



**COMILLAS**

UNIVERSIDAD PONTIFICIA

ICAI

# GRADO EN INGENIERÍA EN TECNOLOGÍAS INDUSTRIALES

TRABAJO FIN DE GRADO

## DISEÑO DE UN SISTEMA ANTIRROBO CONECTADO PARA INSTALAR EN EXPLOTACIONES AGRÍCOLAS

Autor: Mario Ayerra Basés

Director: Álvaro Pérez Bello

Madrid

Junio de 2020



# **AUTHORIZATION FOR DIGITALIZATION, STORAGE AND DISSEMINATION IN THE NETWORK OF END-OF-DEGREE PROJECTS, MASTER PROJECTS, DISSERTATIONS OR BACHILLERATO REPORTS**

## ***1. Declaration of authorship and accreditation thereof.***

The author Mr. /Ms. Mario Ayerra Basés

**HEREBY DECLARES** that he/she owns the intellectual property rights regarding the piece of work: "Diseño de un sistema antirrobo conectado para instalar en explotaciones agrícolas" that this is an original piece of work, and that he/she holds the status of author, in the sense granted by the Intellectual Property Law.

## ***2. Subject matter and purpose of this assignment.***

With the aim of disseminating the aforementioned piece of work as widely as possible using the University's Institutional Repository the author hereby **GRANTS** Comillas Pontifical University, on a royalty-free and non-exclusive basis, for the maximum legal term and with universal scope, the digitization, archiving, reproduction, distribution and public communication rights, including the right to make it electronically available, as described in the Intellectual Property Law. Transformation rights are assigned solely for the purposes described in a) of the following section.

## ***3. Transfer and access terms***

Without prejudice to the ownership of the work, which remains with its author, the transfer of rights covered by this license enables:

- a) Transform it in order to adapt it to any technology suitable for sharing it online, as well as including metadata to register the piece of work and include "watermarks" or any other security or protection system.
- b) Reproduce it in any digital medium in order to be included on an electronic database, including the right to reproduce and store the work on servers for the purposes of guaranteeing its security, maintaining it and preserving its format.
- c) Communicate it, by default, by means of an institutional open archive, which has open and cost-free online access.
- d) Any other way of access (restricted, embargoed, closed) shall be explicitly requested and requires that good cause be demonstrated.
- e) Assign these pieces of work a Creative Commons license by default.
- f) Assign these pieces of work a HANDLE (*persistent* URL). by default.

## ***4. Copyright.***

The author, as the owner of a piece of work, has the right to:

- a) Have his/her name clearly identified by the University as the author
- b) Communicate and publish the work in the version assigned and in other subsequent versions using any medium.
- c) Request that the work be withdrawn from the repository for just cause.
- d) Receive reliable communication of any claims third parties may make in relation to the work and, in particular, any claims relating to its intellectual property rights.

## ***5. Duties of the author.***

The author agrees to:

- a) Guarantee that the commitment undertaken by means of this official document does not infringe any third party rights, regardless of whether they relate to industrial or intellectual property or any other type.

- b) Guarantee that the content of the work does not infringe any third party honor, privacy or image rights.
- c) Take responsibility for all claims and liability, including compensation for any damages, which may be brought against the University by third parties who believe that their rights and interests have been infringed by the assignment.
- d) Take responsibility in the event that the institutions are found guilty of a rights infringement regarding the work subject to assignment.

**6. Institutional Repository purposes and functioning.**

The work shall be made available to the users so that they may use it in a fair and respectful way with regards to the copyright, according to the allowances given in the relevant legislation, and for study or research purposes, or any other legal use. With this aim in mind, the University undertakes the following duties and reserves the following powers:

- a) The University shall inform the archive users of the permitted uses; however, it shall not guarantee or take any responsibility for any other subsequent ways the work may be used by users, which are non-compliant with the legislation in force. Any subsequent use, beyond private copying, shall require the source to be cited and authorship to be recognized, as well as the guarantee not to use it to gain commercial profit or carry out any derivative works.
- b) The University shall not review the content of the works, which shall at all times fall under the exclusive responsibility of the author and it shall not be obligated to take part in lawsuits on behalf of the author in the event of any infringement of intellectual property rights deriving from storing and archiving the works. The author hereby waives any claim against the University due to any way the users may use the works that is not in keeping with the legislation in force.
- c) The University shall adopt the necessary measures to safeguard the work in the future.
- d) The University reserves the right to withdraw the work, after notifying the author, in sufficiently justified cases, or in the event of third party claims.

Madrid, on 17..... of June, 2020....., .....

**HEREBY ACCEPTS**

Signed Mario Ayerra Basés.....

Reasons for requesting the restricted, closed or embargoed access to the work in the Institution's Repository

Declaro, bajo mi responsabilidad, que el Proyecto presentado con el título  
“Diseño de un sistema antirrobo conectado para instalar en explotaciones  
agrícolas”

en la ETS de Ingeniería - ICAI de la Universidad Pontificia Comillas en el  
curso académico 2019/2020 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.: Mario Ayerra Basés

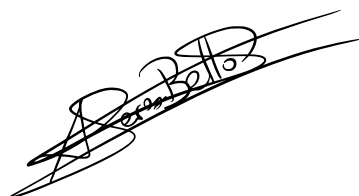
Fecha: 17/ 06/ 2020



Autorizada la entrega del proyecto  
EL DIRECTOR DEL PROYECTO

Fdo.: Álvaro Pérez Bello

Fecha: 17/06/2020







**COMILLAS**

UNIVERSIDAD PONTIFICIA

ICAI

# GRADO EN INGENIERÍA EN TECNOLOGÍAS INDUSTRIALES

TRABAJO FIN DE GRADO

## DISEÑO DE UN SISTEMA ANTIRROBO CONECTADO PARA INSTALAR EN EXPLOTACIONES AGRÍCOLAS

Autor: Mario Ayerra Basés

Director: Álvaro Pérez Bello

Madrid

Junio de 2020





# DISEÑO DE UN SISTEMA ANTIRROBO CONECTADO PARA INSTALAR EN EXPLOTACIONES AGRÍCOLAS.

**Autor: Ayerra Basés, Mario.**

Director: Pérez Bello, Álvaro.

