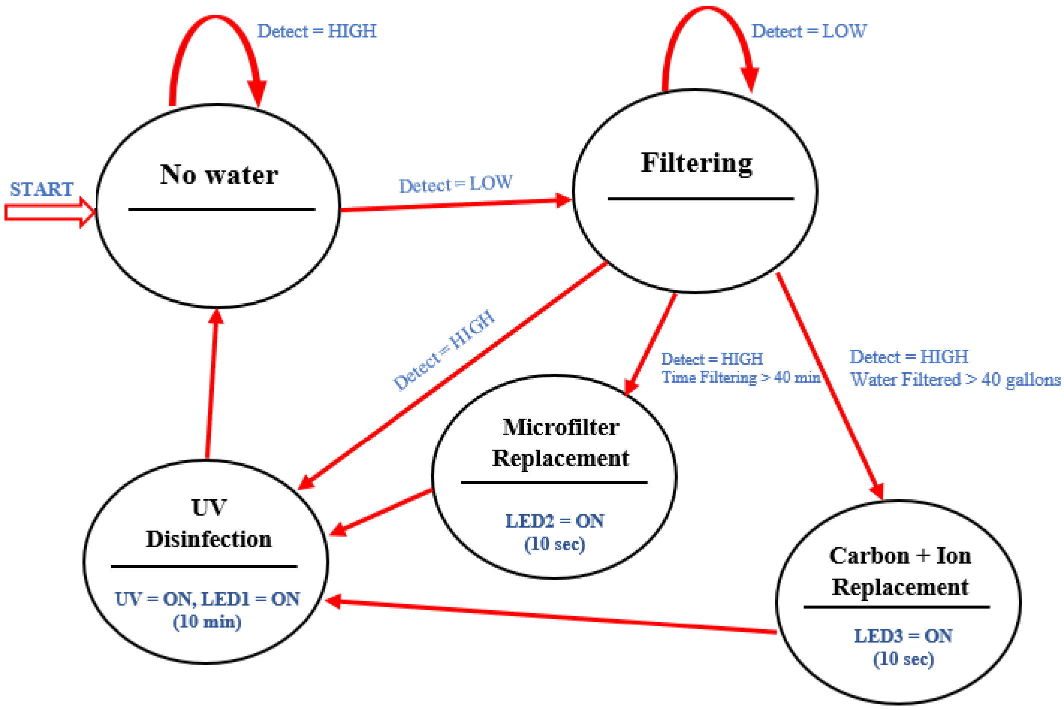

Illustration 3 – States Machine

2.4 Performance testing

Finally, the design was evaluated to ensure that it worked correctly. First, the hardware was evaluated to ensure that it worked correctly, analyzing each subsystem separately so that likely problems in one subsystem would not interfere with other subsystems causing problems on them. When all the hardware was working correctly, the program was included and checked that it also worked correctly as designed, although with some limitations.

3. *RESULTS*

Overall, a portable and functional water filtration and purification system has been created, although it does not work exactly as designed since the water flow sensor stopped working and there was no time to replace it.

It has been possible to create a product that runs exclusively on solar energy 24 hours a day thanks to a backup battery that is charged during the day by the excess output of the solar panel. Furthermore, although no samples have been analyzed in any laboratory, the filters used have already been tested by their manufacturer and guarantee a 99.99% disinfection of most of the impurities that the water may contain. As for the disinfection of water with ultraviolet light, the power applied is higher than the minimum recommended by the studies. Therefore, the first high-level requirement that consists of eliminating almost all the impurities, is believed to have been fully achieved.

The second high-level requirement which is to guarantee the proper function of the user interface has also been met, as all three LEDs light up when they are supposed to thanks to the microcontroller. However, the replacement of the filters would be more accurate if the water flow sensor were used so that constant flows during the filtration were not assumed.

Finally, the project has been designed to be as economical as possible, but due to the low filtering rate and therefore the need for an exactly accurate flow sensor and being solar powered, the last price is quite high. However, the price per liter filtered will be reduced considerably by building a larger product with a higher water filtering capacity.

4. *CONCLUSIONS*

Although it has succeeded in meeting all the high-level requirements and thus creating a complete and portable water filtration and disinfection system, it is still a prototype. Before its possible commercialization or global use, it must be proven to work correctly by building the physical design made in CAD, including the flow sensor and PCB. Next, even if it theoretically correctly works, a complete analysis of several samples must be performed in the laboratory to ensure that the water quality after being treated by the product is good enough for consumption.

Finally, because it is a solidarity project with the aim of bringing access to clean water to as many people as possible, the price of the product should be minimized as much as possible. In this way, the cost per liter of filtered water will be considerably reduced because a large solar panel is less expensive than the sum of several small panels and only two sensors per tank can be used regardless of the tank size.

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[3] World Health Organization. "Drinking-water.", [Online], March 2022. [Accessed: 2 May 2022]. Available at: https://www.who.int/news-room/fact-sheets/detail/drinking-water#:~:text=Contaminated%20water%20can%20transmit%20diseases,000%20diarrhoeal%20deaths%20each%20year.

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CHAPTER 1. INTRODUCTION

Water consumption is essential to avoid dehydration throughout the day because approximately 60% of our body content is water. The Institute of Medicine of the National Academies recommends drinking 2.7 litres for an adult woman and 3.7 litres for men to stay healthy [1].

Unfortunately, there are many places in the world where people do not have access to clean drinking water and are forced to drink contaminated water to maintain the water levels needed to survive. The latest published information on Access water published in 2019 by WHO and UNICEF show that in 2017, more than 884 million people did not have safe water to drink [2]. This is a huge problem because contaminated water can transmit diseases such as diarrhoea, dysentery, typhoid, and polio. To put this in perspective, drinking contaminated water is estimated to cause 48,500 diarrhoeal deaths each year [3].

The installation of a water filtration and purification system is very expensive, and many people do not have the resources to afford it. In less developed countries the problem is even greater as water is used directly from lakes or rives, which tend to be more contaminated with pollutants and contain a higher diseases content. In addition, it is common that many of these less developed countries also do not have access to electricity grid. As a result, some water disinfection techniques are limited.

The aim of the project is to create a portable tank that allows the removal of impurities and bacteria through a series of filters, and then disinfect the water filtered by eliminating the possible presence of viruses using ultraviolet light. To be totally portable and not depend on having access to the electricity grid, the system will be powered exclusively by solar energy.

The project has been designed with the aim of increasing the number of people who have access to clean water in less developed countries. However, due to its characteristics, it can also be used for domestic use to improve the quality of tap water.

CHAPTER 2. TECHNOLOGY DESCRIPTION

This section will discuss the specific technologies and tools that have been used to carry out the project to facilitate reading and understanding the rest of the paper.

2.1 PCB

A PCB (printed circuit board) is a circuit whose components and conductors are contained within a mechanical structure. The conductive functions include copper traces, terminals, heat sinks or flat conductors. The mechanical structure is made of insulating laminate material sandwiched between layers of conductive material. The overall structure is plated and covered with a non-conductive solder mask and a printing screen for electronic component legend location [4]. Figure 1 shows a rendering of a PCB that has several components soldered to it.

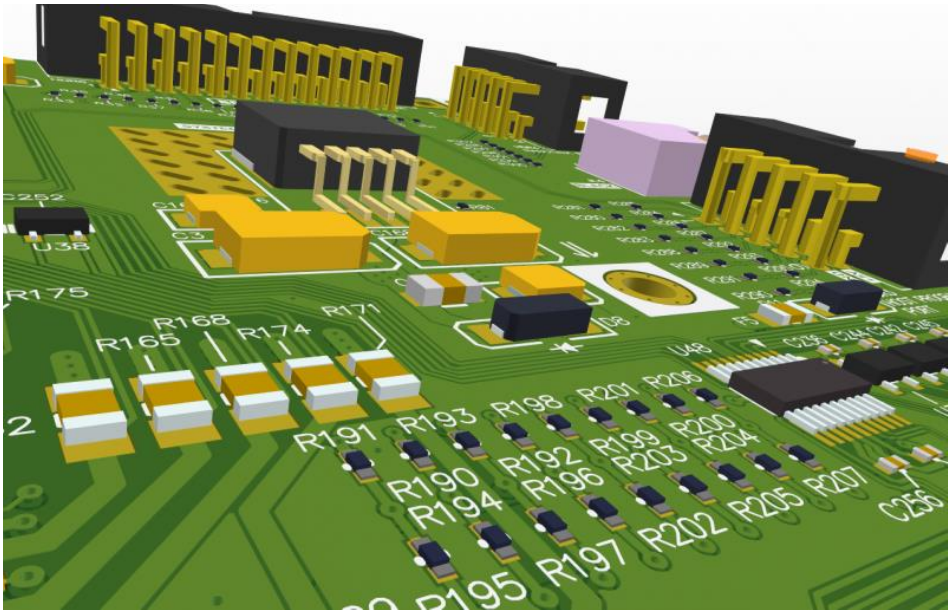

Figure 1. PCB with components soldered to it [4]

The printed circuit board is constructed by alternating layers of conductive copper with layers of non-conductive insulating material. During fabrication, the inner copper layers are etched leaving intentional copper traces to connect the circuit components. Once laminated, the insulation material is etched to the copper layers and so on until the printed circuit board is complete.

The components are added to the outer layers of the printed circuit board when all layers have been etched and laminated together. In this project, both surface mount components and through-hole parts have been soldered manually.

Before PCBs, electrical circuits were built by attaching individual wires to components. Large circuits with many components contain many wires. The number of wires was so large that they could become entangled or take up a large amount of space within a design. In addition, soldering components directly to wires is more laborious and complicated.

2.2 UV DISINFECTION

UV disinfection is a process that, as its name indicates, consists of using ultraviolet light rays to disinfect surfaces or eliminate the presence of viruses in the air or in any liquids such as water.

Ultraviolet light is light whose wavelength is between 200 nm and 400 nm as shown in Figure 2.

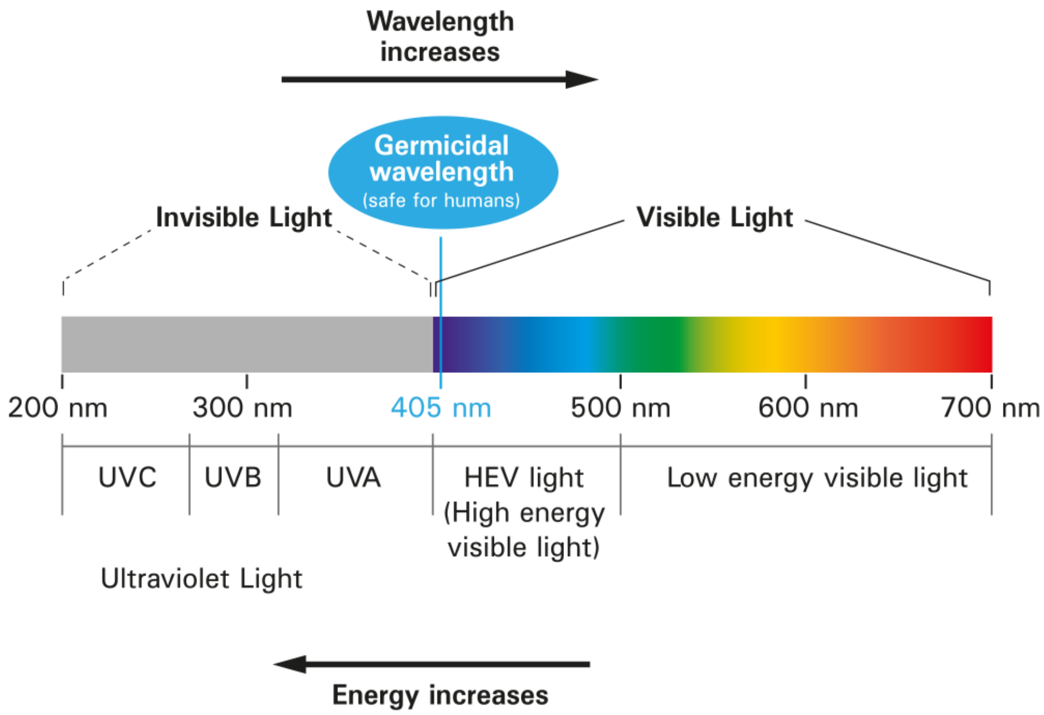

Figure 2. Electromagnetic spectrum [5]

Specifically for the elimination of virus, UVC light is used whose wavelength is between 200 nm and 280 nm. The UVC light is the part of UV light that contains a higher energy because it has a shorter wavelength.

UVC light allows eliminating the presence of viruses since the rays of this type of light are absorbed by the nucleic acids (in RNA and DNA) causing damage to them [5]. UV light can directly kill or generally eliminate the reproductive capacity of microorganisms so that they cannot spread and eventually die.

The problem is that just as it can eliminate virus content, direct exposure to this type of light is also harmful to human tissues and therefore exposure should be avoided. If tissues are damaged and lose the ability to reproduce and therefore regenerate, the next harmful exposure could cause the onset of cancer.

Fortunately, ultraviolet C light from the sun is completely filtered by the ozone layer and therefore it is not a significant risk. Handling ultraviolet light lamps or LEDs must be careful but using the right equipment such as goggles and long clothing should not lead to any health problems.

CHAPTER 3. STATE OF THE ART

For the complete disinfection and purification of water, it is necessary to perform three disinfection processes. Currently, no system can perfectly improve water quality because the implementation of only one process after the other would make the disinfection process very costly and not very useful in many cases.

This chapter aims to explain the current state of disinfection techniques. These three techniques are the ones that have served as the basis for creating the new project, improving its functionality, and achieving a complete and economical disinfection system that does not exist at present.

3.1 MICROFILTER

In general, in developed countries such as the United States, the most widely used disinfection system is the use of a microfilter. There are many conventional products such as jars or tanks that have a built-in filter of this style, which must be replaced from time to time. Some of the best manufacturers of these most famous products are Brita, LifeStraw, and Laica.

The operation of the filter is quite simple. The water is introduced in a previous tank and is filtered by passing through a pore size membrane equal to 0.2 micrometres. This filter can effectively remove bacteria, parasites, and microplastics. Typically, this filter needs to be replaced once per year, but it depends on the quality of water introduced to be filtered and the number of litres that has filtered.

The filtering time is quite long because all the water must pass through a very small pore size membrane. To filter a litre of water, with a filter in perfect condition usually takes at least 6 minutes. There are other types of filters with larger pore size that are placed directly on the tap, but they reduce the pressure which is not convenient in some cases.

3.2 ION + CARBON FILTER

The Ion + Carbon filter is a less conventional filter but companies like LifeStraw already have it for sale as one of their products. This filter must be replaced more frequently (about 2 months with a familiar daily use), but it is very useful. This new technology greatly reduces the content of heavy metals such as lead, mercury, chromium, cadmium, copper... It also reduces the content of chlorine and pesticides and improves the smell and taste of the water.

Carbon filters are made of small pieces of carbon in block or granular form that have been pre-treated to be extremely porous. As water passes through the filter, contaminants and other substances are absorbed by the carbon pieces, and thus removed. The efficiency of this type of filter depends on the flow rate of the water, the lower the flow rate, the higher the efficiency. It is therefore better to place the carbon filter after a microfilter because the flow rate is lower. In addition, having already removed some particles, the carbon filter will have a longer life.

Figure 3 shows a microfilter and a carbon filter of the brand LifeStraw that have been used in this project.

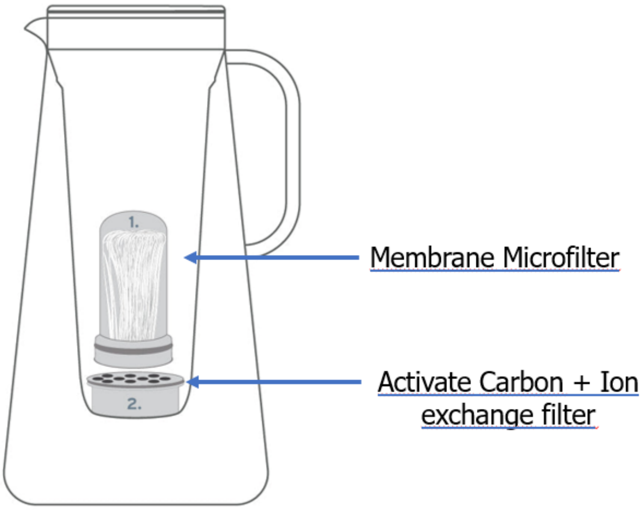

Figure 3. LifeStraw Microfilter and Carbon Filter [6]

3.3 UV LIGHT DISINFECTION

UV light type C (wavelength between 280nm and 200nm), is very effective in eliminating viruses and bacteria in water. In the disinfection process, the viruses present in the water are exposed to ultraviolet light which attacks the genetic code of the microorganism eliminating its reproduction function. This technique is explained in greater depth in section 2.

Nowadays, the most widely used products to disinfect water and therefore eliminate the viruses present in it, are placed in a part of the pipe so that when the water circulates through it, the ultraviolet light disinfects the water. However, this system is not very efficient, and it is very expensive. Because the water circulates with a high flow inside the pipe, the exposure time to the ultraviolet light is minimal and that is why the light power of the ultraviolet light must be very high. In addition, for proper operation, the light must be on all the time. In economic terms it is also a problem since this type of systems usually cost between 700 and 1000 euros, so its use in poor places with few resources is impossible.

CHAPTER 4. PROJECT DEFINITION

4.1 SOLUTION

As a solution to the problem presented in the introduction, about the huge amount of people who do not have access to clean water for their own consumption, a portable water filtration and disinfection system has been designed. For a complete improvement in water quality, the system must be able to remove most impurities, metals, bacteria, and viruses from water.

The system designed is a two-tank system. In the first tank will be introduced the water to be filtered, which will periodically flow through the microfilter and the carbon filter to the second compartment. Thanks to these two filters most impurities, metals and bacteria will be removed. In the second tank, once all the water introduced in the first tank has been filtered, to increase the efficiency, ultraviolet light will be applied to eliminate the possible virus content it may contain.

This is a general idea of how the project works; however, the system is actually much more complex as it consists of several sensors, a microcontroller, a solar panel, a battery, LEDs... among other components. The detailed process of the system is described below.

First, the water to be filtered is introduced into the first tank. At the bottom of this first tank there is a water detector sensor that is always operating and will send a signal to the microcontroller when it detects the presence of water through its traces. This sensor will be used to indicate to the microcontroller that it has to start storing the measurements obtained by the water flow sensor which will be discussed later. It will also be used to know when the first tank is empty and therefore all the water has been completely filtered to start the UV disinfection. During disinfection, because the UV light is quite dangerous, an LED will light up to indicate to the user that the UV light is on to prevent the tank from being left on, leaving the lights visible.

Between the two tanks are the filters and a water flow sensor that measures the flow rate of the water after it has been filtered by both filters. This sensor allows to determine when each of the filters should be replaced, to indicate it to the user with two additional LEDs. This function is very important because when the filters are heavily used, they stop working properly. If one of the two filters needs to be replaced, this will be indicated to the user just before starting disinfection with UV light. The ultraviolet light will still be applied to at least remove the virus content even if the impurities have not been completely removed.

When the microfilter is heavily used, the filtration rate decreases and so does the flow rate at the filter outlet. Therefore, when the maximum flow rate at the filter outlet is considerably lower than typical, it is a symptom that the microfilter should be replaced.

As for the carbon filter, the flow remains unchanged so the waterflow sensor measurement cannot be used directly. To indicate when it should be changed, the manufacturer's recommendation on the maximum number of litres it can filter will be followed. With the measurements of the waterflow sensor and considering the time that it is filtering thanks to the water detector, the amount of water that has been filtered can be calculated and stored in the microcontroller. When this amount is greater than the limit, the LED that indicates its replacement will light up.

Finally, the entire system is powered exclusively by solar energy. During the day, the system is powered by the solar panel while the backup battery is being charged. At night or when the power generated by the solar panel is less than what the circuit needs, the battery will be in charge of providing the necessary energy.

To clarify the understanding of the realized system, a sketch drawing has been created to serve as a visual aid. Figure 4 below shows the visual aid.

Figure 4. Visual aid to help interpret the product

4.2 HIGH-LEVEL REQUIREMENTS

For the project to work properly and really be useful to solve the problem of access to clean water, it must meet 4 requirements mentioned below.

- ***Eliminate 99.99% of bacteria, viruses, and heavy metals present in water***

The design of a system of a microfilter and a carbon + ion filter requires a lot of research and investment and is therefore outside the scope of this work. Therefore, to guarantee 99.99% removal of bacteria and heavy metals, two conventional filters (microfilter and carbon + ion filter) will be chosen. Both filters must have been tested for proper operation by analysing water samples in a laboratory. In addition, it will be necessary to analyse how often they must be replaced, and a system will be implemented to alert the user when they must be replaced.

- ***LEDs that indicate the replacement of filters should indicate the correct thing***

The user interface consists of 3 LEDs, which must light up exclusively when convenient.

The first LED indicates that the UV light is on. Because prolonged exposure to ultraviolet rays can cause skin or eye problems, it is convenient to warn the user when the UV light is on. However, the system is set up so that the UV light is not visible at any time and can cause this problem.

The second LED should light up when the microfilter needs to be replaced. To know when it needs to be changed, a water flow sensor will be used so that when the water flow decreases considerably it is time to change it.

The third LED should light up when the carbon + ion filter needs to be replaced. Since the flow rate does not decrease when this filter is in bad condition, the LED will light up when the number of litres indicated by the manufacturer as recommended has been filtered. For this, the flow rate will be measured with the water flow sensor and the time to calculate the number of litres filtered

- ***The system should be able to operate all day long using only solar energy***

To be installed in locations without access to the electrical grid, the system must operate exclusively on solar energy. For this purpose, a solar panel will be used to power the circuit and charge a battery during the day, and the energy stored in the battery will be used at night. In this way, the system should be operational 24 hours a day.

- ***The project must be as economical as possible***

Although some elements such as the solar panel or batteries will increase the cost of the project, the disinfection system will be designed to be as economical as possible. This is one of the most important main goals because the more economical it can be the more families will have access to clean drinking water.

4.3 SUSTAINABLE DEVELOPMENT

The SDGs (Sustainable Development Goals) is a set of goals adopted by the UN (United Nations) to eradicate poverty, protect the planet, and ultimately improve the global situation [7]. The intention of this section is to relate some of these goals to the project done to demonstrate that it meets them.

- ***Objective 3: Health and well-being***

The improvement of water quality due to its filtration will reduce the number of diseases due to the ingestion of contaminated water. It will therefore improve the health of users and prevent many annual deaths.

- ***Objective 6: Clean water and sanitation***

The project focuses on the complete filtering and disinfection of the water, so this is the main objective it fulfils. The final water will be free of impurities, heavy metals harmful to health, bacteria, and viruses.

- ***Objective 7: Affordable and non-polluting energy***

The entire project will run exclusively on renewable energy as it will be powered solely by a solar panel. Therefore, only the manufacturing process would be polluted. During operation, pollution emissions would be zero and all the energy produced would be completely free.

- ***Objective 11: Sustainable cities and communities***

This is only a prototype that could be used by one or two families exclusively. If rescaled it could be used in public places in cities to allow citizens of less developed countries to become a little more sustainable by having a clean water source.

4.4 WORK METHODOLOGY

First, a study and all the necessary research was carried out to ensure that the water, once filtered and disinfected by the product, is in perfect condition. To do this, we chose which filters (microfilter and carbon filter) are the most convenient to use considering the percentage of elimination of each of the impurities, duration, and cost. In addition, the minimum possible UV light power was chosen to eliminate possible viruses present in the water in the correct period. At this stage of the project, it was also decided which sensors and which microcontroller were the most appropriate to fully automate the water filtering process.

Once all the main components of the system were chosen, the voltage at which each of them worked was observed to achieve by means of voltage regulators and boost converters the right voltage for each of them. Voltage regulators are very important because not all components can operate at the same voltage. For example, the microcontroller and sensors are powered at 5V, but the ultraviolet light needs more voltage to illuminate with the necessary power to kill viruses. Finally in this first stage of the project, a current analysis was performed to know the minimum power needed to supply the solar panel to power the circuit and charge the battery that will be used at night when the sun goes down.

Once all the components were chosen, a PCB (printed circuit board) was designed using the free KiCad software and then ordered through PCBWay. It was decided to use a PCB to reduce the size of the circuit by soldering all the components on it instead of connecting them through wires to a breadboard. This avoids crossover between wires, provides stronger connections, and reduces the size of the circuit, ultimately improving the functionality of the project. In addition, by using a PCB, the circuit has a higher resistance, useful life, and better thermal dissipation.

Then, while waiting for the arrival of the components and the PCB, a physical design of the project was made using CAD to show the mechanical workshop (assistants to perform the mechanical part of the project from the electrical and computer engineering department of the University of Illinois) how the project was intended to be physically and the approximate measurements of each part. They were also provided with all the large components of the project such as the sensors or the solar panel as soon as they arrived so that they could include them in the design.

Once the PCB arrived, all the components previously ordered and tested were soldered on the main board. To test it properly, first each component was tested separately, and then each subsystem was tested separately to check its correct functioning. The project consists of 5 subsystems which are: Power Subsystem, Detection Subsystem, Control Subsystem, Disinfection Subsystem and User Interface Subsystem. The power subsystem consists of a solar panel, a battery and all the voltage regulators needed to create the circuit. The detection subsystem consists of the water detector and the water flow sensor. The control subsystem is the microcontroller that will be used to program the project. The disinfection system is in charge of the filtering with the microfilter and the carbon + ion filter and the removal of viruses with the ultraviolet light. The 5 subsystems will be better explained in section 5 in which the entire project design is addressed.

Finally, once all the hardware was working, the microcontroller was programmed using Arduino IDE so that the ultraviolet lights and the user interface would turn on exclusively when needed based on the measurement of the two sensors (water detector and water flow sensor).

Table 1 below shows approximately how much work was done during each week to complete the project.

WEEK	WORK PLAN
02/07	— Get the project idea approved — Finish the project proposal with the 3 main high-level requirements and the basics of the project.
02/14	— Find more specific information and add it to the proposal — Find how to power the system with the battery and the solar panel at the same time. — Design the entire circuit
02/21	— Order first components — Finish PCB design — Complete Design Document
02/28	— Get PCB approved — Start testing some components
03/07	— Order PCB — Make a CAD design of our project
03/14	— Spring Break
03/21	— Complete PCB board assembly with soldering and mounting — Help program the microcontroller
03/28	— Test hardware systems and fix possible problems — Help to finish software
04/04	— Perform full system testing with software — Fix major communications between software and hardware
04/11	— Test and debug the full system — Final Assembly
04/18	— Mock demo with the TA — Implement TA advice — Prepare the demonstration with the professor
04/25	— Demonstration to the professor — Elaborate on the final presentation slides
05/02	— Deliver the final presentation — Finish the final paper to Illinois
Rest of May	— Write a final paper to ICAI

Table 1. Distribution of the tasks during the week

4.5 COSTS

To estimate the cost calculation, we have differentiated between the labor hours spent in the project, the cost of the components and the manufacturing cost.

4.5.1 LABOUR COST

Based on the average salary of an Electrical and Computer Engineering from University of Illinois ($40/hr) and estimating that we have worked 10 hours per person per week on the project throughout the semester. In addition, we add a 2.5 multiplier for all costs associated with scaling up the project to a company and the uses of university laboratories and instruments.

$$Cost_{labor} = {}^{\$}/_{Hour} * {}^{Hour}/_{Week} * weeks * members * multiplier =$$

$$= 40 * 10 * 15 * 3 * 2.5 = \$45{,}000$$

4.5.2 PARTS COST

The costs of the components are shown in Table 2 below.

PART	PART NAME	PRICE PER UNIT	QUANTITY	PRICE
Full Replacement Filter	LifeStraw Home Full Replacement Filter	$24.95	1	$24.95
Ion + Carbon Filter replacement	LifeStraw Home Replacement Filters	$12.95	1	$12.95

Continued on next page

PART	PART NAME	PRICE PER UNIT	QUANTITY	PRICE
Coffee filter as pre filter	10-12 permanent Coffee filter	$8.99	1	$8.99
Solar Panel	Large 6V 3.5W Solar panel – 3.5 Watt	$45	1	$45
Boost Converter 7V	DCP020507	$11.31	1	$11.31
Boost Converter 5V	RP400N501A	$1.41	1	$1.41
Solar Charge Controller	Model Adafruit Product ID 4755	$14.95	1	$14.95
Battery 3.7V 10050 mAh	Model Adafruit Product ID: 5035	$29.95	1	$29.95
DC Jack Adapter Cable	3.8 / 1.3mm or 3.5 / 1.1mm to 5.5 / 2.1mm DC Jack Adapter Cable	$1.50	1	$1.50
Water flow sensor	FS1025-2001-DL	$58.12	1	$58.12
Water detector	101020018	$3.2	1	$3.2
Microcontroller	ATMEGA48-20AU	$2.76	1	$2.76
UV Lights	ELUC3535NUB-P7085Q15070100-	$7.08	2	$14.16
Mosfets	MOSFET N-CH 30V 100MA USM	$0.23	2	$0.46

Continued on next page

PART	PART NAME	PRICE PER UNIT	QUANTITY	PRICE
Schottky diodes	SBR1A20T5-7	$0.41	2	$0.82
LEDs	SSI-LXH312ID-150	$1.24	3	$3.72
Resistor 20 Ω	RMCF2512FT20R0	$0.37	1	$0.37
Resistor 140 Ω	RC0805FR-07140RL	$0.09	3	$0.27
Resistor 2.2 kΩ	CRGCQ0805F2K2	$0.09	2	$0.18
Resistor 2.8 kΩ	RNCP0805FTD2K80	$0.09	2	$0.18
Resistor 10 kΩ	RNCP0603FTD10K0	$0.09	1	$0.18
Capacitor 1 uF	CL21B105KAFNNNE	$0.09	1	$0.18
Capacitor 2.2 uF	DFE252012F-2R2M=P2	$0.34	1	$0.34
Capacitor 10 uF	CL21A106KOQNNNE	$0.1	2	$0.1
Inductor 10 uH	L0603B100KDWFT	$0.44	1	$0.44
2 Pins Connectors	900-0022232021-ND	$0.14	8	$1.12
4 Pins Connector	PBC04SACN	$0.49	1	$0.49
6 Pins Connector	2057-BHR-06-VUA-ND	$0.24	1	$0.24
ISP Connector	SBH11-NBPC-D03-	$0.75	1	$0.75
			Total	$239.09

Table 2. Parts cost

4.5.3 MACHINE SHOP COST

Approximately cost of the machine shop to create a compartment to adhere to the tank to place our components and coat the project with a UV light filter to prevent damage to the user.

PARTS	PRICE
CONTAINER	\$100
UV Light film	\$28
Labor	\$400
Total	\$528

Table 3. Fabrication cost by the machine shop

4.5.4 SUM OF COST

The total cost of the project is:

$$Cost_{total} = Cost_{labour} + Cost_{parts} + Cost_{machine\ shop} =$$

$$= 45{,}000 + 238.29 + 528 = \$45{,}767.09$$

The total cost of the project may seem very high for a solidarity project aimed at ensuring that as many people as possible have access to clean water to drink every day. Because it is a solidarity project, all the hours of work invested would be free, reducing the cost to a great extent. In addition, the price of the components for water that is filtered. This is because the solar panel, the battery and the waterflow sensor among others have a very high price. However, by rescaling the project to filter a larger amount of water, the price would increase much less compared to the growth in the number of litres filtered.

4.6 ETHICAL CONSIDERATIONS

In this section we intend to discuss all the ethical considerations and safety measures necessary to carry out the project and its subsequent use.

4.6.1 ETHICAL REQUIREMENTS

Ethical considerations in the project are fundamental because it is a research project and involves the collaboration of professors. The work done by them must be rigorously accredited.

1. Commitment not to commit any type of plagiarism during the realization of this project and to respect the copyrights of the documents and audio-visual media used in the realization of this project. If other resources are used, they will be properly cited, and credit will be given to anyone who has participated in the realization of the project. I-1, 7.8.I-3, 7.8.I-4, and 7.5.I-5 of the IEEE Code of Ethics [8].

2. The project should not violate any ethical guidelines and should strive to help people gain access to safe drinking water. The goal is to help all people who cannot access clean drinking water for any reason to purify their drinking water using the new device. Therefore, sections 7.8.II-7 of the IEEE Code of Ethics [8] are complied with.
3. Commitment to accept all kinds of comments and constructive criticism that will help to improve the device and make it safer for its users. This is because the device has the potential to affect many people. Therefore, it complies with section 7.8.II-5 of the IEEE Code of Ethics [8].
4. Commitment to treat all people involved in this project with respect, to not allow any harassment, and to avoid harming others by adhering to strict safety codes. I-7, 7.8.I-8, and 7.5.I-9 of the IEEE Code of Ethics [8].
5. Commitment to follow all laboratory rules and regulations while in use and ensure that no laboratory equipment is damaged. In case of any damage caused by improper use of the equipment, the laboratory managers shall be informed immediately.

4.6.2 SAFETY REQUIREMENTS

Although there are no U.S. federal regulations specific to water filtration and treatment or residential purification systems, it is necessary to adhere to a strict safety code of conduct, as our device has the potential to harm humans if misused or if proper safety measures are not followed in its manufacture.

1. Commitment to prioritize the safety of all people working on the project, as well as the safety of the user. The project uses UVC lights to disinfect the water. Direct exposure to this type of light is harmful to human skin and eyes. Therefore, they are a health hazard for people and can cause serious eye or skin problems, even cancer if there is repeated and prolonged exposure. Therefore, the device should be tested and confirmed that there is no UVC light leakage outside using a UV light sensor before it is used by a user outside the laboratory without proper safety measures.

2. Commitment not to harm any person present in the laboratory during the project fabrication process. This involves the proper use of voltage sources and covering and warning others in the laboratory before turning on the UV light.
3. Limit user interaction to introducing water into the first tank and changing filters, when necessary, never making modifications to the UV disinfection process.
4. Due to the use of high currents to power the entire circuit, special care should be taken and all modifications to the circuit should be made when all sources or batteries are disconnected. In addition, the current produced by the voltage source should always be limited to reduce the risk of an accidental short circuit. Currents higher than 10mA can be sufficient to cause muscular paralysis, while currents higher than 75mA can cause muscular defibrillation which can be lethal if medical assistance is not received promptly.
5. To avoid any kind of risk, it is never possible to work in the laboratory individually because, in case of any problem, no one could help, and this could cause a huge problem such as loss of life.

6. Promise to always be honest about the efficiency of the created device and the extent to which it can purify water. Since the consumption of not properly treated water containing large impurities and viruses can cause huge health problems such as dangerous diseases, it is unacceptable to lie about the efficiency of the project. Giving wrong information about the filtering system can harm many people. Therefore, before the commercial use of the product, numerous tests should be carried out on water samples with different content of impurities and contaminants.
7. Final commitment to ensure that our product is safe for use by others before attempting to demonstrate its performance universally.

These guidelines apply to everyone involved in the project, must be adhered to, and each member must be held accountable for following these guidelines as specified in 7.8. III10 [8].

CHAPTER 5. PROJECT DEVELOPMENT

This chapter will explain all the design decisions taken during the realization of the project. First, the proposed physical design will be analysed and then the hardware and software design (in the control subsystem) will be explained.

5.1 PHYSICAL DESIGN

5.1.1 PERSONAL DESIGN

For the creation of the complete water filtration system in physical form, it is believed convenient to use a design similar to the LifeStraw Home Dispenser [9] because the two filters intended to be used are specialized for this product. The dispenser consists of two large reservoirs connected through the filters. In the upper reservoir, the contaminated water is introduced and periodically filtered by passing it to the lower compartment. As shown in Figure 5, the filters (microfilter and carbon filter) are located inside the white cylinder that connects the two tanks.

At the bottom of the first tank, the water detector would be located, placing the connections on the outside because they are not waterproof. To avoid a leakage of water that could damage the connections, the hole through which they exit must be properly sealed with silicone or some similar material.

The water flow sensor, on the other hand, would be located inside the grey box in the second compartment. In this way, the connections would be protected and would have direct access through a side to be connected to the PCB. In addition, the water flow sensor would be placed vertically, letting the water flow in favour of gravity so as not to experience a reduction in velocity and that the flow measured by the sensor, is the filtered one.