Entidad colaboradora: Altair.

## RESUMEN DEL PROYECTO

**Abstracto.** – En este proyecto se propone una solución al problema de los robos de equipos agrícolas. En particular, se diseña un dispositivo IoT para proteger grupos electrógenos diésel de estos robos. Previamente, se han estudiado las tecnologías existentes y se han escogido las más adecuadas para el diseño. Este producto está conectado a una plataforma IoT y ofrece otras capacidades como la generación de estadísticas acerca del uso del generador. Finalmente, se expone un estudio de mercado y un modelo de negocio para lanzar el producto en el mercado.

**Palabras clave.** – *Internet de las cosas, IoT, conectividad, antirrobo, agricultura, generador diésel, GPS, GSM, GPRS, MQTT, plataforma.*

### 1. Introducción

Recientemente, los agricultores en España han estado sufriendo robos de material y equipamiento agrícola de forma frecuente. Algunos factores como la despoblación rural, o las tecnologías cada vez más caras que se emplean en la agricultura. La mayor incidencia de este problema se observó tras la crisis financiera de 2008 y se espera que de nuevo repunte en los próximos años si se cumplen las previsiones económicas. Algunos equipos que son objeto frecuente de robos son los paneles solares, las baterías de ácido-plomo, el cobre de

pivots de riego o transformadores, piezas de sistemas de riego, generadores diésel, etc. Este proyecto se va a centra en el problema de los robos en generadores diésel situados en terrenos agrícolas.

Tras una búsqueda exhaustiva de soluciones existentes a este problema, se ha observado que la mayoría de ellas no solucionan el problema completamente, o no están ampliamente utilizadas debido a su alto precio o bajas prestaciones. La empresa Traxco® vende un sistema antirrobo que consiste en varios sensores (acelerómetros) conectados a un repetidor central, que manda un mensaje SMS en caso de que alguno detecte movimiento. Este sistema con un solo sensor cuesta 252€ y cada sensor adicional cuesta 24€ [1]. La empresa METOS® oferta una solución diferente que permite al propietario monitorizar la posición de sus equipos y maquinaria agrícola. Estos dispositivos utilizan un sensor GPS que envía datos a una plataforma a través de NB-IoT o GPRS. Si la posición medida se encuentra fuera del área donde se espera que se encuentre el equipo, entonces se envía una alerta de robo al agricultor [2]. Este dispositivo está especialmente diseñado para su uso en aplicaciones agrícolas y su precio está en torno a los 350€, más una suscripción anual a la plataforma. Otras soluciones que existen son módulos GPS genéricos que envían sus coordenadas periódicamente, cámaras de videovigilancia ocultas, o la construcción de cobertizos donde alojar los equipos.

Algunas tecnologías que se han desarrollado en los últimos años podrían ser empleadas para solucionar este problema. El Internet de las Cosas (IoT) es una disciplina que ha observado un gran progreso recientemente y que permite la conexión de objetos cotidianos a Internet. LPWAN (Low Power Wide Area Networks) son redes de comunicación ideales para aplicaciones IoT que tengan necesidad de ahorro de energía [3]. como es el caso de este proyecto. Las redes LPWAN más ampliamente utilizadas son LoRa, Sigfox y NB-IoT. La red LoRa todavía no ha sido totalmente desplegada en España, por lo que no se considerará para su uso en este proyecto [4]. La red Sigfox resulta más económica que NB-IoT, pero permite el envío de menor número de mensajes diarios, y de menor tamaño. La elección de una red u otra depende de las características de cada proyecto en particular. La Figura 1 muestra una comparación de estas tecnologías considerando diferentes factores.

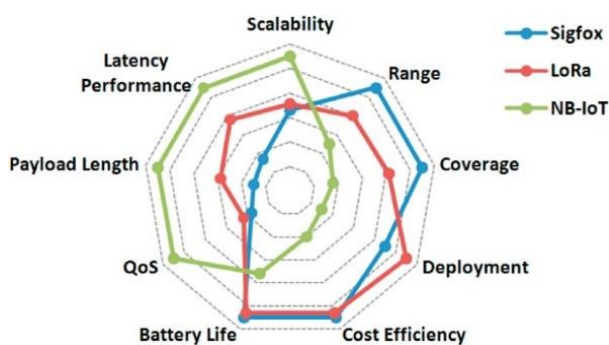


Figura 1. Comparación de redes LPWAN [5]

Otra alternativa a las redes LPWAN son las redes de comunicación móvil tradicionales. Las redes GSM y GPRS son las tecnologías más maduras y están desplegadas en todo el mundo. Esto hace que el prototipado y diseño de productos con estas tecnologías sea barato y rápido. Las redes 3G, 4G y 5G también son una alternativa para aplicaciones en las que se necesita enviar gran cantidad de datos, lo cual no es el caso en este proyecto.

Existen varios protocolos de comunicación especialmente diseñados para aplicaciones IoT. Uno de los más utilizados es

MQTT (Message Queuing Telemetry Transport), que es un protocolo ligero y fácil de implementar. Está especialmente diseñado para aplicaciones con necesidad de ahorro de energía, así que resulta totalmente adecuado para este proyecto. Es un Servicio de Mensajería Pub/Sub. Esto significa que el emisor asigna un ‘topic’ a cada uno de los mensajes que envía y los receptores pueden suscribirse a los ‘topics’ de los que estén interesados para recibir estos mensajes [6]. Además, no existe ninguna cola para almacenar los mensajes en caso de que la conexión se pierda, a pesar del nombre del protocolo. El ‘broker’ se encarga de distribuir los mensajes desde los emisores a los subscriptores.

Un dispositivo que pueda resolver el problema de los robos en el campo necesita conocer su posición, para así poder encontrar los equipos en caso de que el ladrón escape. Dos tecnologías diferentes se pueden utilizar con este objetivo. El Sistema Global de Navegación por Satélite (GNSS) permite calcular la posición a partir de una serie de señales emitidas por satélites en órbita. Esta tecnología se basa en la multilateración y genera la medida a partir de la diferencia de tiempo de llegada (TDOA por sus siglas en inglés). El sistema GNSS más utilizado es el GPS, desarrollado por el departamento de defensa estadounidense, aunque existe otros sistemas como GLONASS o Galileo, desarrollados por Rusia y la Unión Europea respectivamente. La segunda tecnología estima la posición a partir de señales enviadas desde antenas situadas en la superficie terrestre. Este tipo de tecnología está implementada ya en las redes de Sigfox y LoRa. Ambas redes utilizan un indicador de fuerza de la señal recibida (RSSI por sus siglas en inglés) en lugar de TDOA para calcular la posición. Esta tecnología ofrece una precisión mucho peor que la geolocalización por satélite, con errores superiores a 1 km [7]. LoRa también posibilita el uso de una tecnología basada en el TDOA que permite una precisión entre 20 y 200 m en

las estimaciones [8]. En comparación con GNSS, estas tecnologías ofrecen peor precisión, pero son más baratas, consumen menos energía y funcionan en interiores.

El objeto de este proyecto es el diseño de un dispositivo que pueda evitar el problema de los robos en el campo. En particular, se diseña un dispositivo para proteger un generador diésel, aunque este se podría emplear para proteger otros equipos con pequeñas modificaciones. Este dispositivo recoge datos del generador que además pueden ser usados para otros propósitos diferentes de la prevención de robos, aportando así un valor añadido al producto. Los datos recogidos por el dispositivo se envían a una plataforma en la nube, donde se almacenan y se analizan. El agricultor recibirá avisos de robo y estadísticas de uso a través de una aplicación móvil o a través de mensajes SMS. Otro objetivo del proyecto es la optimización del coste del dispositivo diseñado y el estudio del mercado actual para diseñar un plan de negocio óptimo.

## 2. Metodología

El dispositivo diseñado en este proyecto detecta el movimiento de un grupo electrógeno a partir de los datos de un acelerómetro y distingue si el generador está funcionando o está siendo movido. Además, detecta la posición del generador con un sensor GPS. Esta información se envía a la nube, donde es analizada (Figura 2).

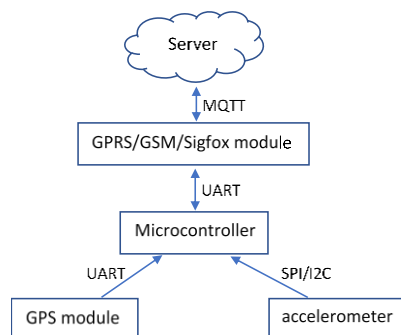


Figura 2. Flujo de datos

De este análisis se obtienen estadísticas sobre el uso del generador y es posible avisar inmediatamente al agricultor cuando produce un robo (Figura 3). Aunque durante la fase de investigación se concluyó que Sigfox era la tecnología más adecuada para este proyecto, finalmente se ha decidido emplear GPRS. Esta decisión se ha tomado debido a las limitaciones temporales del proyecto y a la rapidez en el diseño y prototipado que permite una tecnología madura como es el GPRS.

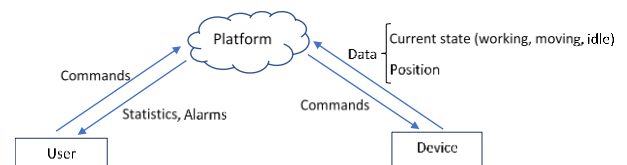


Figura 3. Esquema de comunicaciones

El dispositivo diseñado está conectado a la batería de ácido-plomo que el generador diésel utiliza para arrancar, aunque también tiene una batería interna que le proporciona cierta autonomía en caso de que el ladrón corte el cable de alimentación.

Durante este proyecto se ha diseñado un prototipo del dispositivo. Utiliza el acelerómetro y el GPS, y ejecuta el algoritmo para detectar si el generador está funcionando, si se está moviendo o si está parado. Esta información se envía a la plataforma utilizando Wifi y el protocolo MQTT. En el producto final, el Wifi tendrá que ser sustituido, pero el propósito de este prototipo no era probar la red de comunicaciones. Los principales objetivos de este prototipo eran recibir señales del GPS y el acelerómetro y probar el algoritmo de detección de robos. Este prototipo ha sido diseñado (incluida una PCB y una carcasa imprimible en 3D), construido y probado en un grupo electrógeno real.

El prototipo utiliza un Arduino NANO 33 IoT. Además del microcontrolador, esta placa incluye un acelerómetro y un módulo Wifi que han sido empleados en este proyecto. En cuanto al GPS, se ha empleado el módulo Neo-6M.