The ultraviolet LEDs have been placed at the bottom of the second tank, creating a kind of transparent box made of a material that does not block the passage of ultraviolet rays. This location is the most convenient because the light can be evenly distributed throughout the tank, thus maximizing light exposure.

Additionally, inside the upper grey cylinder, there would be a pre-filter to filter the biggest impurities and avoid the clogging of the microfilter. On the side inside a box would be the PCB and just outside the user interface and the solar panel located vertically.

To make the idea more visual it has been decided to create a CAD design using Fusion360. Figure 5 below shows the main views of the design and the overall dimensions of the product.

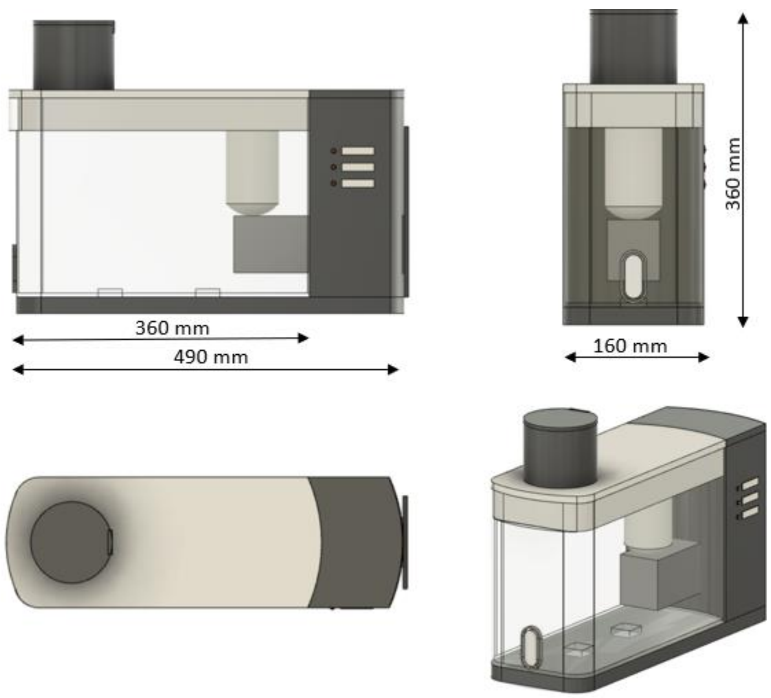

Figure 5. CAD of the Physical Design

A more detailed drawing of the final product with all the important measurements and views can be found in Appendix A.

5.1.2 MACHINE SHOP DESIGN

Starting from the physical design created in CAD and letting them know all the specifications that the project had to have at a physical level for its correct operation, the machine shop designed the sketch represented in figure 6 [10].

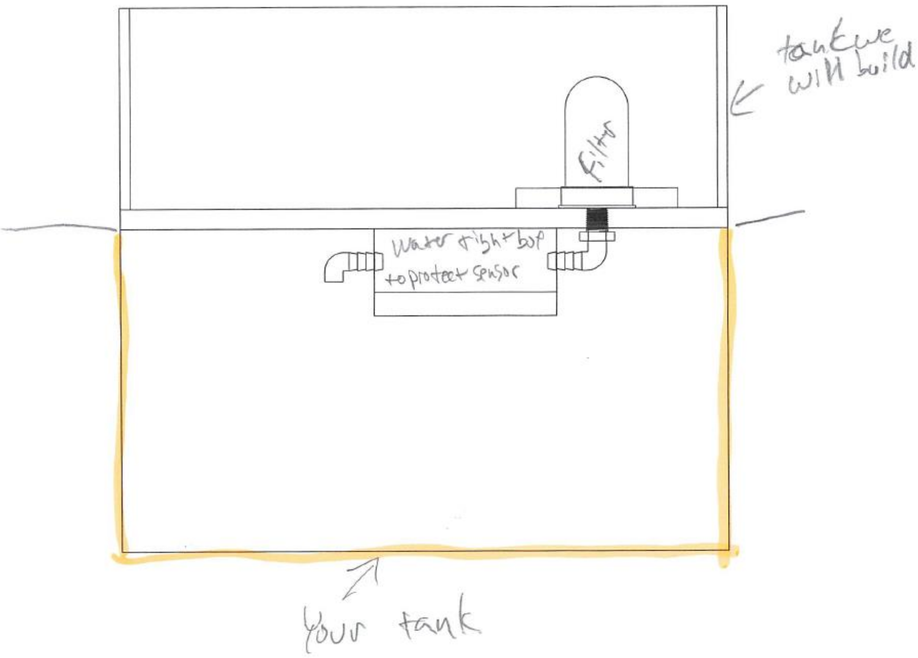

Figure 6. CAD of the Physical Design by Machine Shop [10]

As can be seen in the image, the physical design that was finally created differs a lot from the physical design made in CAD. Once the sketch was received, we tried to make some modifications to try to make the design more similar to the original one, such as placing the water flow sensor vertically or positioning the filters as in the original design. However, justifying that the project is simply a prototype and not a final product and for simplicity, it was decided to build the project following the sketch proposed by the machine shop.

A photo of the final physical project is shown in Figure 7 below.

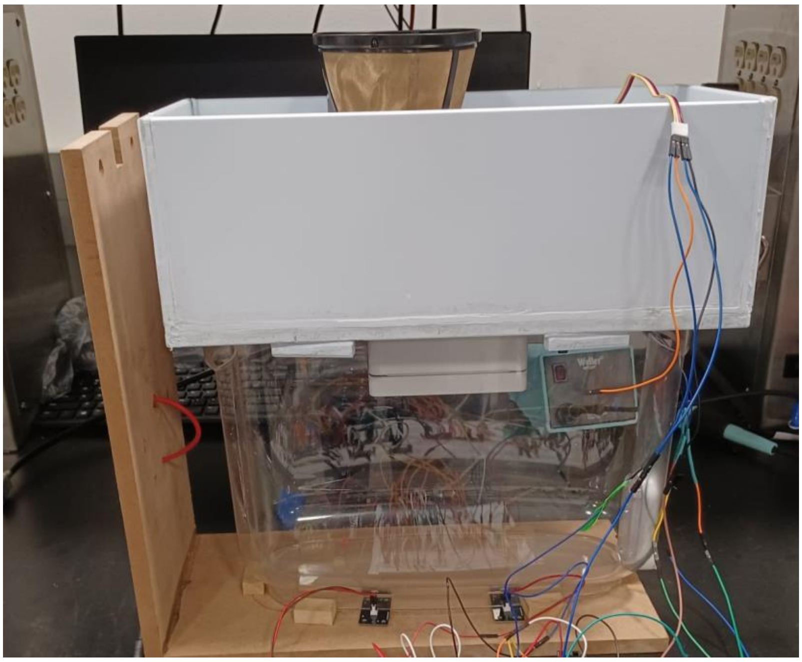

Figure 7. Physical Final Product

The design works well as a prototype to test the correct operation of all the parts, but it cannot be a final product with this design for several reasons that will be discussed below.

One of the fundamental problems when using this design is that when the carbon + ion filter was placed after the microfilter the filtering flow was practically null. Leaving the project filtering all night, it was only able to filter a few centilitres. This is because in the new design the water does not exert the necessary pressure for the carbon filter to be able to filter properly. In the original design, the filters are located inside the white cylinder inside the second reservoir as shown in Figure 7. This way, as the filters are located lower down, they have a much larger water column above them, which exerts sufficient pressure for the correct operation of the carbon filter.

Another important problem is that the water detector sensor is completely inside the first tank simply fastened with screws. This is a problem because the non-waterproof sensor connections are exposed to splashing and this prevents the first tank from being filled completely. It can only be filled to a certain level because the height at which the connections are located cannot be exceeded. The user using the product would have to be careful not to exceed this limit instead of not worrying about it and simply filling it to the maximum.

The water flow sensor in the new design is positioned horizontally instead of vertically so the filter flow is slightly reduced due to having to pass through the 90° bend in the pipe. This is not a serious problem because in the end the amount of water filtered is the same, but it must be considered when analysing the maximum flow during each filtering process.

Finally, a hole with a compartment was also not created to insert the UV LEDs inside the second tank. They were simply placed under the second tank so the amount of UV light that hits the water is less than expected.

However, as mentioned above, the design they have created filters the water and is functional. Our project is a prototype and not a commercial product.

5.2 HARDWARE DESIGN

For a better construction of the hardware, it has been decided to separate the project into 5 different subsystems. This way each subsystem can be tested separately, making it easier to find possible problems. In addition, a failure in one subsystem may cause another part of the project to break completely independently.

The 5 subsystems are the power subsystem, sensing subsystem, control subsystem, disinfection subsystem, and user interface subsystem. Each subsystem has a specific function, and they communicate with each other to achieve the overall correct functioning of the project.

Figure 8 below shows a diagram representing the interconnections between the various subsystems as well as the voltages used for each part of the circuit.

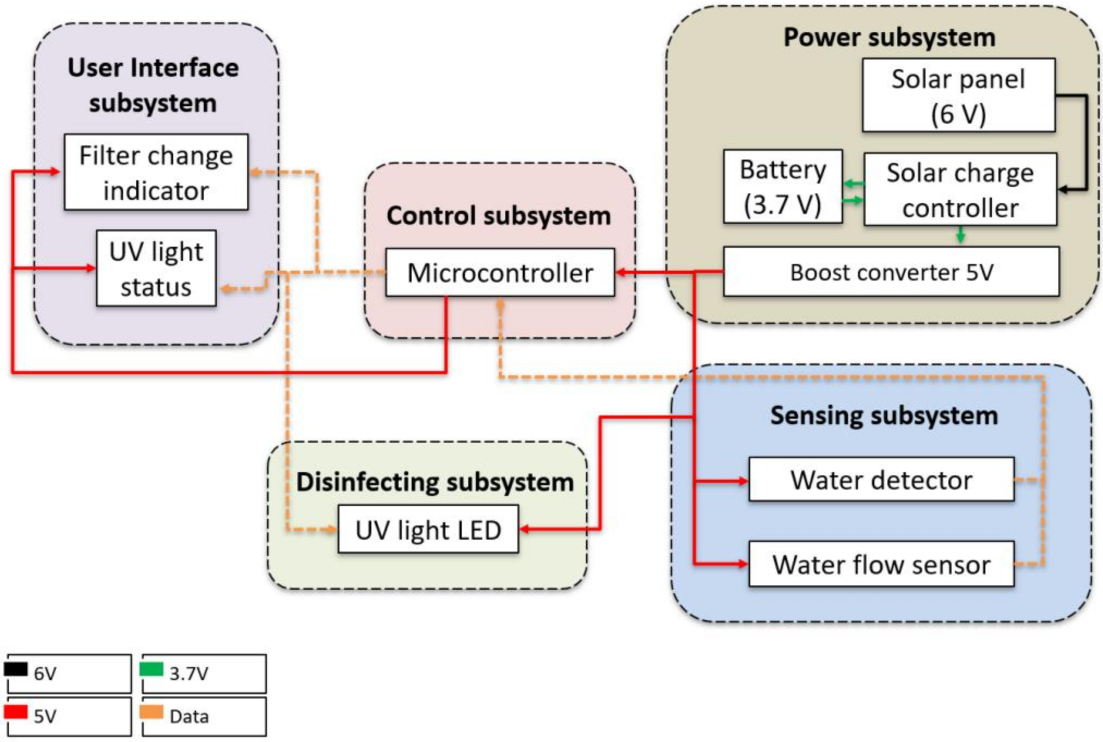

Figure 8. Block diagram of the system divided into subsystems

Each subsystem will be explained separately below, also explaining the complications that have arisen that have necessitated modifications to the original design.

5.2.1 POWER SUBSYSTEM

The main function of the power subsystem is to generate and feed energy for the correct operation of the rest of the components. This subsystem consists of a solar panel, a solar charge controller, a battery, and 2 boost converters (one to 5V and the other one to 7V) as well as resistors, capacitors and inductances recommended to stabilize the voltage and reduce the ripple voltage.

First, the 6V photovoltaic panel converts the sun's rays through its cells into photovoltaic energy. The solar panel is connected to the solar charger which is dedicated to distributing this energy to the rest of the circuit or charging the battery depending on the power needed by the circuit at any given moment. The output of the solar charge controller is 4.3 V, too low to power most components so it is directly increased to 5V using a boost converter. 5V has been chosen because this is the voltage at which all the components in the circuit such as the microcontroller and sensors can operate. The only components that need a higher voltage are the UV LEDs, so once the voltage is increased to 5V, it is increased again to 7V using another boost converter.

In the design of the power subsystem, the most challenging thing was to find a system that would allow the solar panel to be used as a constant DC source all day long. The problem is that the sunlight is not constant so during the day the output current would be quite variable and at night practically null. To solve the night-time problem, it was decided to use a battery because the user should also be able to filter water even if there was no light.

However, the battery could not be charged by the solar panel and continuously discharged directly by powering the circuit at the same time. It was thought to use a blocking diode between the solar panel and the battery to avoid this problem, but it made the system inefficient because when the system was running the battery could not be charged. Finally, it was found that the solar panel manufacturer itself had a solar charge controller that could do just what was needed.

The solar charge controller is connected to the solar panel and the battery as shown in Figure 9 below.

Figure 9. Solar charger connected to the battery and solar panel [11]

The operation of the solar charge controller used is as described below. If the power provided by the solar panel is greater than that required by the circuit, the remaining energy is used to charge the battery. If the power provided by the solar panel is less than that needed by the circuit (typically at night), it is the battery with the previously stored energy that is responsible for powering the circuit.

Furthermore, the solar energy provided by a panel is not constant, in the case of the solar panel used the voltage remains constant at 6V but the current is variable depending on the solar incidence. Figure 10 below shows a graph representing the voltage, current, and power of several solar panels that are compatible with the solar charger. In addition, the vertical red line is the one that provides the maximum power and therefore the highest efficiency and is the one that the output should be close to.

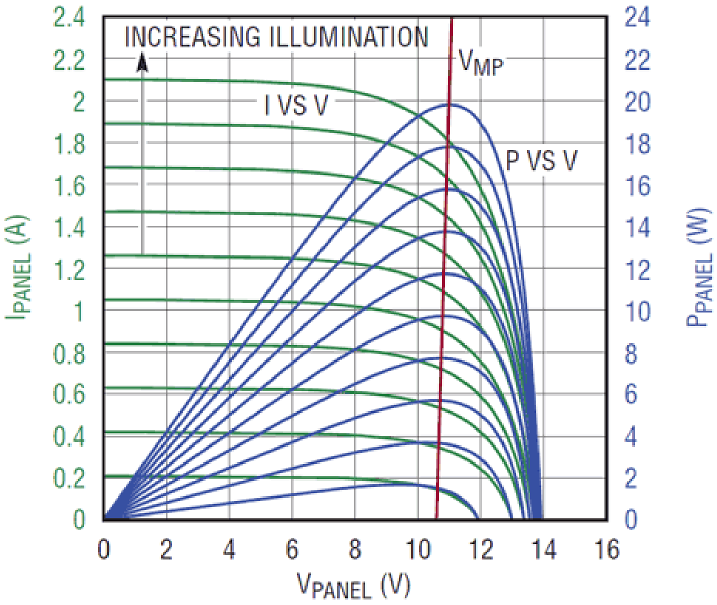

Figure 10. Solar panels operating conditions [11]

The most efficient way to obtain an output that maximizes the power obtained is to use a buck converter (DC/DC converter) to stabilize the voltage. However, when using relatively low voltages (4.5 V - 6 V) and the voltage difference between the battery and the panel is not very high, the efficiency of using a linear regulator is similar. The charge controller, therefore, uses a linear regulator because it allows reducing the price of the device by half [11].

For the choice of the solar panel, we have chosen to use a 6V panel because it has a small size and a voltage close to that needed by the circuit components. In this way, the efficiency increases by not having to decrease the voltage much as in the case of using other conventional 24V panels. In addition, an approximate current analysis has been carried out once the rest of the components to be used in the circuit have been chosen to determine the minimum power that the solar panel should produce to allow the operation of the project during the whole day. Figure 11 shows a sketch of the circuit with the approximate voltages and currents and powers.