El algoritmo que detecta si el generador está funcionando o si está siendo movido utiliza los datos de aceleración en los tres ejes. Para reducir el consumo de energía, estos datos se recogerán a una frecuencia de 104 Hz durante periodos de tiempo cortos (en torno a 2 segundos) y cada cierto tiempo (por ejemplo, cada 20 segundos). Cada una de estas muestras de 2 segundos de duración se pasan a través de un algoritmo que consta de diferentes pasos:

- 1- Se elimina la contribución de la gravedad en las medidas empleando un filtro paso alto.
- 2- Se calculan dos parámetros para cada eje: una integral que representa el incremento de velocidad observado en este tiempo ( $\Delta v$ ) y el valor cuadrático medio de la muestra filtrada ( $a_{rms}$ ).
- 3- Entre los tres ejes, se escogen los valores máximos y estos se comparan con unos valores límite que permiten estimar el estado del generador, siguiendo el árbol de clasificación mostrado en la Figura 4.

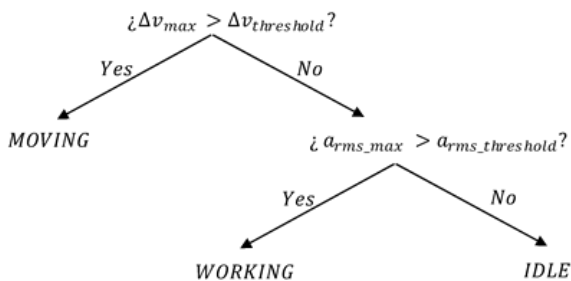


Figura 4. Árbol de clasificación.

- 4- Después de probar el algoritmo, se observó que cuando el dispositivo pasaba de estar moviéndose a estar parado, en algunas ocasiones se estimaba erróneamente que estaba funcionando. Por ello, se añadió un paso final para filtrar esta estimación utilizando las dos últimas estimaciones (sin filtrar), de modo que el algoritmo solo considera que el generador está funcionando si se ha detectado que lo está en tres estimaciones consecutivas.

La plataforma que se ha utilizado en este proyecto está desarrollada por la empresa Altair®. En la plataforma se reciben los datos enviados por los dispositivos, y se guardan asociados a una entidad llamada ‘thing’. Cada una de estas entidades tiene propiedades (‘properties’), acciones (‘actions’) y eventos (‘events’) asociados, que están definidos en una estructura en formato JSON. Esta manera de gestionar entidades está basada en el trabajo de la corporación W3C acerca del WoT (Web of Things), que proporciona un estándar para la ‘Web of Things’[9].

El primer prototipo, soldado y montado se muestra en la Figura 5, y su funcionamiento ha sido probado en un generador diésel de verdad.



Figura 5. Prototipo montado.

Finalmente, se ha realizado un estudio de mercado y se ha diseñado un plan de negocio. Este estudio está compuesto principalmente por:

- Previsión de ventas.
- Análisis de costes.
- Análisis de ingresos
- Previsión de beneficios.

### 3. Resultados

Se ha comprobado que el algoritmo diseñado para determinar el estado del generador funciona de forma exitosa. Primero se testó para detectar el movimiento y las vibraciones de un pequeño generador

doméstico y finalmente se testó en un grupo electrógeno real. En cada caso, los valores límite empleados en el algoritmo de clasificación se adaptaron a la magnitud de las vibraciones.

Los resultados de las pruebas del dispositivo en el generador diésel se muestran en la Figura 6. Estos gráficos muestran los valores máximos (entre los tres ejes) de  $\Delta v$  y  $a_{rms}$  observados durante tres arranques y paradas del generador. A partir de estos gráficos, los valores límite de  $\Delta v$  y  $a_{rms}$  se deben fijar para este generador en torno a 1,5 y 0,05 respectivamente.

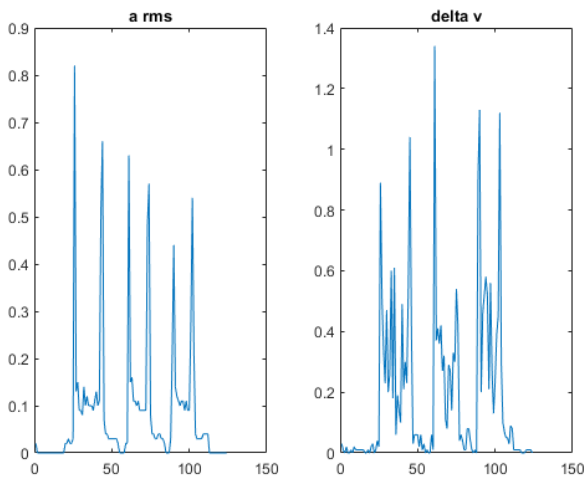


Figura 6. Resultados de la prueba en el campo

El sensor GPS también funcionó correctamente, incluso con la antena situada en el interior de la carcasa. Se observó una precisión en torno a los 2 metros.

Basado en el prototipo que se ha construido previamente, se ha diseñado un nuevo prototipo que incluye una batería interna y comunicación por medio de GSM/GPRS. Para evitar dañar la batería interna o que pierda capacidad de carga, se ha diseñado un sistema de gestión de esta empleando el chip LM317. Dado que el tiempo de carga no es demasiado relevante en este proyecto, la batería se cargará utilizando una corriente pequeña constante (en torno a 0.1C). Para controlar la carga de la batería y detenerla cuando esta esté llena se emplean unos transistores operados por el

microcontrolador. Como el dispositivo no puede disponer de un interruptor de encendido y apagado, se ha diseñado un circuito para auto-apagar el dispositivo. Esta acción se activa de forma inalámbrica y solo funciona cuando el dispositivo no está conectado a la batería externa. Previene que la batería entre en zona de descarga profunda cuando el dispositivo no está en uso. El dispositivo se volverá a encender automáticamente cuando se le conecte la alimentación externa.

La conexión a Internet del segundo prototipo se ha diseñado para que se realice a través de GPRS. EL módulo GSM/GPRS utilizado se basa en el chip SIM800L de SIMCom y se controla mediante el envío de comandos AT a través de la comunicación UART.

Los resultados del estudio de mercado muestran que el precio óptimo para vender este dispositivo está en torno a los 180€. A partir de los pronósticos de ventas y de los costes estimados, se ha calculado anualmente el beneficio neto de la inversión. Los resultados obtenidos se muestran en la Tabla 1.

Tabla 1. Beneficio neto previsto (en €).

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Net profit	-5034	7859	19988	64275	128948	335738

Además, se ha calculado el TIR y el VAN de la inversión, arrojando los siguientes resultados:

$$TIR = 301 \%$$

$$VAN = 330.417 \text{ € (tasa de interés del 0,1)}$$

#### 4. Conclusiones

En este proyecto se ha propuesto una solución para los robos de generadores diésel. Esta solución está basada en un dispositivo que detecta cuando el generador está funcionando y cuando está siendo movido. Esta información se envía a una plataforma IoT, desde donde es posible comunicarse con el usuario. Se ha

comprobado que el prototipo construido funciona correctamente y se han cumplido todos los objetivos del proyecto. Finalmente, los resultados del estudio de mercado que se ha desarrollado sugieren que el producto representa una inversión rentable en el mercado actual. Estos resultados se deben especialmente a la baja inversión inicial que se necesita para empezar el negocio, y el bajo riesgo que este entraña.

[9] World Wide Web Consortium, "Web of Things at W3C," [En línea]. Disponible: <https://www.w3.org/WoT/>

## 5. Referencias

- [1] Traxco, "Sistema Antirrobo," [En línea]. Disponible: <https://www.traxco.es/tienda/sistema-antirrobo>
- [2] Metos, "iMetos Trackers," [En línea]. Disponible: <http://metos.at/es/imetos-trackers/>
- [3] Wikipedia, "LPWAN" [En línea]. Disponible: <https://en.wikipedia.org/wiki/LPWAN>
- [4] Madrid Business, "Redexia Nace En España La Primera Red Nacional LoRaWAN Dedicada Al IoT". *madridbusiness*.
- [5] K. Mekki, E. Bajic, F. Chaxel and F. Meyer, "A comparative study of LPWAN technologies for large-scale IoT deployment," *ICT Express*, vol. 5, no. 1, pp. 1-7, 2019.
- [6] L. LLamas, "Protocolos de comunicación para IoT," [En línea]. Disponible: <https://www.luisllamas.es/protocolos-de-comunicacion-para-iot/>
- [7] Sigfox, "Geolocation technologies," [En línea]. Disponible: <https://build.sigfox.com/geolocation-technologies>
- [8] LoRa Alliance™ Strategy Committee, "Geolocation whitepaper," 01 2018. [En línea]. Disponible: [https://lora-alliance.org/sites/default/files/2018-04/geolocation\\_whitepaper.pdf](https://lora-alliance.org/sites/default/files/2018-04/geolocation_whitepaper.pdf)

# DESIGN OF AN ANTI-THEFT CONNECTED SYSTEM FOR AGRICULTURAL EQUIPMENT.

**Author: Ayerra Basés, Mario.**

Director: Pérez Bello, Álvaro.

Collaborating entity: Altair.

## PROJECT ABSTRACT

***Abstract.* – In this project, a solution for thefts of agricultural equipment is proposed. In particular, an IoT device to protect diesel generators from robberies is designed. Previously, the existing technologies have been studied and the most suitable ones have been chosen for the design. This product is connected to an IoT platform and it offers other capabilities, like the generation of statistics about the usage of the generator. Finally, a market study and a business model to launch the product in the market are exposed.**

***Key words.* – Internet of Things, IoT, connectivity, anti-theft, agriculture, diesel generator, GPS, GSM, GPRS, MQTT, platform.**

### 1. Introduction

In recent years, farmers in Spain have been suffering from frequent thefts of materials and equipment. Some factors, like the depopulation of the rural areas, or the increasingly expensive technology that is used in agriculture are in the origin of this situation. The biggest incidence of this problem was observed after the 2008 financial crisis, and it is expected to raise again in the following years if the economic predictions become true. Some equipment that is affected by these robberies are the copper from center-pivot irrigation systems and transformers, lead-acid batteries, parts of other irrigation systems, solar panels, diesel generators, etc. This project is centered

in the problem of the thefts of diesel generators placed in the countryside.

After an exhaustive research of the existing solutions that exist to solve this problem, it was found that most of them did not solve it completely, or they were not widely used due to their high price or poor performance. The company Traxco® sells an anti-theft system that consists of some sensors (accelerometers) that are connected to a central transmitter which sends an SMS message in case a movement is detected. This system with just one sensor costs 252€, and each additional sensor costs 24€ [1]. The company METOS® sells a different solution that allows the owner to track the equipment with a GPS sensor and sends data to a platform using NB-IoT or GPRS. If the position measured is outside an area, it will send a robbery alert [2]. It is especially designed to be used in the farm and is costs around 350€, plus an annual subscription to the platform. Other solutions are generic GPS modules that send the coordinates periodically, video surveillance hidden cameras, or huts to place the equipment inside.

Some technologies that have been developed in the last years could be used to solve this problem. The Internet of Things (IoT) is a field that has seen a big progress recently, and it allows the connection of ordinary objects to the Internet. LPWAN (Low Power Wide Area Network) are communication networks that are ideal for IoT

applications with low power consumption requirements [3], like the one studied in this project. The most widely used LPWANs are LoRa, Sigfox and NB-IoT. LoRa is not fully deployed in Spain yet [4], so it will not be further considered in this project. Sigfox is more cost-efficient and energy-efficient than NB-IoT, but it allows less messages per day and shorter payloads. The election of one network or another depends on the requirements of each particular application. Figure 1 shows a comparison of these technologies that consider several factors.