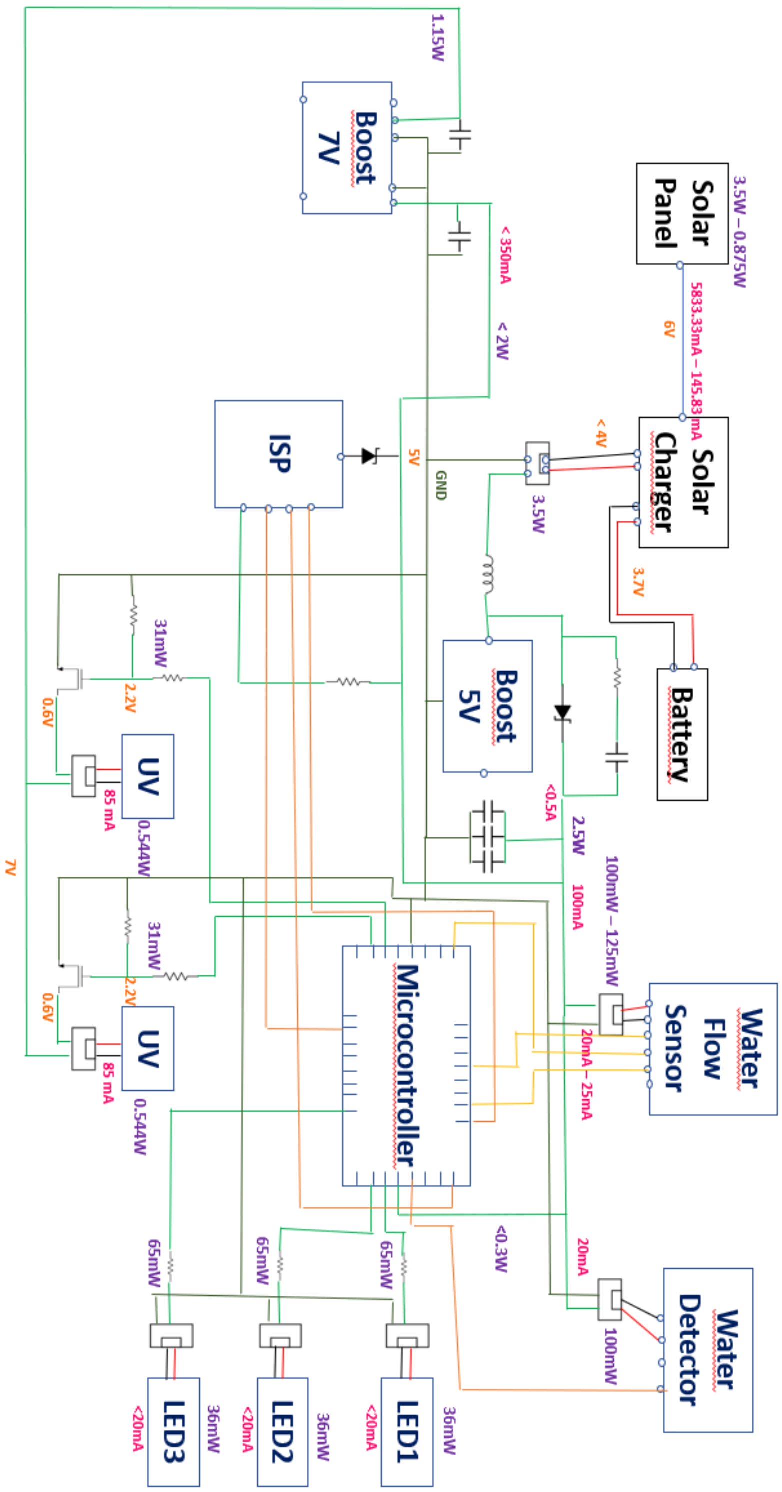

Figure 11. Circuit sketch with approximate operating points

As can be seen in the drawing, for the operation of the project with all the LEDs on at the same time and the ultraviolet lights on (impossible case in practice) the circuit needs 583.33 mA, while with the ultraviolet lights off it needs at most 145.83 mA. Therefore, the maximum power consumed by the circuit is 3.5 W with everything on and 0.875 W without the ultraviolet lights.

It has therefore been decided to use a solar panel with a maximum power of 3.5 W. Since the UV light should only be on for a relatively short period, most of the time there will be enough power left over to charge the battery.

The battery of choice is a 10050 mAh rechargeable battery, which means that it can provide approximately 10 A for one hour or one ampere for 10 hours. In the worst-case scenario where the system needs 583.33 mA, it could run for more than 17 hours. The battery has been oversized to prevent several consecutive cloudy days with lower solar incidence from causing the system to stop working.

For the design of the boost converters, the design example proposed in the datasheet of the components has been followed. The 5 V and 7 V boost converter circuits are shown in Figure 12 and Figure 13.

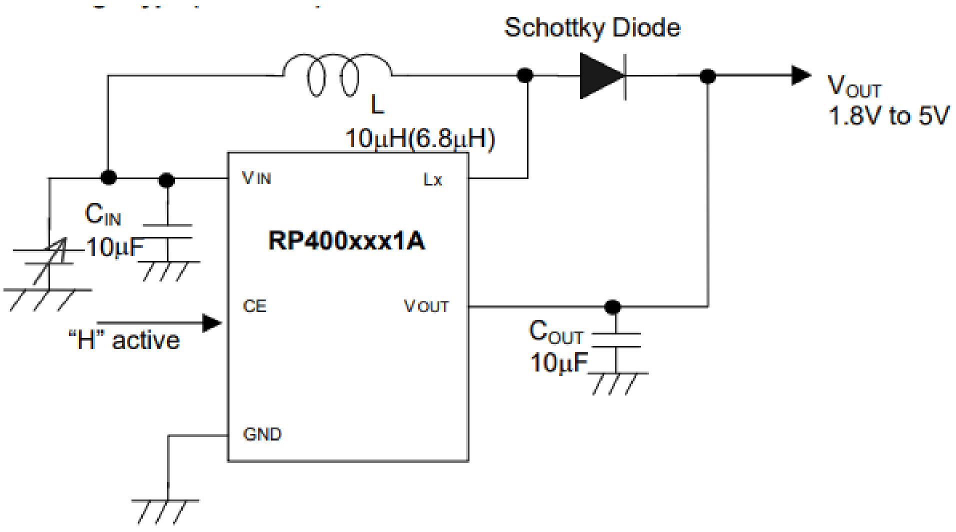

Figure 12. Circuit of 5V boost converter [12]

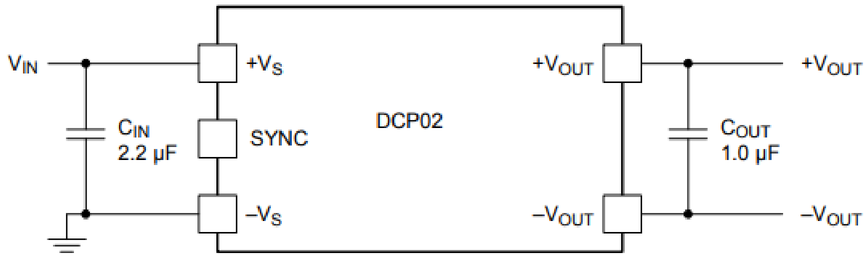

Figure 13. Circuit of 7V boost converter [13]

Finally, the complete circuit of the power system is shown in figure 14 below.

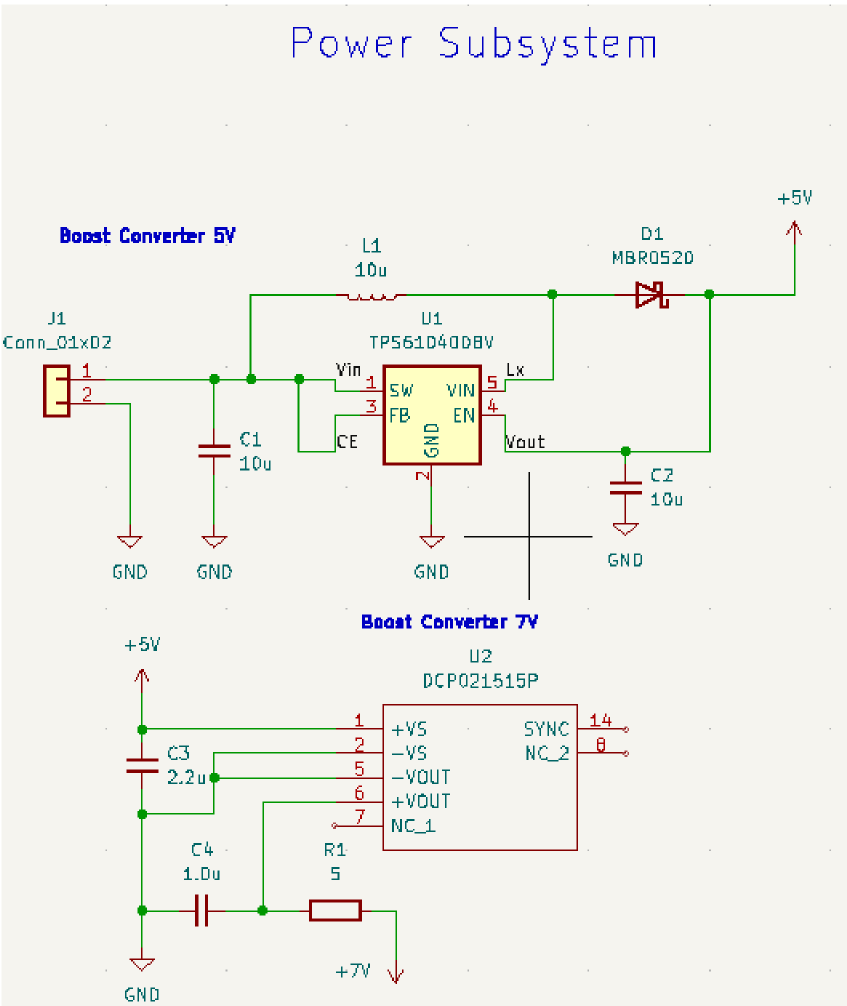

Figure 14. Power subsystem circuit

5.2.2 SENSING SUBSYSTEM

The sensing subsystem is formed by two sensors that are in charge of sending signals to the microcontroller to later turn on the ultraviolet light or the LEDs of the user interface. These two sensors are a water detector and a water flow sensor.

For the water detector sensor, we have chosen a simple device with a digital output that depending on the amount of water detected with its sensor traces will give one value or another. When it does not detect water, the output is HIGH, and when it detects water LOW. Figure 15 shows a picture of the sensor where you can see its connections and sensor traces.

Figure 15. Grove water detector sensor [14]

The choice of the water flow sensor was more complicated since the filtration rate is quite slow and therefore the flow rate is small. Therefore, we had to choose a very accurate water flow sensor capable of detecting flows above 0 L/min to 7L/min, without having any minimum flow.

This sensor has both digital output (based on several counts) and analog output. For convenience. it has been decided to use the analog output, which will serve as an analog input to the microcontroller. The graph represented in figure 16 below shows the analog output obtained as a function of the water flow.

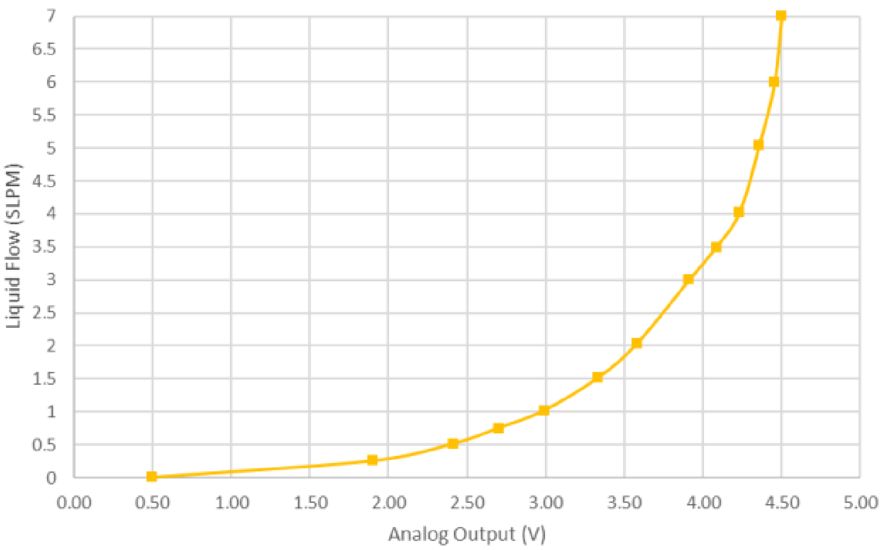

Figure 16. Liquid flow vs Analog output graph [15]

The exact values with which the graph has been made are shown in table 4.

Flow (Litres/min)	Analog Output (V)	Flow (Litres/min)	Analog Output (V)
0	0.50	2.997	3.91
0.251	1.90	3.494	4.08
0.513	2.41	4.015	4.23
0.752	2.70	5.045	4.36
1.016	2.99	6.000	4.46
1.515	3.33	7.000	4.50
2.033	3.58		

Table 4. Analog Output equivalent to liquid flow [15]

Theoretically, the filter manufacturer claims that the system is capable of filtering one litre of water in less than 6 minutes. This implies a flow rate of 0.1667 L/min.

$$1\ L\ in\ 6\ min = 0.1667\ {}^{L}/_{min}$$

Approximating each section of the graph to a straight line, we therefore obtain that the expected value as analog output is1.4298 V.

$$Analog\ Output = 0.5 + \frac{0.1667}{0.251} * (1.9 - 0.5) = 1.4298\ V$$

The complete circuit of the sensing subsystem is shown in figure 17 below.

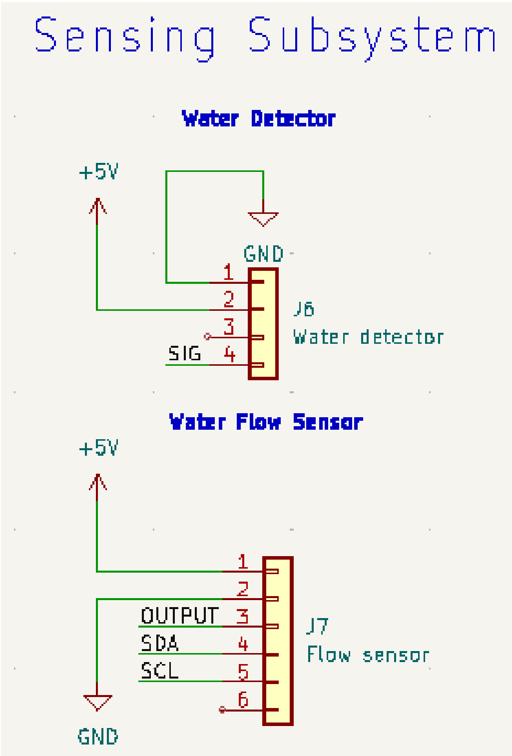

Figure 17. Sensing subsystem circuit

5.2.3 CONTROL SUBSYSTEM

The control subsystem is the brain of the project formed by the microcontroller and the programmer. This subsystem is in charge of receiving the information provided by the sensors (digital input of the water detector and analog input from the water flow sensor) and processing it to control the ultraviolet LEDs and the user interface.

It has been decided to use the ATMEGA48-20AU as a microcontroller because it has EEPROM (a type of non-volatile ROM) and therefore allows for store flow rates. It is necessary to store the flow rates to determine the maximum flow rate at each filtration (to determine the change of the microfilter) and the memory is also needed to store the total water filtered by the product.

In addition, the ATMEGA48-20AU has been chosen because it has an internal clock that will be used to calculate the total filtered water and to control the time of the ultraviolet LEDs and the red LEDs that make up the user interface. Finally, this microcontroller has also been chosen because it is quite common and therefore its manufacture is large allowing to have units in stock in most of the important component's websites such as Mouser or Digikey.

To program the microcontroller an ISP (In-System Programming) programmer has been used because it allows the program of the chip once installed in the complete system. This avoids having to program it before assembly. It also makes it easier to make changes in case of a software programming error.

The software used and specific code will be explained independently in section 5.3.4. Figure 18 below shows the programmer and microcontroller connections that make up the subsystem control circuit.

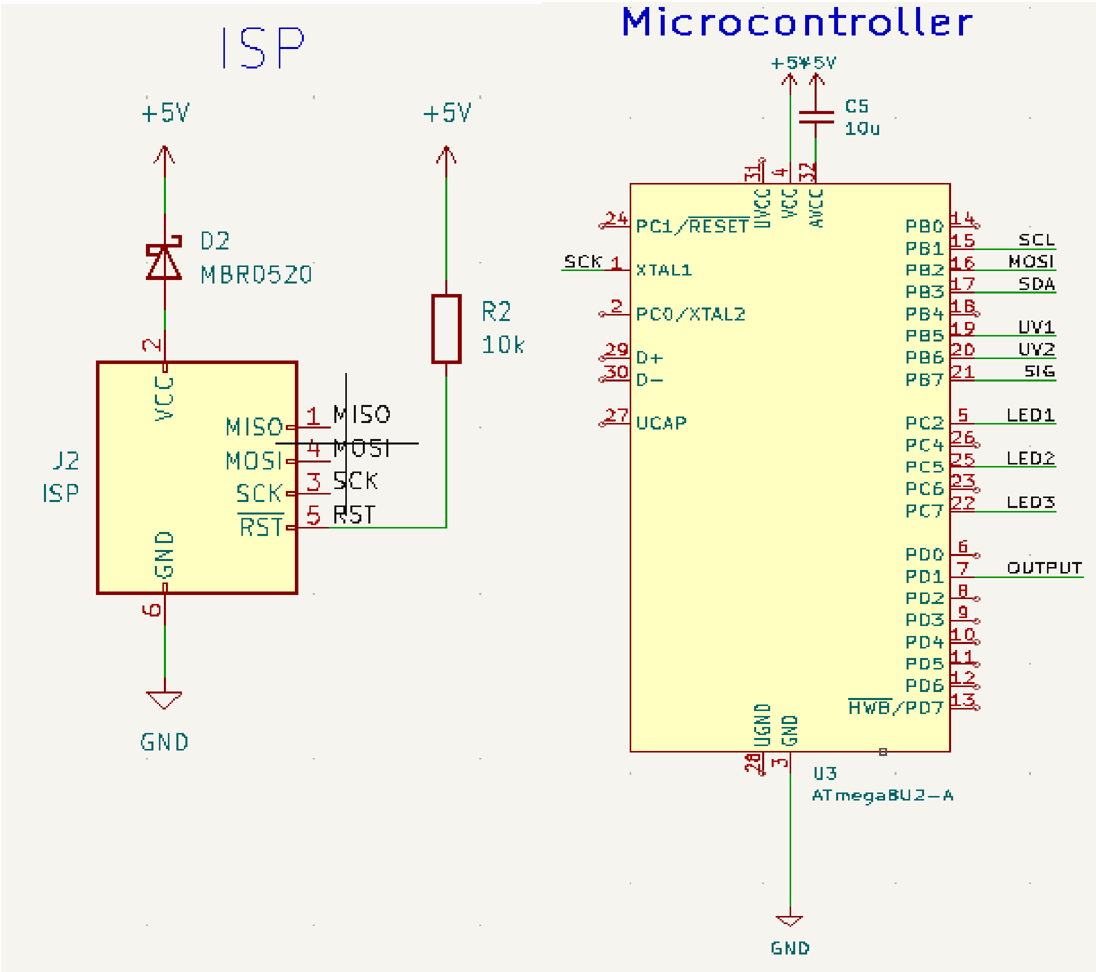

Figure 18. Control subsystem circuit

5.2.4 DISINFECTING SUBSYSTEM

The disinfecting subsystem is in charge of the water filtering and disinfection process. It consists of the three filters and the circuitry necessary for the UV LEDs.

First, it has been decided to place a reusable metal coffee filter to remove larger impurities. It has been decided to add this extra filter because some lake or river water may have large impurities that can cause the microfilter to clog if they have not been removed before. A filter with a pore size of 20 microns (100 times larger than the pour size of the microfilter) has been chosen. It is also a reusable metallic filter, so when it is dirty it is enough to turn it upside down and apply a little water to clean it.