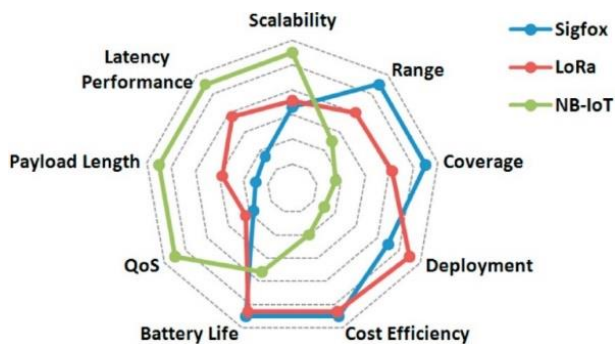


Figure 1. Comparison of LPWAN [5]

An alternative to LPWAN are the traditional mobile communication networks. GSM and GPRS are the most mature networks and they are present all over the world. This makes it relatively cheap and fast to design products that use these networks. 3G, 4G and 5G are other alternatives for applications where big amounts of data need to be transmitted, which is not the case of this project.

There exist also various communication protocols especially designed for IoT applications. One of the most widely used is MQTT (Message Queuing Telemetry Transport), which is light and easy to implement. It is especially designed for applications with low-power requirements, so it fits perfectly in this project. It is a Message Service Pub/Sub protocol. This means that the sender devices assign a topic to every message that they send, and the receivers can subscribe

to the topics that they are interested in, to receive them [6]. Also, there is no queue to store the messages when the connection is lost, despite the name of the protocol. The broker handles the communication flow from the publishers to the subscribers.

A device that solves the robbery problem needs to know its position, so that it can be found in case it is stolen. Two different technologies are available for this purpose. The Global Navigation Satellites Systems (GNSS) can compute the position of the device from signals sent by the satellites. This technology is based on the Time Difference of Arrival (TDOA) technique. The most used GNSS is the American system, known as GPS, but there are other systems like GLONASS or Galileo, developed by Russia and the European Union, respectively. The second technology estimates the position of the device using signals received from communication stations. This technology is already developed in Sigfox and LoRa networks. Both networks use the Received Signal Strength Indicator (RSSI) instead of TDOA to calculate the position. This technology offers much worse precision than GNSS (worse than 1 km) [7]. LoRa also enables a TDOA technology which provides a precision of 20 to 200 m [8]. Compared to GNSS, these technologies offer a lower precision, but they are cheaper, they consume less power and they work well indoors.

The object of this project is to design a device that can solve the problem of the robberies in the countryside. In particular, a device to protect diesel generators is designed, although it could be used to protect other equipment with little modifications. This device collects data from the generator that could be used for other applications different from theft-detection, which gives the product an added value. The data collected by the device is sent to a platform in the cloud, where it is stored and analyzed. The farmer will receive robbery alerts and useful usage



statistics through a mobile application or SMS messages. Another objective of this project is to optimize the cost of the device and study the existing market to design a business strategy that is profitable

## 2. Methodology

The device designed in this project detects the movement of a diesel generator using an accelerometer and it distinguishes if the generator is working or it is being moved. Also, it detects the position of the generator with a GPS sensor. This information is sent to a cloud platform, where it can be analyzed (Figure 2).

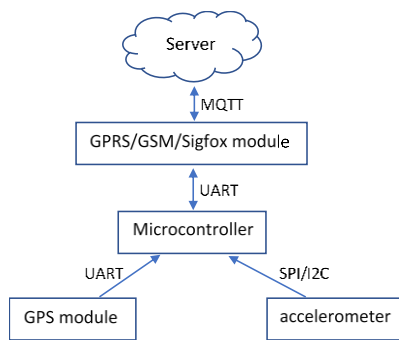


Figure 2. Data flow

From this analysis, some statistics about the usage of the generator can be generated, and it is possible to warn the farmer in case a theft is detected (Figure 3). Although in the research stage it was concluded that Sigfox was the most suitable technology for this project, the network that has been finally used to transmit this data is GPRS, due to the fast product development and cheap prototyping that a mature technology like this allows.

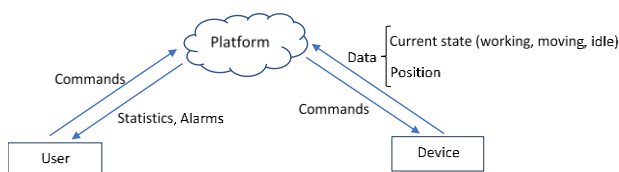


Figure 3. Communications diagram

The device designed is connected to the lead-acid battery that the diesel generator uses to start-up, although it has some autonomy in case the power supply cable is cut by a thief.

During this project a prototype of the device has been designed. It uses the accelerometer and the GPS, and it executes the algorithm to detect if the generator is working, moving or idle. This information is sent to the platform using Wi-Fi and the MQTT protocol. Wi-Fi will need to be substituted in the final product, but it was not the purpose of this prototype to test the communication network. The main objectives of this prototype were to receive signals from the GPS and the accelerometer, and to test the theft-detection algorithm. It was designed (including a PCB and a 3D-printable case), built and tested in a real generator.

The prototype uses an Arduino NANO 33 IoT. As well as the microcontroller, this board includes an accelerometer and a Wi-Fi module, which were used in the prototypes. The GPS used is a Neo-6M module.

The algorithm that detects when the generator is working and when it is being moved uses the data of the acceleration in the three axes. To reduce power consumption, this data is collected at a frequency of 104 Hz for small periods of time (around 2 seconds) periodically (every 20 seconds, for example). Each of these 2-seconds samples are passed through the different steps of the algorithm:

- 1- The contribution of the gravity to the measurements is eliminated, using a high-pass filter.
- 2- Two parameters are calculated for each axis: an integral that represents the increase in velocity observed during this time ( $\Delta v$ ) and the root mean square of the filtered sample ( $a_{rms}$ ).
- 3- The maximum of these parameters in each of the three axes is compared with two different threshold values to

estimate the state of the generator, following the classification tree shown in Figure 4.

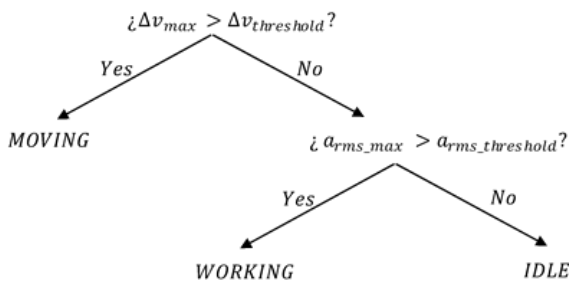


Figure 4. Clasification algorithm

- 4- After testing the algorithm, it was found that when the device changed from ‘moving’ to ‘idle’, an erroneous estimation of ‘working’ was sometimes observed. Therefore, a final step was added to filter the estimation using two previous unfiltered estimations, so that the algorithm only considers that the generator is working if it has detected it to be working in three consecutive estimations.

The platform that was used in this project is developed by the company Altair®. In the platform, the data sent by a device is received and stored attached to an entity, also called ‘thing’. Each ‘thing’ has some ‘properties’, some ‘actions’ and some ‘events’ that are define in a JSON structure. This way of managing entities is based on the W3C work on the Web of Things (WoT), which provides a standard for the Web of Things [9].

The first prototype was assembled, as shown in Figure 5 and it was tested in a real diesel generator.

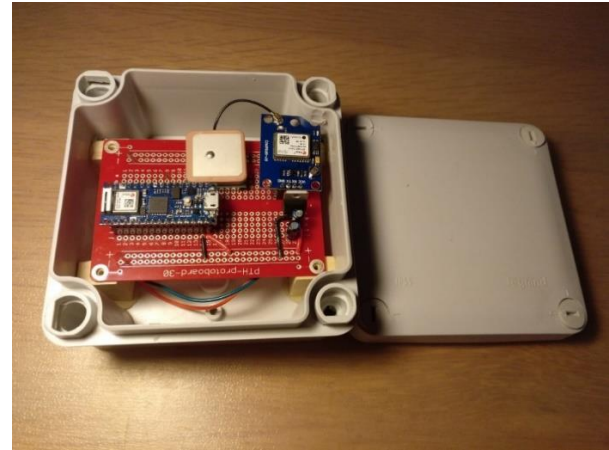


Figure 5. Device assembled

Finally, a market study was carried out and business plan was designed. This study is composed of:

- Sales forecast.
- Cost analysis.
- Income analysis.
- Profit forecast.

### 3. Results

The algorithm designed to determine the state of the generator has been proved to work successfully. It was first tested to detect the movement and vibrations of a domestic fan heater, and finally it was tested in a real generator. In each case, the threshold values used in the classification algorithm were adapted to the magnitude of the vibrations.

The results of testing the device in a diesel generator are shown in Figure 6. These graphs show the maximum values (between the three axes) of  $\Delta v$  and  $a_{rms}$  obtained during three starts and stops of the generator. From these graphs, the threshold values for  $\Delta v$  and  $a_{rms}$  in this generator were calibrated to be around 1.5 and 0.05, respectively.

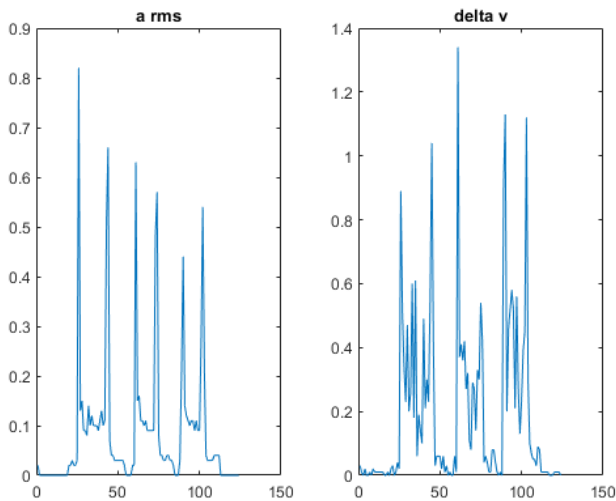


Figure 6. Results of the test on the ground

The GPS sensor also worked successfully, even with the antenna placed inside the plastic case. The precision observed was around 2 meters.

Based on the prototype previously built, a new one was designed, which includes an internal battery and GSM/GPRS communications. To avoid damaging the internal battery or losing charge capacity, a battery management system has also been designed using an LM317 chip. Since the charging time is not relevant in this project, the battery is charged using a small constant current (around 0.1C). Some transistors are used to control the charging of the battery and open the circuit when it is full. Since the device cannot have an on/off switch, a circuit to auto-shut off the device has been engineered. This action is activated wirelessly, and it only works when the device is not connected to the external battery. It prevents the battery from deep discharging when the device is not in use. The device will turn itself on again when the external battery is connected.

The connection to the Internet in the second prototype was designed to be done using GPRS. The GSM/GPRS module used is based on the SIMCom SIM800L chip and it is handled sending AT commands through the UART port.

The results of the market study show that the optimum price to sell the device is around 180€. From the sales forecasted and the costs estimated, the estimated net profit has been calculated yearly. The results obtained are shown in Table 1.