The water then passes through the microfilter. For the microfilter, we have chosen one of the company LifeStraw because it has a pore size of 0.2 microns. Most other conventional filters, such as the one from the company Brita, have a pore size of 1 micron. The problem with this type of filter is that it is not able to remove the bacteria present in the water due to its smaller pore size (0.5 microns). This filter can effectively remove bacteria, parasites, and microplastics.

The third filter used is the carbon + ion filter, also from LifeStraw. This specific filter was chosen for convenience because it works well with the previous one and because it is the only one found capable of removing heavy metals. The removal of heavy metals is very difficult and with the new ion technology, this company can remove them. This filter as said greatly reduces the content of heavy metals such as lead, mercury, chromium, cadmium, and copper. It also reduces the content of chlorine and pesticides and improves the smell and taste of the water.

A complete analysis carried out in a laboratory by LifeStraw proves the perfect function of the system. All the information provided by the laboratory can be found in this document [17].

For ultraviolet disinfection, it was decided to use two surface mount LEDs of ultraviolet light type C (200nm to 280nm bandwidth), specifically of 275 nm wavelength. These LEDs were chosen because they consume much less energy than larger ultraviolet lamps. Because this project is only powered by a solar panel, the power supplied is limited and they also require a lot of current that currents the components used cannot withstand.

To correctly eliminate the presence of viruses in water, it has been shown that a minimum of 16,000 µWatt-sec/cm^2 is needed, so it is not necessary to use so much power if it does not matter if the disinfection process takes longer.

Each LED used has a UV light radiant flux of 10 mW and when two are used, therefore 20 mW are being applied. In addition, the base of the second tank where the LEDs are located is 576 cm^2.

$$A_{base} = 36 * 16 = 576\ cm^2$$

Therefore, using 20,000 µWatt-sec/cm^2 as the minimum power needed as other currently existing systems use, we obtain that the ultraviolet light must be on for at least 10 min.

$$20{,}000\ \mu\mathrm{W} * {}^{n\ sec}/_{576\ cm^2} = 20{,}000 =>$$

$$=> 576\ \mathrm{sec} = 9.6\ \mathrm{min} \approx 10\ min$$

This may seem like a long time but compared to the filtering process it is not so long. The project takes approximately 25 minutes to filter one gallon of water so 10 minutes more is not that long and therefore allows you to get 1 gallon of clean water every 35 minutes.

The ultraviolet LEDs are controlled by the microcontroller. The problem is that the microcontroller can only provide 5V and 20mA, so it is necessary to use a system that allows increasing the voltage and current. For this purpose, we have used a MOSFET that acts as a source of adjustable current from the Vgs voltage. Figure 19 shows the circuit used to clarify the understanding.

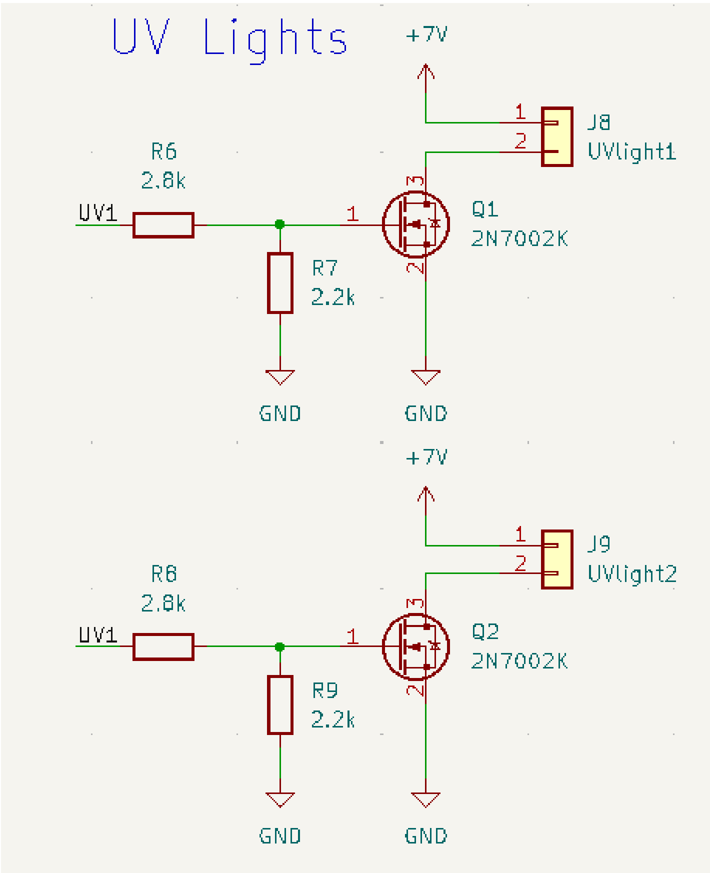

Figure 19. UV Lights circuit

The resistors of values 2.8k and 2.2k have been chosen to get Vgs to be 2.2V and to limit the current provided by the microcontroller. With this value of Vgs and Vds equal to 0.6 V, as can be seen in the graph of the transistor characteristics sheet shown in figure 20, a current value of 85 mA is obtained, which is necessary for the correct operation of the ultraviolet light.

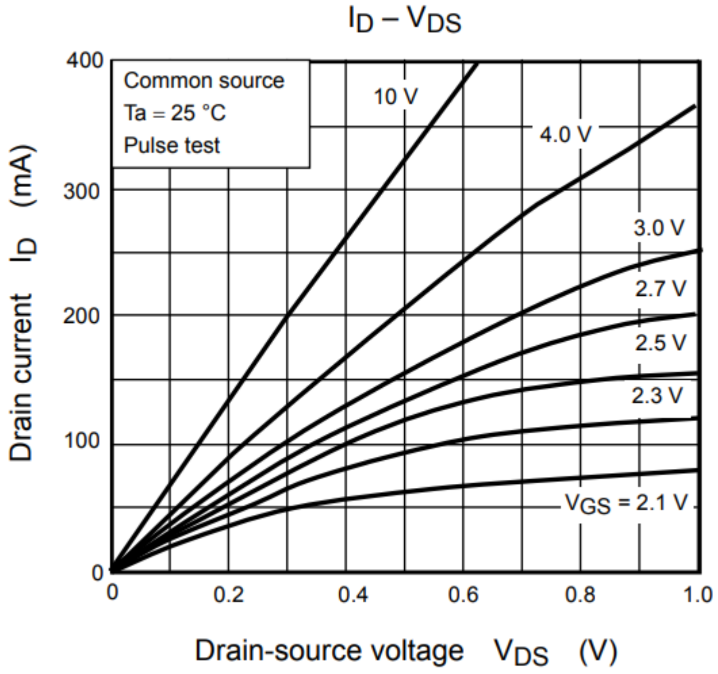

Figure 20. Drain current vs Drain-source voltage [18]

In order to place the UV lights under the second tank, a small PCB has been designed to solder each of the LEDs. This PCB has a connector and is connected directly through a jumper to the main PCB which has another connector.

5.2.5 USER INTERFACE SUBSYSTEM

The user interface consists of three red LEDs placed vertically so that the upper one is LED1, and the lower one is LED3. The function of the LEDs is to warn the user when the ultraviolet light is activated and to indicate when each of the filters should be replaced.

LED1 indicates that the ultraviolet light is active and will therefore light up at the same time as the ultraviolet LED lights up (for 10 minutes after complete filtering). LED2 will light up for 10 seconds after filtering if it is detected that it needs to be replaced. Finally, LED3 will also light up for 10 seconds if after filtering the maximum number of litres filtered has been reached and therefore the carbon filter needs to be replaced.

The user interface circuit is a simple circuit that allows turning on three LEDs through the microcontroller, therefore the only design element is the choice of the necessary resistor to limit the current and not force the microcontroller or burn the LED. The red LED operates at 2.2V and 20mA, and the voltage at the output of the microcontroller is 5V. Therefore, for a 2.8V drop at 20mA to occur, a 140Ω resistor is required. Figure 21 below shows the circuit used.

$$R = \frac{5 - 2.2}{0.02} = 140\Omega$$

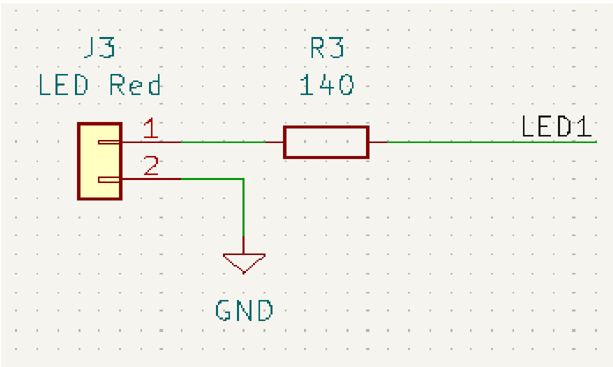

Figure 21. User interface circuit

5.3 IMPLEMENTATION

The implementation process followed cost 4 distinct parts. First, the PCB was designed where the circuit will be soldered. Then the hardware will be tested by analysing the subsystems separately until the correct operation is achieved. Finally, the software necessary for its operation will be programmed.

5.3.1 PCB

The design and creation of the PCB are very important since they will be the basis of the whole circuit. To build the PCB we used the free software KiCad in which we first made a schematic and then converted it to PCB tracing all the connections. Finally, the PCB has been ordered through PCBWay (a company in charge of printing and distribution all over the world).

The first order was placed during the first weeks of the project once it was decided which components were going to be used. Two PCBs were ordered; the main PCB and the one on which the ultraviolet LEDs will be soldered. Figures 22 and 23 show respectively the PCB design for the LEDs and the main PCB design.

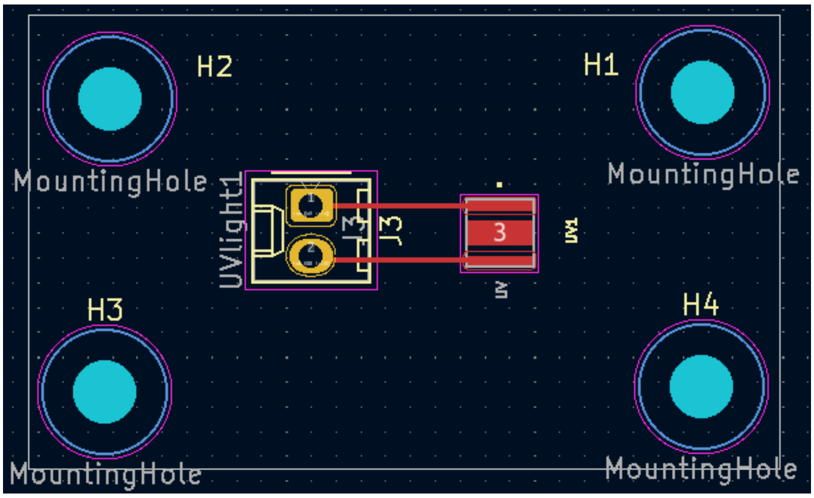

Figure 22. UV light PCB

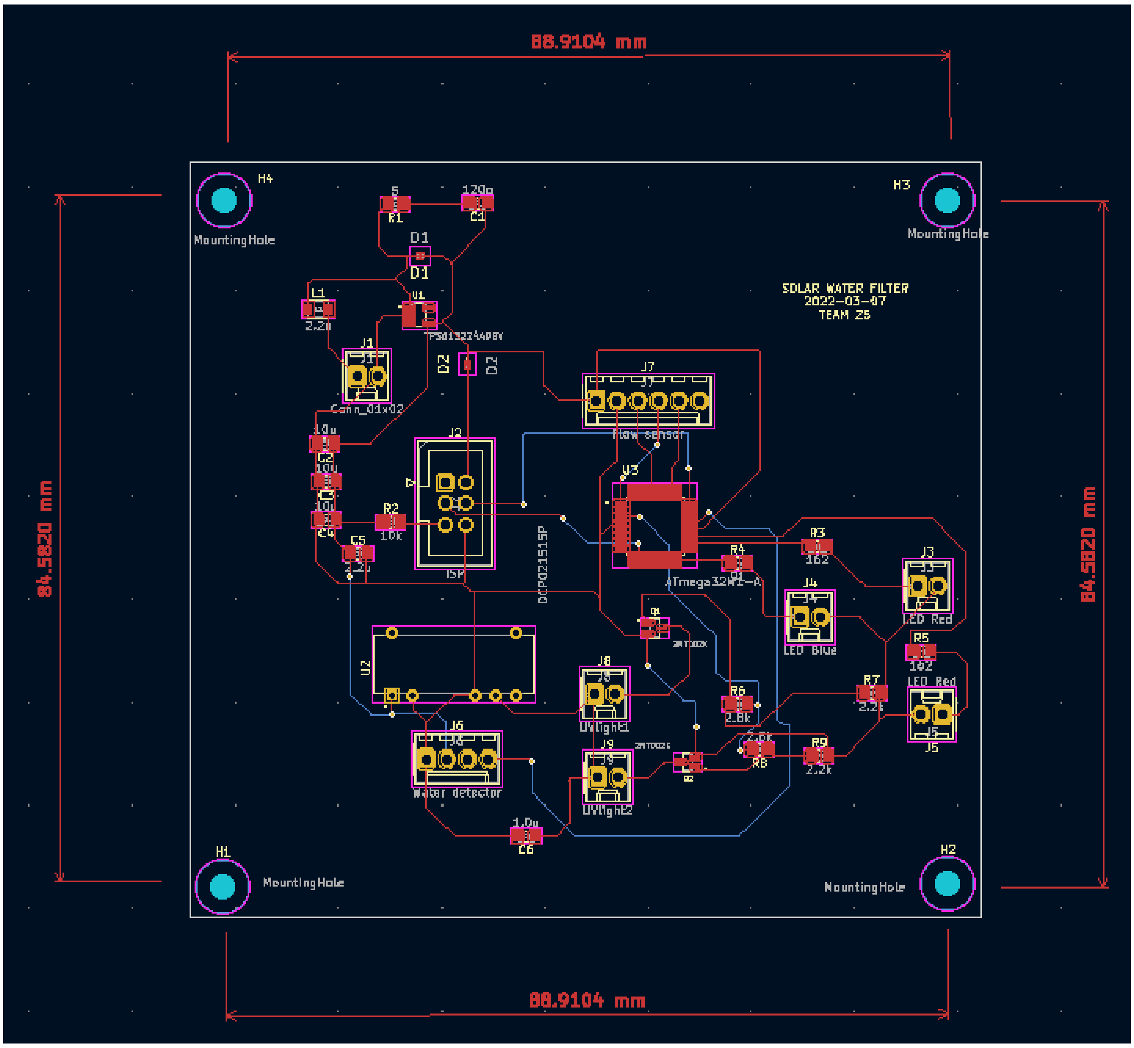

Figure 23. Original PCB connections

The LED PCB worked correctly, but there were several problems with the other PCB. All these problems will be explained in more depth in chapter 6, each one in the subsystem it belongs to.

One of the problems that were first observed was that the diodes D1 and D2 chosen were very small and therefore impossible to solder manually. However, the problem was solved by soldering some wires to the PCB connections and using larger diodes (about the same size as the resistors).

Later the 5-voltage regulator and the microcontroller had to be changed, so the connections of the new ones were different, and the same circuit could no longer be used. That is why it was decided to order a second PCB, whose connections are shown in Figure 24.

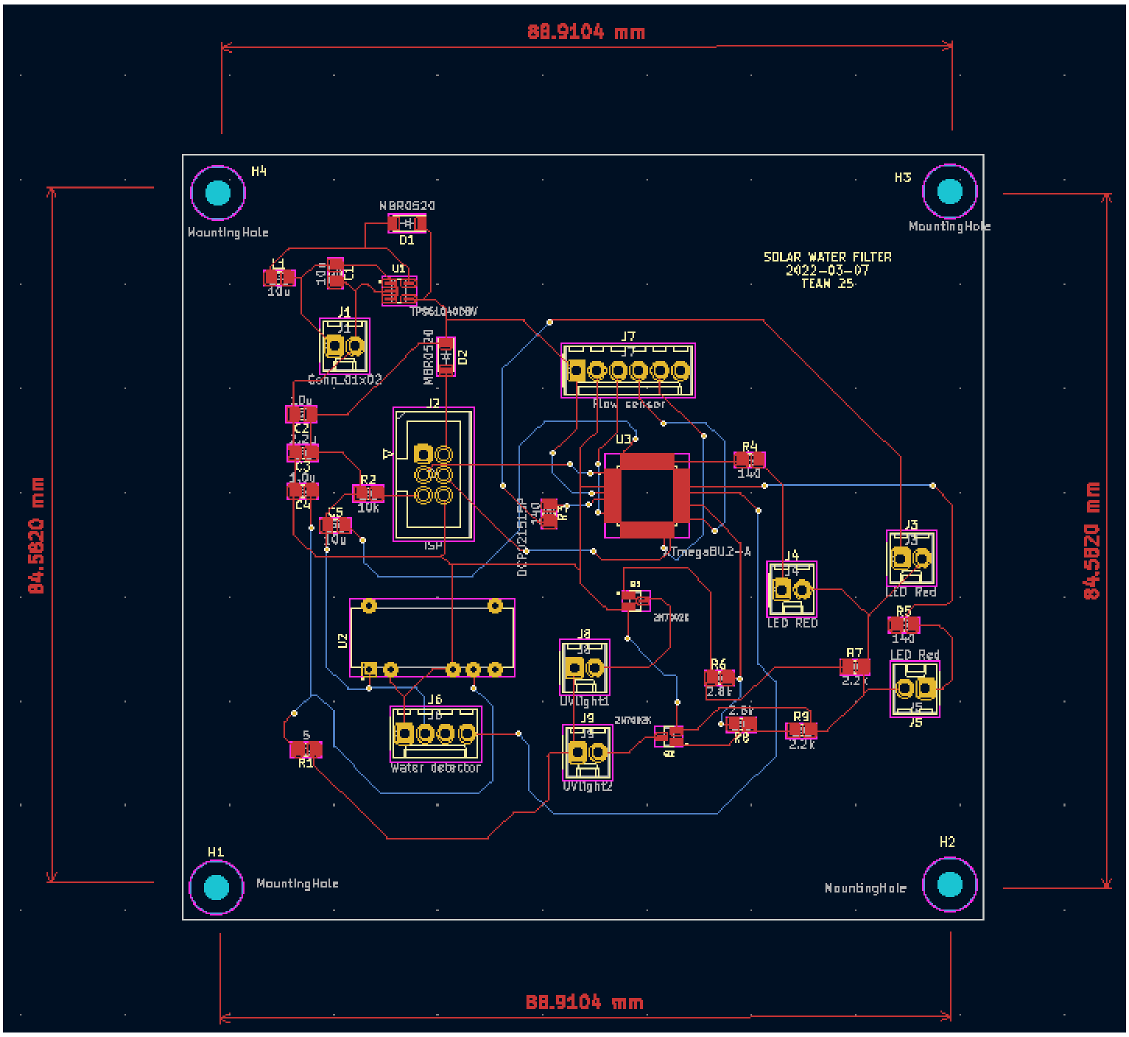

Figure 24. Modified PCB connections

However, due to an unexpected delay and having ordered it in the last weeks of the project, the PCB did not arrive in time before the demonstration, so the circuit had to be recreated using a breadboard. All internal connections were built externally with wires and jumpers.

5.3.2 SOLDERING

Once the PCB was received, all the components were soldered on it using the typical metal alloy of lead or tin combined with brass or silver that is used for soldering electronic circuits because they have a low melting point. For convenience, we soldered all the surface mount components first and then the ones that were through the hole.

If any component did not work properly or was not soldered correctly, a hot air gun was used to desolder it and then re-solder it again.

5.3.3 TESTING

To test that the hardware was working properly, we first analysed component by component its correct operation by soldering it on small PCBs created for this purpose. Then the operation of each subsystem was checked separately to ensure that failures in one subsystem did not cause failures in the others. Finally, the correct operation of the complete hardware was analysed.

5.3.4 PROGRAMMING

Finally, the system software was realized by programming the code necessary for the operation of the project. To program the microcontroller an ISP (In-system Programming) programmer has been used because it allows the program of the chip once installed in the complete system.

Due to a lack of stock due to the component's crisis caused by the Covid19, in the end, it was not possible to use the ATMEGA48-20AU microcontroller for which the project had been designed and an ATMEGA328 had to be used. For its programming, the Arduino IDE application was used using the pin configuration shown in Figure 25 below. For more programming information, refer to Appendix D.

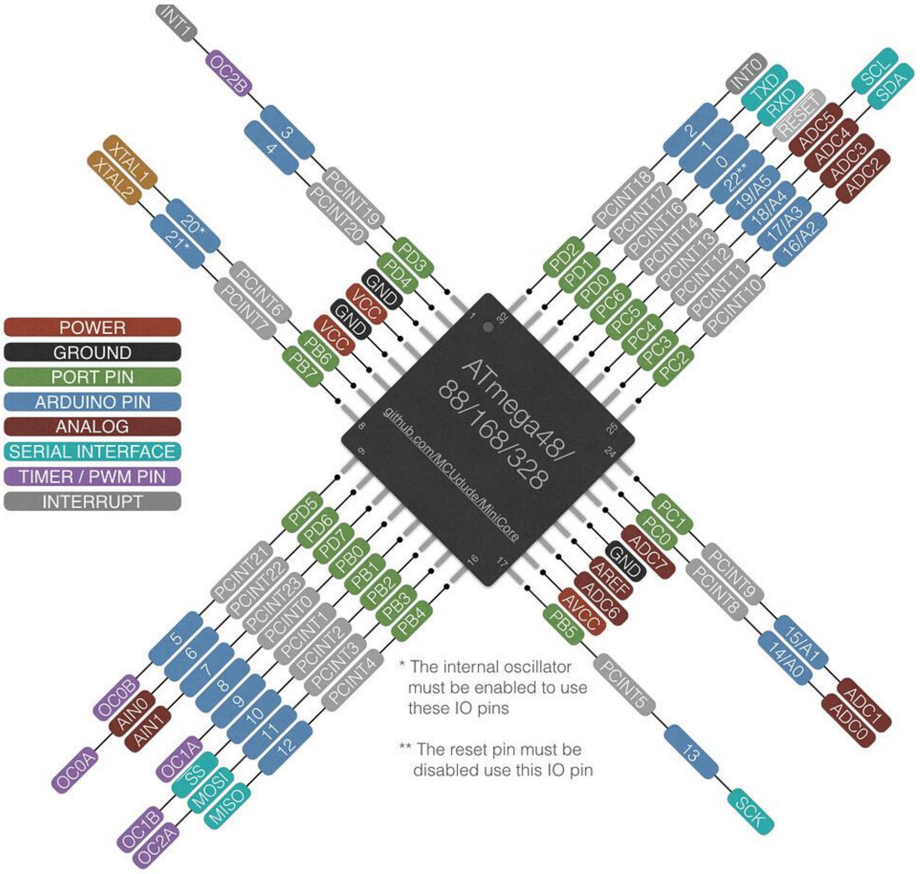

Figure 25. ATMEGA328 Pinout [19]

As for the code used, due to having only two sensors acting as system input and more than two different possible outputs, it has been decided to perform state-based programming. Depending on the state in which it is found, a given input will lead to a change of state or not. Figure 26 shows the state diagram used and in appendix B, the complete code.

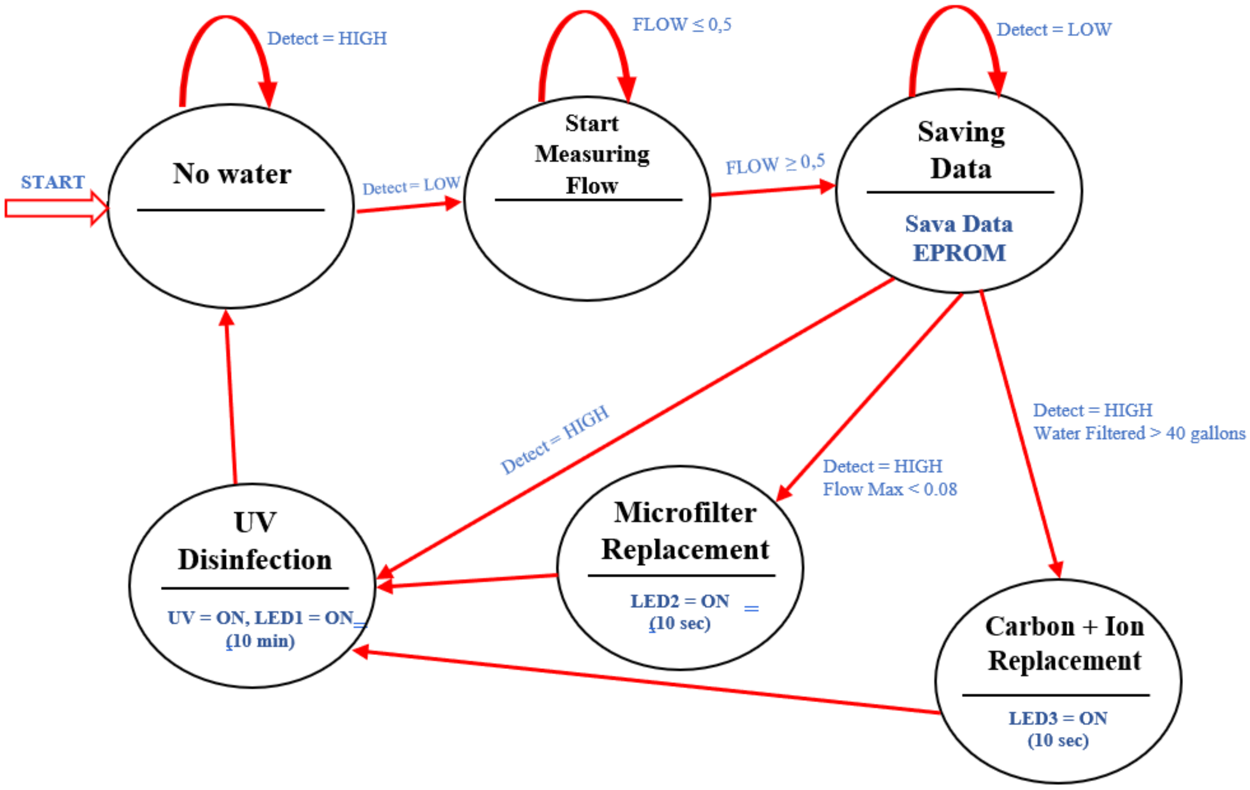

Figure 26. State diagram using a water flow sensor

The system starts in the idle state "No water" which means that there is no water in the first tank, so it is not filtering anything. As soon as the water detector detects the presence of water, its output will be set to LOW, and it will go to the next filtering state. During this state, the system will start to store all the water flow measured by the other sensor in the microcontroller memory until the water detector detects high again indicating that all the water has been filtered. During this state, the amount of water filtered during that cycle will be added to the total and the maximum flow of the cycle will be saved. The change to the next state will depend on these two variables.

When the water detector has a HIGH output (no water detected), the filtering process will be finished, and the max flow and water filtered variables will be analysed to see which state to change to. If the water filtered variable is higher than 40 gallons (the maximum amount of water that the carbon filter can filter), it will switch to the "Carbon + Ion replacement" status by turning on LED3 for 10 seconds.

If instead, the maximum flow rate of the cycle is detected to be less than 0.08 (half of the typical flow rate when the filter is brand new) and therefore the analog output is less than 1V, it means that there has been a considerable change in the filtering rate indicating that the microfilter is dirty and must be replaced and therefore it will go to the "Microfilter Replacement" status. In this case, very similar to the previous state, LED 2 will light up for 10 seconds.

Finally, if no filter replacement is to be performed, it will go directly from the filtering state to the UV Disinfection state. This state will also be reached automatically at the end of the 10 seconds during which the replacement LEDs light up. The output of this state is the lighting of the UV lights and LED1 for 10 minutes to ensure complete disinfection of the water. At the end of the 10 minutes, the system will return to the initial "No water" state where the system will remain at rest until the next cycle is started.

In addition, because the water flow sensor was damaged by a bad connection the week just before the demonstration, a special code has been made trying to keep all the functionality by making some assumptions such as assuming a constant water flow. The problem with the water flow sensor will be better explained in section 6 within the control subsystem. Figure 27 shows the state diagram without a water flow sensor and the code can be found in Appendix C.

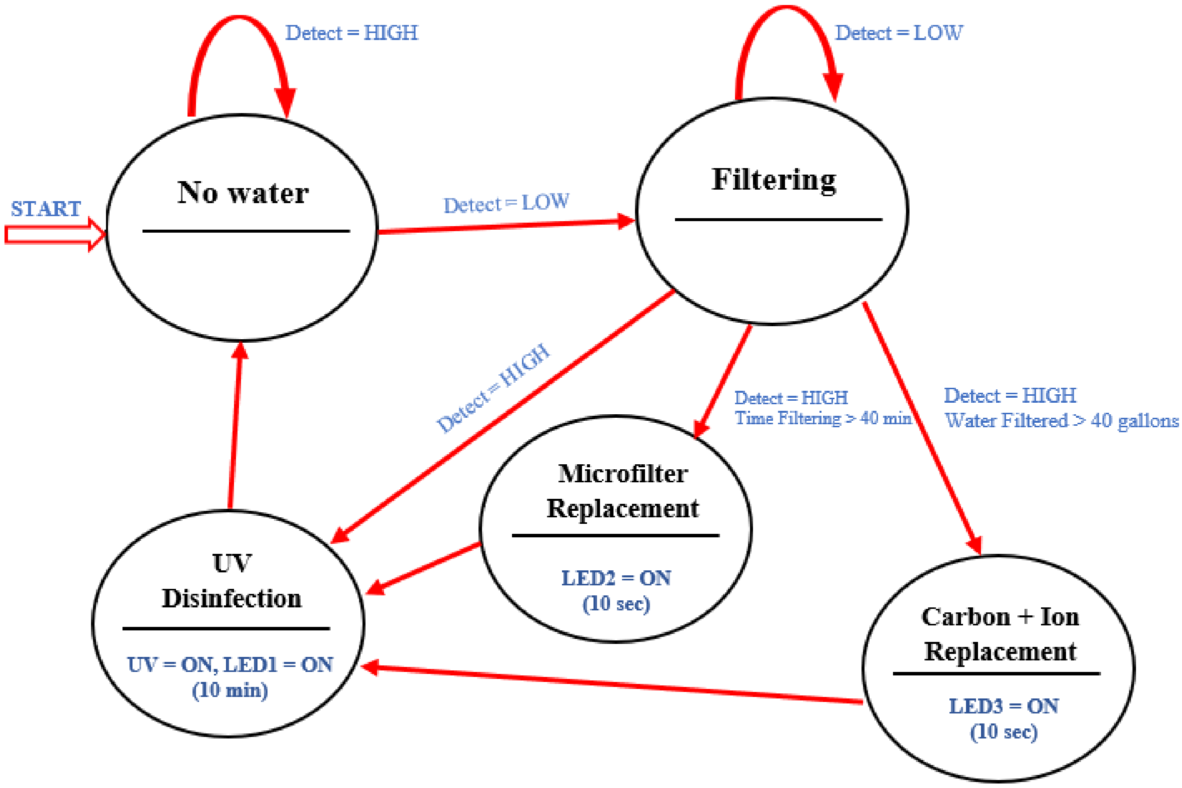

Figure 27. State diagram without water flow sensor

The number of states and the state outputs are the same, except that when the water flow sensor does not work, the flows measured in the filtering state will no longer be stored in the microcontroller memory. The only thing that changes is the variables used for the change between some states. Specifically, the changes that lead to the replacement of some of the two filters.

To change from filtering to a carbon + ion replacement state, it is still maintained that the amount of filtered water is higher than 40 gallons (because this is what the filter manufacturer recommends). The difference is that for the calculation of the filtered water in this case a constant flow rate of 0.166 L/min is assumed since the water flow rate cannot be known at any time. In this way, the functionality of the carbon filter replacement is maintained. The calculated filtered water will be higher than the actual filtered water, so the filter will have to be changed more frequently, reducing its efficiency.

For the replacement of the microfilter, because its measure of change was considerable variations in the maximum flow rate measured in one cycle, it has been replaced by the filtering time. The project with a full microfilter takes approximately 20 minutes to filter 1 gallon of water. So, if the filtration rate is half that, it will take 40 minutes. This is the maximum filtration time considered correct and therefore higher values will indicate that the filter is dirty or clogged and should be cleaned or replaced.

CHAPTER 6. RESULTS ANALYSIS

The purpose of this chapter is to explain the results obtained in the project and the challenges that have arisen during its implementation. In order to analyse it completely, it has been divided into subsystems as it has been done with the design section. In addition to an explanation for each subsystem, a table has been included with the operating requirements and the verifications performed.

6.1 *POWER SUBSYSTEM*

The power subsystem is responsible for supplying each component with the current and intensity it needs. The result will be correct if only the solar panel is used to supply each component with the appropriate voltage and current.

REQUIREMENTS	VERIFICATION	VERIFICATION STATUS (Yes/No)
1. Power the entire circuit exclusively using solar energy 24 hours a day.	Perform a complete current and power analysis. Check that the battery can be charged with the solar panel and used when the solar incidence is lower.	Yes
2. Provide a voltage of 6.4 V +/- 0.5% from the battery to the UV lights. The UV lights should operate at 85 mA.	Measure the output voltage using a voltmeter to ensure it is within 5% of 6.4 V. Measure this subcircuit current using an ammeter to ensure it is 85 mA.	Yes
3. Provide a voltage of 5 V +/- 0.5% to all the parts of the device except the UV lights.	Measure the voltage of any subcircuit in operation using a voltmeter to ensure it is within 5% of 5 V.	Yes

Table 5. Requirements and verifications table of Power Subsystem

Table 5 shows the requirements necessary for the correct operation of the power subsystem and the checks performed to ensure compliance. As can be seen, all requirements have been verified.

CHALLENGES

The power subsystem has worked correctly and there have been no major difficulties. Only the original 5V regulator had to be replaced by another one with similar characteristics in terms of voltage and maximum current because the original one burned out during testing and there were no more units in stock. It burned out for not putting a sufficiently high equivalent resistance at the output of the voltage regulator when doing the first tests so the current exceeded the maximum current that the regulator can support.

The change of the voltage regulator did not involve any change in the power subsystem because the new component was able to get 5V stable output. The only problem was that because its pins and connections were different, the PCB had to be redesigned and reordered. Finally causing to have to build the circuit on a breadboard because the new PCB ordered did not arrive on time.

6.2 SENSING SUBSYSTEM

The sensing subsystem is responsible for detecting the presence of water in the first tank and for measuring the flow after filtering periodically. Therefore, its result is correct if the output of these sensors always measures what it should measure. The output of the sensors will be used in the control subsystem by the microcontroller as input to detect when the filters should be replaced, and the UV LEDs turned on.

REQUIREMENTS	VERIFICATION	VERIFICATION STATUS (Yes/No)
1. It should sense if there is water present in the first water tank.	This can be verified by checking what signal the water sensor sends to the microcontroller. Check that when there is no water the output signal of the sensor is HIGH (> 3 V) and when the sensor detects water is LOW (< 3 V). This can be verified using a voltmeter to measure the voltage between the output and ground.	Yes
2. The water detector will operate at 5 V as it is the only voltage it can operate. The water detector should operate between 20-25 mA.	Measure the voltage provided to the sub-subsystem. If the Voltage is within 5% of 5 V, then it is working as planned. Measure this subcircuit current using an ammeter to ensure it is within 20-25mA.	Yes
3. The water flow sensor should sense the different flow rates of the water from the first tank to the second tank.	Access to the different water flow rates stored in the microcontroller and check them manually for the microcontroller to see if the water flow rates are being measured or not.	Yes
4. The water flow sub-subsystem should sense if the water membrane microfilter needs to be changed.	If the water flow levels are too low (50% of the initial flow rate), that means the filter needs to be changed. This data would be collected by the microcontroller. It would send a signal to the led to light up and it would light up outside the device.	No

Continued on next page

REQUIREMENTS	VERIFICATION	VERIFICATION STATUS (Yes/No)
5. The water flow sub-subsystem should sense if the carbon filter needs to be changed.	If the filter has filtered 150L of water, the carbon filter should be changed. This information would be measured and stored by the microcontroller. When this threshold has been reached, it would send a signal to the led to light up outside the device.	No
6. The water flow sensor will operate at 5 V and using a current of 20mA	Measure the voltage provided to the sub-subsystem. If the voltage is within 5% of 5 V, then it is working as planned.	Yes

Table 6. Requirements and verifications table of Sensing Subsystem

Table 6 shows the requirements necessary for the correct operation of the sensing subsystem and the checks performed to ensure compliance. As can be seen, all requirements have been verified minus the numbers 4 and 5 because the water flow sensor stopped working.

The water detector worked correctly with its output signal being 4.559 (HIGH >3 V) when no water was detected. When water was introduced in the first tank the output was LOW, typically around 1.20 but it depended a little on the amount of water detected. Figure 28 below shows the typical values obtained.

Figure 28. Typical digital outputs of the water detector

CHALLENGES

A couple of weeks before the final demonstration of the project the water flow sensor stopped working because of a short between ground signal and the ground. This is because, in one of the tests performed, a colleague of the project made the connections backward and did not limit the current provided by the voltage source. Therefore, one of the internal protections must have been broken.

The problem was found by observing that when the voltage source was set to 5V, and the current was limited to 25mA (max rated current) the voltage was just over 1V. No matter at what limit the current was set, the voltage source always supplied that limit so there was a complete short inside. Using an ohmmeter, we measured the resistance between all the connections and observed that there was a short between the output signal and ground and therefore the internal resistance was close to zero as can be seen in figure 29.

Figure 29. Short between signal and ground

Due to this problem that occurred in the last weeks of the project development, it was not possible to order another sensor to test it together with the code and check the correct operation in conjunction with this sensor. Fortunately, the water flow sensor had been tested in the previous months and was able to always measure the flow.

When no water was being filtered, the analog output of the sensor was 0.534 V, very close to the 0.5 V specified by the manufacturer when the flow rate is 0. The analog output when water is filtered with a brand-new filter is 1.395V. Both outputs are plotted in Figure 30.

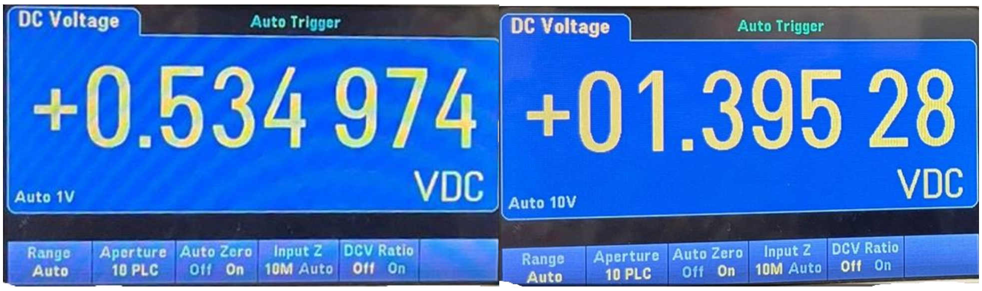

Figure 30. Analog outputs of the water flow sensor

The obtained value of 0.1395 V makes sense because it represents a flow rate of 0.160 L/min being the same as saying that it filters 1 L in 6.23 min. The filter manufacturer says that the system is capable of filtering 1 L in 6 minutes, so the value obtained by the sensor is correct.

$$Flow = 0.251 * \frac{1.395 - 0.5}{1.90 - 0.50} = 0.160 \ {}^{L}/_{min}$$

$$0.16 \ {}^{L}/_{min} = 1L \ in \ 6.23 \ min$$

6.3 CONTROL SUBSYSTEM

The subsystem control is in charge of receiving the signals from the master, processing them, and sending the necessary signals to turn on the ultraviolet light and the LEDs of the user interface.

REQUIREMENTS	**VERIFICATION**	**VERIFICATION STATUS (Yes/No)**
1. It would operate at about 5 V. That is the best voltage to operate because most of the other modules also operate at 5 V.	Measure the voltage provided to the microcontroller. If the voltage is within 5% of 5 V, then it is working as planned.	Yes
2. Control when different modules are turned on and off.	Measure the voltage at the output of the microcontroller to check that the signal is sent when required. For convenience and visualization, LEDs will be connected to all outputs to verify the operation of the control.	Yes
3. Check that the system goes through all the states of the state machine.	Connect an LED to simulate each state so that it lights up if the system is in that state. Check the correct change between states in case of variations in the sensors.	Yes

Table 7. Requirements and verifications table of Control Subsystem

All requirements in table 7 have been verified by measuring the signals at the output of the microcontroller and checking that the state machine works correctly. Therefore, it can be assured that the subsystem control works perfectly.

CHALLENGES

Initially, it was intended to use the ATMEGA48-20AU microcontroller because it has a fairly stable internal clock and EEPROM size of 256 x 8 so it could store the flow for later calculation of the number of litres filtered. However, because the PCB had to be changed because other components such as the 5V boost converter were changed and the second round of PCBs did not arrive on time, it was decided to mount the circuit on a breadboard. That is why we ended up using the ATMEGA328-PU microcontroller as it was more convenient to use, and it was in stock at that time because due to the materials crisis caused by the pandemic most of the chips were out of stock.

Also, indirectly the failure in the water flow sensor caused the code to be changed, reducing the number of states and assuming constant flow during the whole filtering process. With the new code, the system worked correctly but was less accurate in making assumptions.

6.4 DISINFECTING SUBSYSTEM

The disinfecting subsystem must be able to eliminate practically 100% of all impurities and bacteria in the water using the microfilter and the carbon + ion filter. To subsequently eliminate the possible presence of viruses by applying ultraviolet light. The performance of this subsystem is difficult to demonstrate without the use of a laboratory expert in water treatment.

REQUIREMENTS	VERIFICATION	VERIFICATION STATUS (Yes/No)
1. The UV lights should be turned on for 10 minutes to kill the bacteria and viruses.	Measure the time from when the UV lights LED switches on and close to verify this.	Yes
2. The UV lights operate at 6.4 V each. This is the voltage needed to provide enough power	Measure the voltage provided to the subsystem. If the voltage is within 5% of 5.7 V, then it is working as planned.	Yes
3. The UV lights should kill the bacteria present in the water.	Collect a water sample and measure the virus content and the turbidity content of that sample in a laboratory	No

Table 8. Requirements and verifications table of Disinfecting Subsystem

Table 8 shows the requirements and verifications necessary to verify the correct operation of the disinfecting subsystem. As can be seen in the table, the requirements associated with turning on the ultraviolet light for the appropriate time have been demonstrated; however, it has not been possible to perform an analysis in any laboratory during the project to verify that the virus content has been 100% eliminated.

Analysing a sample in a laboratory is very expensive, so it is beyond the scope of the course. In addition, the handling of water containing viruses must be done with great care and as an engineer, I do not have the necessary knowledge to do it safely.

As for the elimination of bacteria, heavy metals, and microplastics, we are using two conventional filters of the brand LifeStraw in good condition. The manufacturer itself has carried out laboratory tests and guarantees that its filters can eliminate 99.99% of the presence of these contaminants.

For the elimination of viruses, knowing that the necessary power to eliminate the presence of viruses in the water is 16,000 µW*sec/cm2 it is demonstrated that turning on the UV lights for 7.68 mi, will provide enough power. However, for a check, it has been decided to use 20,000 µW*sec/cm2. Therefore, the UV light should be turned on for at least 10 minutes (9.6 minutes) to ensure that the viruses have been eliminated.

6.5 USER INTERFACE SUBSYSTEM

The user interface system, consisting of the 3 LEDs, should indicate to the user when the UV light is on and if any of the filters need to be replaced.

REQUIREMENTS	VERIFICATION	VERIFICATION STATUS (YES / NO)
1. The LED1 should light up when the water is undergoing UV light treatment.	The LED should light up when the signal from the microcontroller is sent to it. To verify this during UV light treatment, it can be measured the voltage between the microcontroller and UV light using a voltmeter. If it is positive and the LED light is turned on, that means our LED is working properly.	Yes
2. The LED2 should light up when the water filter is worn out.	The LED should light up when the signal from the microcontroller is sent to it. It can be verified by replacing the filter with a worn-out filter and checking if the LED light is turned on. If it is turned on, that means our LED is working properly.	Yes
3. The LED3 should light up when the carbon + ion filter should be replaced.	The LED should light up when the signal from the microcontroller is sent to it. It can be verified by replacing the carbon + ion filter with a worn-out filter and checking if the LED light is turned on. If it is turned on, that means our LED is working properly.	Yes

Table 9. Requirements and verifications table of User interface Subsystem

To check the function of the user interface, first it has been verified that the LED1 always lights up at the same time as the ultraviolet light turned on to warn the user that the water is being disinfected at that moment.

The microfilter must be replaced when the flow decreases considerably. The system takes approximately 20 minutes to filter one gallon of water so it has been defined the replacement of the filter if the water detector detects water for a period longer than 40 minutes (twice as long as it should take). To verify the correct operation of the microfilter replacement because the time is so long, we have simulated the 40 minutes with 30 seconds.

The carbon + ion filter must be replaced when the filter has filtered a total of 40 gallons of water cumulatively. For its comprobation, it also has been reduced the amount of water to the filtered water in a single use (1 gallon) to be able to check the correct operation more efficiently.

CHAPTER 7. CONCLUSIONS AND FUTURE WORK

This contribution is intended to summarize what has been achieved and what has not been achieved due to the problems mentioned throughout the paper. It will also discuss the future work that could be done to complete the project, turn it into a commercial product and rescale it globally.

7.1 ACCOMPLISHMENTS

In general terms, it has been possible to create a portable and functional water filtration and purification system, although it does not work exactly as designed because the water flow sensor has not been used.

It has been possible to create a product that works only with solar energy 24 hours a day because it is supported by a battery that is charged during the day with the excess production by the panel. In addition, although no sample has been analysed in any laboratory, the filters used have already been tested and guarantee 99.99% disinfection of most of the impurities that the water may contain. As for the disinfection of water with ultraviolet light, the power applied is much higher than the minimum recommended by the studies. Therefore, the first high-level requirement is believed to be fully achieved.

The second high-level requirement has been achieved since the three LEDs light up when they are supposed to thanks to the microcontroller. However, the replacement of the filters would be more accurate if the water flow sensor is used so that constant flows do not have to be assumed or rely solely on the accuracy of the timer.

Finally, the project has been designed to be as economical as possible but because of the low filtering rate and the need for a very accurate and solar-powered sensor, the final price is quite high. However, it will be reduced by building a larger product with a higher water filtering capacity.

7.2 UNCERTAINTIES

It has been possible to demonstrate all the functionality of the project with the small limitation of the precision in the replacement of the filters. However, the physical design built is only a prototype and could not be commercialized in this format.

In addition to the problems discussed in section 5.1 about the design, such as the fact that the water detector connections are not protected or that a compartment has not been built in the bottom of the second tank to place the UV LEDs, there are more problems. For example, it was not possible to use a PCB and therefore a large breadboard had to be used with many visible cables that can be unintentionally disconnected when moving the product. In addition, all connections are located on the visible outside instead of inside a box on the side as in the CAD design.

7.3 FUTURE WORK

The next future work would be to buy back the water flow sensor and test the initial code in Annex B to check its correct operation. We would also have to disassemble the circuit created on the breadboard and re-solder all the components on the new PCB to test if the design works as designed.

Once all the electronics are working, we will try to create the physical project following the CAD and the designed drawings. This way the project will not only look nicer but will also work better. For example, the user will not have to worry about wetting the connections of the water detector, or unintentionally disconnecting any cable because the whole project will be prepared to improve the user experience.

We will also try to minimize production costs, making a more economical design and using cheaper materials but in no case interfere with the functionality of the project. In case of doubt, if it can affect its functionality, the original design will be maintained.

Finally, due to its social part, since it is intended to be used in less developed countries without access to clean drinking water, the portable feature will be reduced, and larger tanks will be created. By creating larger tanks, this product could be placed in a public space in a village and be used by all its families. It would also reduce the cost per number of people used because the cost is not proportional to the amount of water it can filter.

Two large compartments would be created, and several filters of each type would be placed to increase the filtering speed and minimize the number of times the filters need to be changed. In addition, it would be sufficient to use a water detector and a water flow sensor connected to the outlet of one of the filters, which would greatly reduce the cost. When it is detected that one of the filters needs to be changed, as they have all filtered the same amount of water and under the same conditions, the others of the same type should also be replaced.

A larger ultraviolet light bulb would be used since they are more economical than the LEDs used in this project and provide a higher light output. The solar panel would also save money because larger solar panels are cheaper than the sum of several smaller panels to produce the same power.

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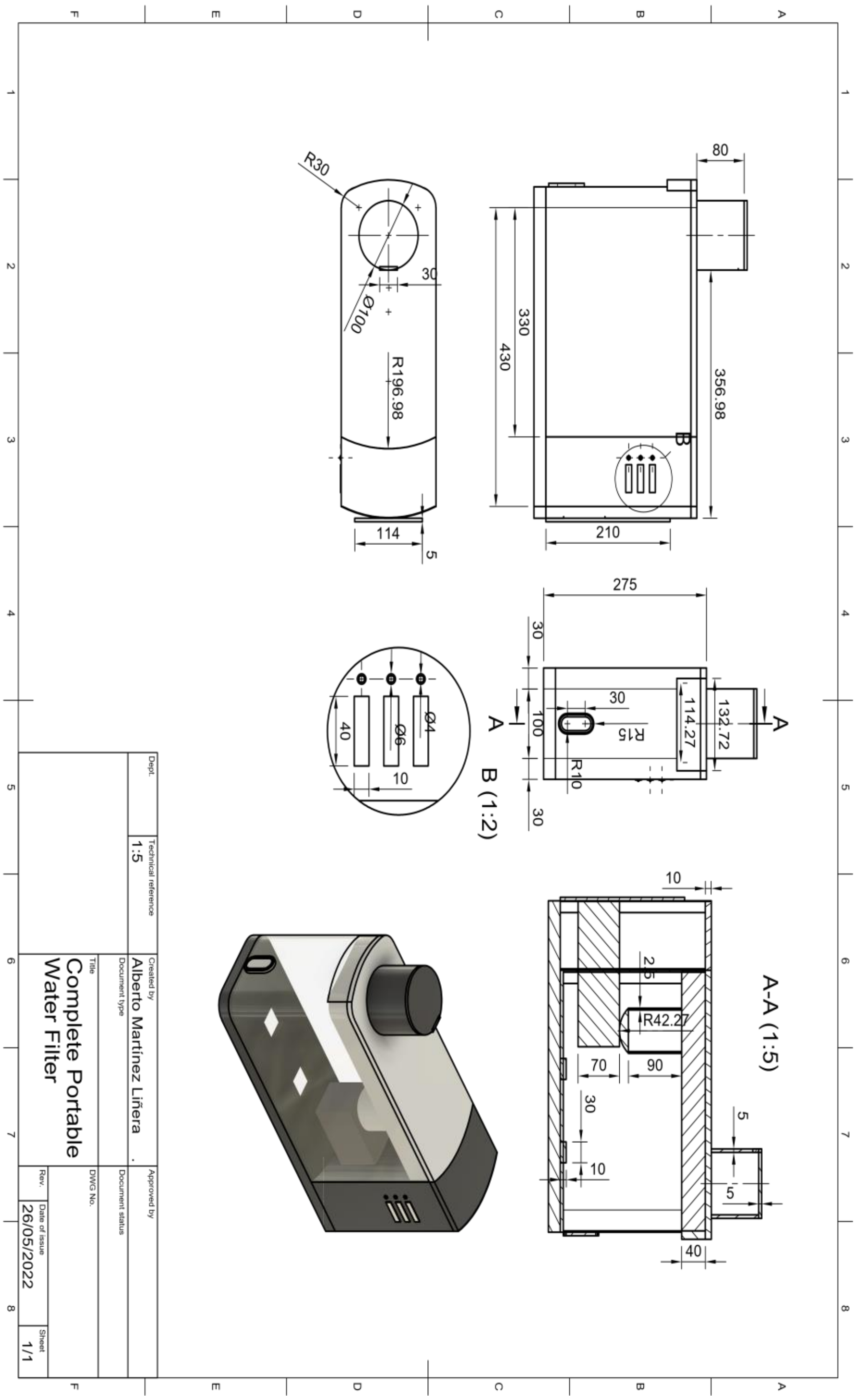
APPENDIX A. PROJECT DRAWING



APPENDIX B. CODE USING WATER FLOW SENSOR

```
Codigo //Arduino equivalent pins to the ATmega328
const int LED1 = 15;  //UV LIGHT ON PC1
const int LED2 = 16;  //MICROFILTER REPLACEMENT PC2
const int LED3 = 17;  //CARBON+ION FILTER PC3
const int Detector = 9; //SIG FROM WATER DETECTOR PB1
const int FLOW = 14; //ANALOG OUTPUT FROM WATER FLOE SENSOR PC0
const int UV1 = 19; //PC5
const int UV2 = 18; //PC6

//Variables declaration
int state;
int LMin;
int Liters;
int FlowMax;

unsigned long previousTime;
unsigned long timefiltering;

void setup() {
  pinMode(Detector, INPUT);
  pinMode(FLOW, INPUT);

  pinMode(LED1, OUTPUT);
  pinMode(LED2, OUTPUT);
  pinMode(LED3, OUTPUT);
  pinMode(UV1, OUTPUT);
  pinMode(UV2, OUTPUT);

//Initialize variables
  state = 0; //state = 0 No water (Initialitation)
             //state = 1 Start measuring flow
             //State = 2 Saving Data and filtering
             //State = 3 Replace Microfilter
             //State = 4 Replace Carbon + Ion Filter
             //State = 5 UVlights on
  Liters = 0;
}

void loop() {
  //Updating states
  if (state == 0){  //No water detected (initialitation)
    if (digitalRead(Detector)== LOW){
      FlowMax = 0;
      state = 1;
    }
  }
```

```
  if (state == 1){
    if (digitalRead(Detector) == HIGH){
      state = 0;
    }else{
      if(analogRead(FLOW)>=0.51){ //0.5 is the analog output when it is not
filtering
        state = 2;
      }
    }
  }

  if (state == 2){
    previousTime = millis();
    //Calculation of the amount of water filtered
    //Conversion of the output to L/s
    if (analogRead(FLOW)> 0.50 && analogRead(FLOW)<=1.90){
      LMin = (0.251-0)/(1.90-0.50)*(analogRead(FLOW)-0.5);
    }else{
      if (analogRead(FLOW)> 1.90 && analogRead(FLOW)<=2.41){
      LMin = 0.251+(0.513-0.251)/(2.41-1.90)*(analogRead(FLOW)-1.90);
      }else{
        if (analogRead(FLOW)> 2.41 && analogRead(FLOW)<=2.70){
        LMin = 0.513+(0.752-0.513)/(2.70-2.41)*(analogRead(FLOW)-2.41);
        }else{
          if (analogRead(FLOW)> 2.70 && analogRead(FLOW)<=2.99){
          LMin = 0.752+(1.016-0.752)/(2.99-2.70)*(analogRead(FLOW)-2.70);
          }
        }
      }
    }

    if (FlowMax <= analogRead(FLOW)){
      FlowMax = analogRead(FLOW);
    }
    delay(1000);
    timefiltering = millis() - previousTime;
    Liters += (LMin/60)*timefiltering;


    if (digitalRead(Detector) == HIGH){
      if (FlowMax < 1){
        state = 3;
      }else{
        if (Liters >= 150){
          state = 4;
        }else{
          state = 5;
        }
      }
    }
  }
```

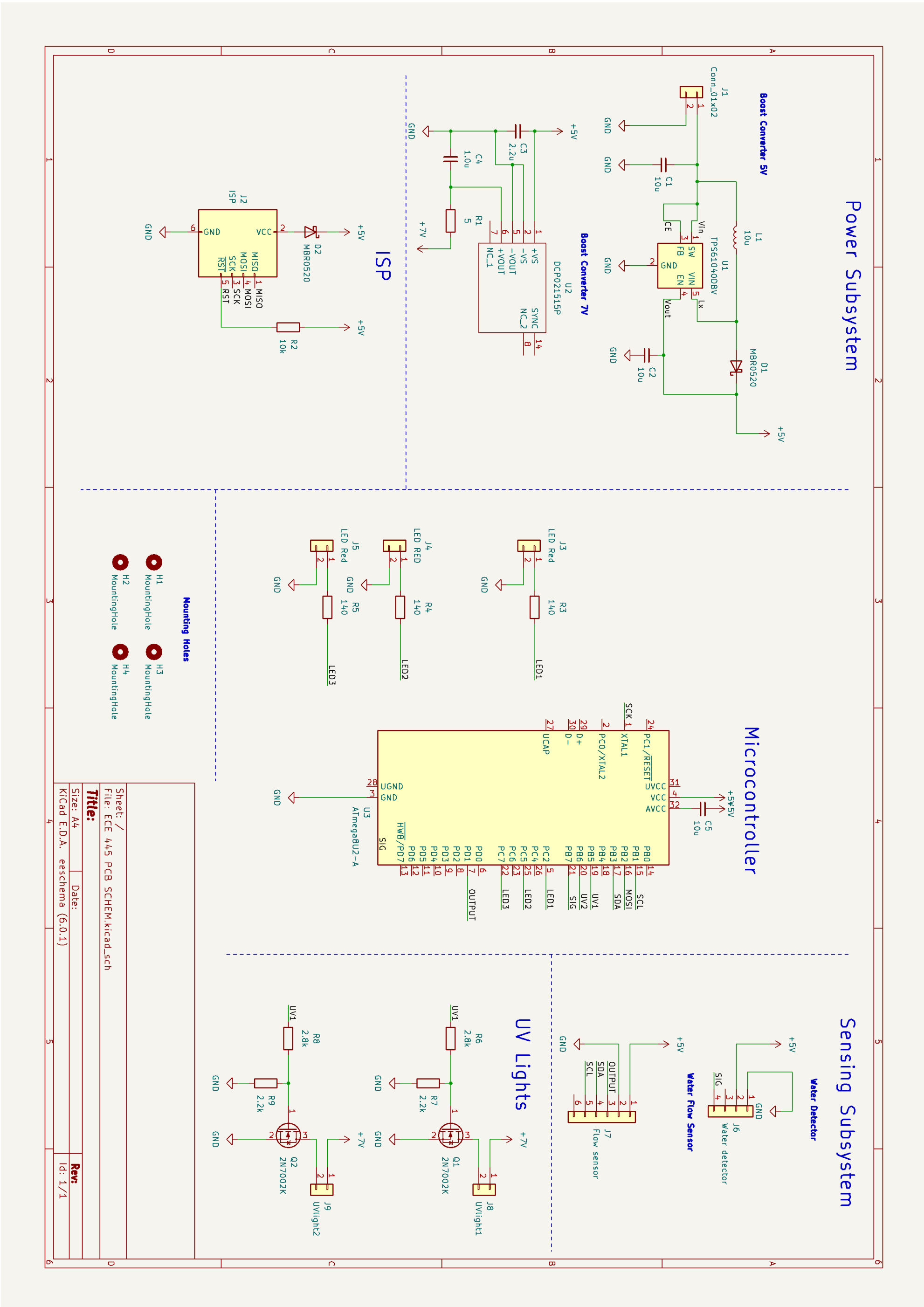
```
  if (state == 3){
    //Turn LED2 for 10 seconds
    digitalWrite(LED2,HIGH);
    delay(10000);
    digitalWrite(LED2,LOW);

    state = 5;
  }
  if (state == 4){
    //Initialize Liter to 0 again
    Liters = 0;

    //Turn LED3 for 10 seconds
    digitalWrite(LED3,HIGH);
    delay(10000);
    digitalWrite(LED3,LOW);

    state = 5;
  }
  if (state == 5){
    digitalWrite(UV1,HIGH);
    digitalWrite(UV2,HIGH);
    delay(600000); //10 minutes
    digitalWrite(UV1,LOW);
    digitalWrite(UV2,LOW);
    state = 0;
  }
}
```

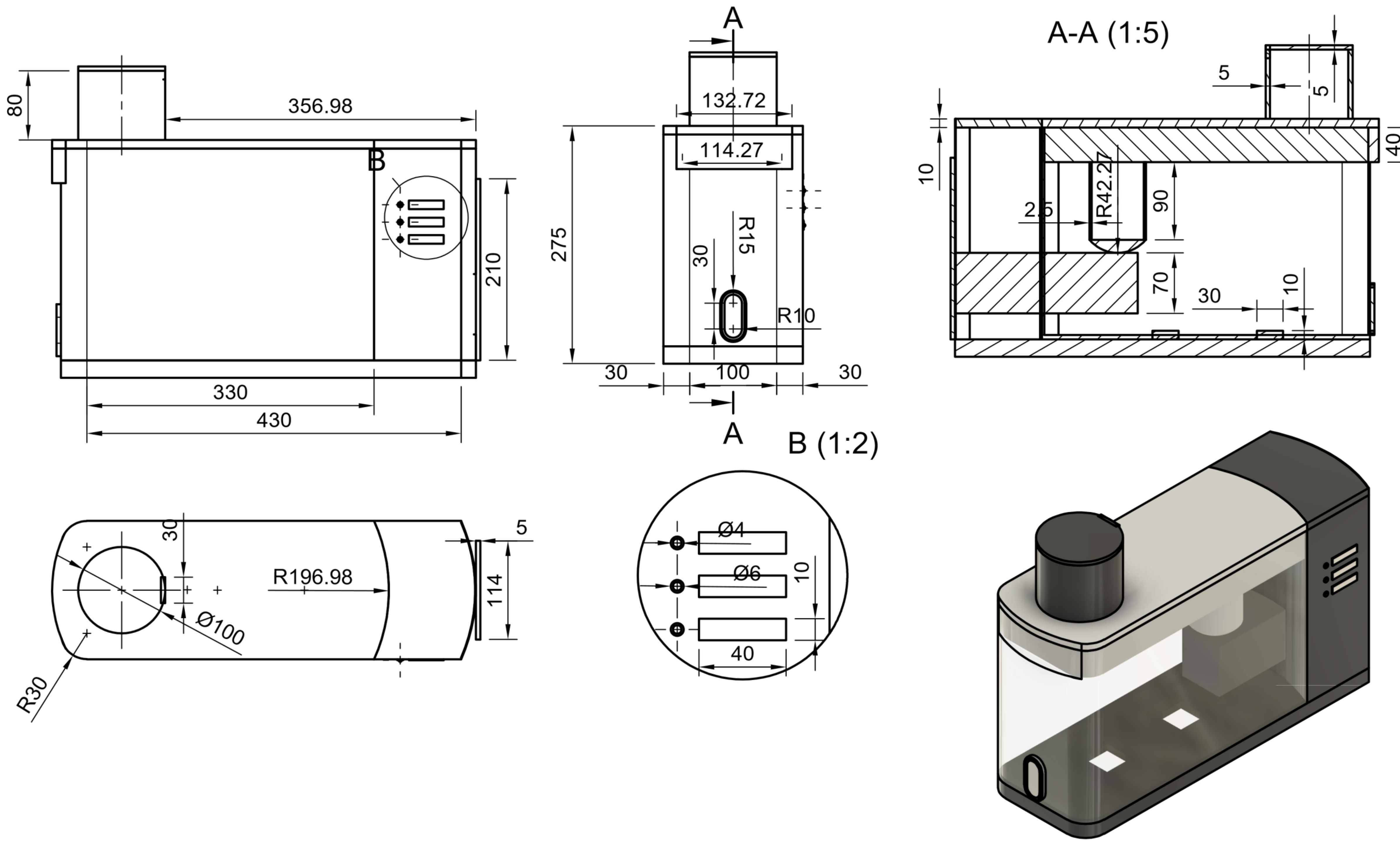
APPENDINX C. CODE WITHOUT WATER FLOW SENSOR

```
//Arduino equivalent pins to the ATmega48
const int LED1 = 15;  //UV LIGHT ON PC1
const int LED2 = 16;  //MICROFILTER REPLACEMENT PC2
const int LED3 = 17;  //CARBON+ION FILTER PC3
const int Detector = 9; //SIG FROM WATER DETECTOR PB1
const int UV1 = 19; //PC5
const int UV2 = 18; //PC6

//Variables declaration
int state;
int Liters;

unsigned long previousTime;
unsigned long timefiltering;
unsigned long timecycle;
unsigned long timefiltmax = 2400; //(40min*60)


void setup() {
  pinMode(Detector, INPUT);

  pinMode(LED1, OUTPUT);
  pinMode(LED2, OUTPUT);
  pinMode(LED3, OUTPUT);
  pinMode(UV1, OUTPUT);
  pinMode(UV2, OUTPUT);

  state = 0; //state = 0 No water (Initialitation)
             //State = 1 Saving Data and filtering
             //State = 2 Replace Microfilter
             //State = 3 Replace Carbon + Ion Filter
             //State = 4 UVlights on
  Liters = 0;
}

void loop() {
  //Updating states
  if (state == 0){  //No water detected (initialitation)
    if (digitalRead(Detector)==LOW){
      timefiltering = 0;
      state = 1;
    }else{
      state = 0;
    }
  }

  if (state == 1){
```

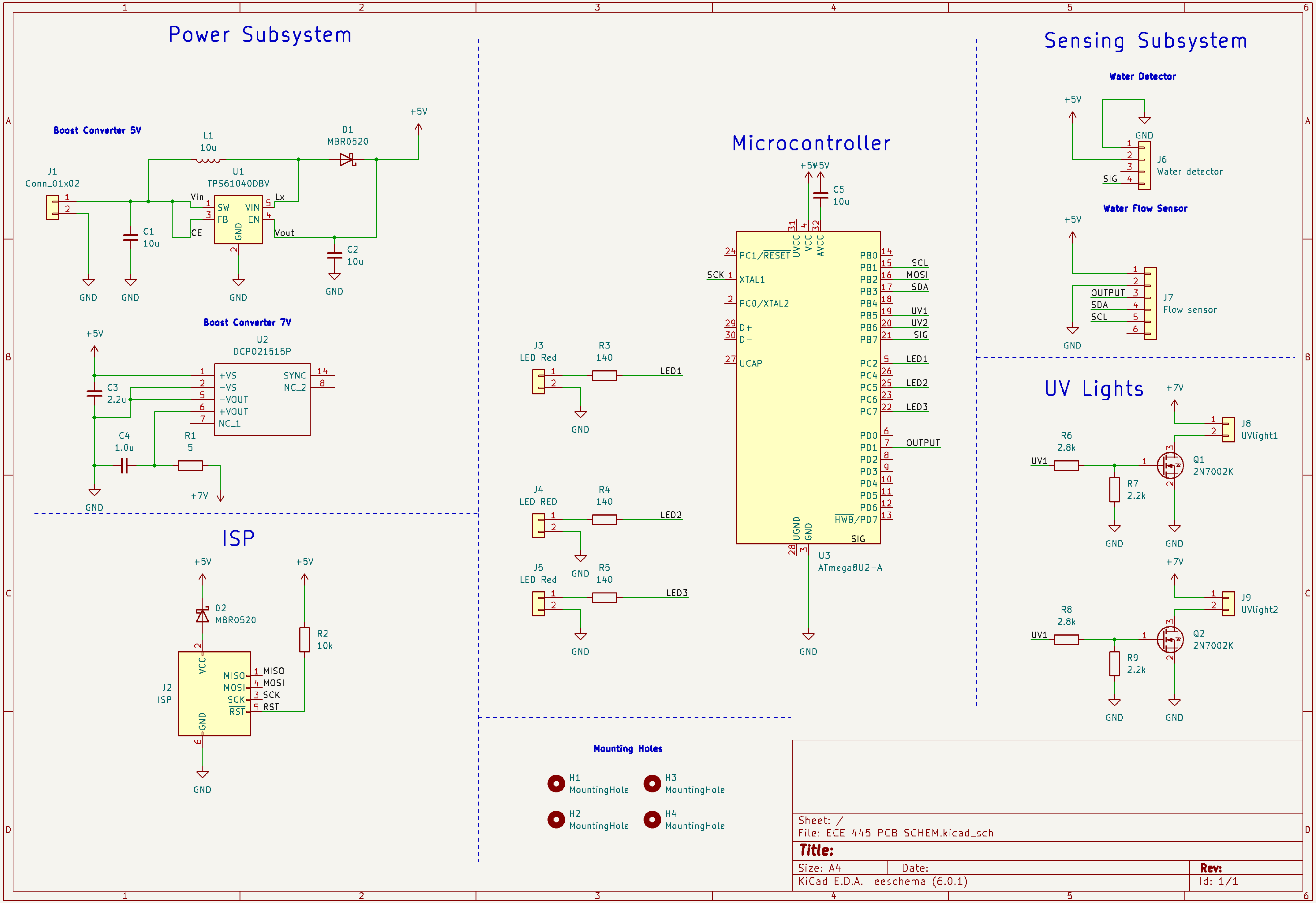
```
    previousTime = millis();
    delay(1000);
    timecycle = (millis() - previousTime)/1000;

    timefiltering += timecycle; //seconds filtering the water

    //to calculate the amount of water filtered we are assuming constant water
flow
    Liters += timefiltering * 0.1614; //0.1614L/min because with the water flow
we were measuring 1.4V

    if (digitalRead(Detector) == HIGH){
      if (timefiltering >= timefiltmax){
        state = 2;
      }else{
        if (Liters >= 150){ //150L = 40 gallons
          state = 3;
        }else{
          state = 4;
        }
      }
    }
  }
  if (state == 2){
    //Initialize Liter again to zero
    Liters = 0;

    //Turn On LED2 for 10 seconds
    digitalWrite(LED2,HIGH);
    delay(10000);
    digitalWrite(LED2, LOW);

    state = 4;
  }
  if (state == 3){
    //Turn On lED3 for 10 seconds
    digitalWrite(LED3,HIGH);
    delay(10000);
    digitalWrite(LED3,LOW);

    state = 4;
  }
  if (state == 4){
    digitalWrite(UV1,HIGH);
    digitalWrite(UV2,HIGH);
    delay(600000); //10 minutes
    digitalWrite(UV1,LOW);
    digitalWrite(UV2,LOW);
    state = 0;
  }
}
```

APPENDINX D. SCHEMATIC





Dept.	Technical reference	Created by	Approved by		
	1:5	Alberto Martínez Liñera .			
		Document type	Document status		
		Title	DWG No.		
		Complete Portable Water Filter	Rev.	Date of issue	Sheet
				26/05/2022	1/1



Power Subsystem
Boost Converter 5V
J1
Conn_01x02
L1
10u
U1
TPS61040DBV
D1
MBR0520
C1
10u
C2
10u
Vin
CE
Lx
Vout
SW
FB
VIN
EN
GND
+5V
Boost Converter 7V
U2
DCP021515P
+VS
-VS
-VOUT
+VOUT
NC_1
SYNC
NC_2
C3
2.2u
C4
1.0u
R1
5
+7V
ISP
J2
ISP
D2
MBR0520
R2
10k
VCC
MISO
MOSI
SCK
RST
Microcontroller
U3
ATmega8U2-A
PC1/RESET
XTAL1
PC0/XTAL2
D+
D-
UCAP
UVCC
VCC
AVCC
UGND
PB0
PB1
PB2
PB3
PB4
PB5
PB6
PB7
PC2
PC4
PC5
PC6
PC7
PD0
PD1
PD2
PD3
PD4
PD5
PD6
HWB/PD7
SIG
SCL
MOSI
SDA
UV1
UV2
LED1
LED2
LED3
OUTPUT
C5
10u
J3
LED Red
R3
140
J4
LED RED
R4
140
J5
LED Red
R5
140
Sensing Subsystem
Water Detector
J6
Water detector
Water Flow Sensor
J7
Flow sensor
UV Lights
R6
2.8k
R7
2.2k
Q1
2N7002K
J8
UVlight1
R8
2.8k
R9
2.2k
Q2
2N7002K
J9
UVlight2
Mounting Holes
H1
MountingHole
H2
MountingHole
H3
MountingHole
H4
MountingHole
Sheet: /
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Size: A4
Date:
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KiCad E.D.A. eeschema (6.0.1)
Id: 1/1