Table 1. Net profit forecasted (in €).

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Net profit	-5034	7859	19988	64275	128948	335738

Also, the IRR and NPV indicators have been calculated, obtaining the following results:

$$IRR = 301 \%$$

$$NPV = 330.417,18 \text{ € (interest rate of 0,1)}$$

#### 4. Conclusions

In this project, a solution to thefts in portable generators has been proposed. This solution is based on a device that detects when the generator is working and when it is being moved. This information is sent to an IoT platform, from where it is possible to communicate with the user. The prototype built has been proven to work correctly and all the objectives of the project has been fulfilled. Finally, the results of the market study that has been carried out suggest that the product represents a profitable investment in the current market. These promising results are a consequence of the low initial investment that is required to start this business, and the low risk that it implies.

#### 5. References

- [1] Traxco, "Sistema Antirrobo," [Online]. Available: <https://www.traxco.es/tienda/sistema-antirrobo>
- [2] Metos, "iMetos Trackers," [Online]. Available: <http://metos.at/es/imetos-trackers/>

[3] Wikipedia, "LPWAN" [Online]. Available: <https://en.wikipedia.org/wiki/LPWAN>

[4] Madrid Business, "Redexia Nace En España La Primera Red Nacional LoRaWAN Dedicada Al IoT". *madridbusiness*.

[5] K. Mekki, E. Bajic, F. Chaxel and F. Meyer, "A comparative study of LPWAN technologies for large-scale IoT deployment," *ICT Express*, vol. 5, no. 1, pp. 1-7, 2019.

[6] L. LLamas, "Protocolos de comunicación para IoT," [Online]. Available: <https://www.luisllamas.es/protocolos-de-comunicacion-para-iot/>

[7] Sigfox, "Geolocation technologies," [Online]. Available: <https://build.sigfox.com/geolocation-technologies>

[8] LoRa Alliance™ Strategy Committee, "Geolocation whitepaper," 01 2018. [Online]. Available: [https://lora-alliance.org/sites/default/files/2018-04/geolocation\\_whitepaper.pdf](https://lora-alliance.org/sites/default/files/2018-04/geolocation_whitepaper.pdf)

[9] World Wide Web Consortium, "Web of Things at W3C," [Online]. Available: <https://www.w3.org/WoT/>

## Table of Contents

<b>1. Introduction</b>	<b>5</b>
<b>2. State of the art</b>	<b>7</b>
2.1. Solutions to thefts in the agricultural sector	7
2.2. Solutions to thefts of portable generators	8
2.3. IoT Communications	9
2.3.1. Communication Networks	9
2.3.2. IoT Communication Protocols	12
2.4. The cloud	12
2.5. Positioning systems	13
<b>3. Objectives of the project</b>	<b>17</b>
<b>4. Project planning</b>	<b>19</b>
<b>5. Design overview</b>	<b>21</b>
5.1. General design of the device	21
5.2. Power supply	22
5.3. Communications overview	25
5.4. The platform	25
<b>6. Design of the prototype</b>	<b>27</b>
6.1. Hardware	27
6.2. Software	29
6.2.1. Reading accelerometer data. State of the generator	30
6.2.2. Reading GPS data	37
6.2.3. Managing embedded WiFi module	37
6.3. Testing the prototype	38
<b>7. Design of the platform algorithms</b>	<b>41</b>
<b>8. Market study and business model</b>	<b>45</b>
8.1. Design of the business model	45

8.2.	Sales forecast.....	46
8.3.	Profit model.....	48
8.3.1.	Cost analysis.....	49
8.3.2.	Price analysis.....	53
8.3.3.	Profit forecast.....	56
<b>9.</b>	<b><i>Optimizations and indications for the final product .....</i></b>	<b>57</b>
9.1.	Second prototype.....	57
9.1.1.	Electronic circuit. Power supply and backup battery. ....	57
9.1.2.	GSM/GPRS module.....	61
9.1.3.	PCB design.....	63
9.1.4.	Case design.....	63
9.2.	Battery.....	65
9.3.	Autoconfiguration.....	66
9.4.	Classification algorithm.....	67
<b>10.</b>	<b><i>References .....</i></b>	<b>69</b>
	<b><i>Annex A: Circuit diagram of prototype 1 .....</i></b>	<b>75</b>
	<b><i>Annex B: PCB plans of prototype 1.....</i></b>	<b>77</b>
	<b><i>Annex C: Plans of the case for prototype 1 .....</i></b>	<b>79</b>
	<b><i>Annex D: Arduino code prototype 1 .....</i></b>	<b>81</b>
	prototype.ino.....	81
	accelerometer.cpp.....	83
	gps.cpp.....	87
	wifi.cpp.....	88
	accelerometer.h.....	90
	gps.h.....	90
	wifi.h.....	90
	credentials.h.....	90
	<b><i>Annex E : Specs of the Arduino NANO 33 IoT .....</i></b>	<b>91</b>

***Annex F: MATLAB code for algorithm testing ..... 93***

***Annex G: Circuit diagram prototype 2 ..... 99***

***Annex H: PCB plans of prototype 2 ..... 101***

***Annex I: Plans of the case for prototype 2 ..... 103***

***Annex J: List of electronic components used in prototype 2 ..... 105***

***Annex K: JSON ‘thing’ structure ..... 107***

***Annex L: Alignment of the project with the Sustainable Development Goals..... 111***





## 1. Introduction

Robbery in the agricultural sector has recently become a big problem in Spain. This fact has been caused by different factors. Firstly, the small population density in the agricultural areas entail an opportunity for the thieves to stay unnoticed. Secondly, the development of the technologies applied to this sector has made possible a big improvement in the productivity, but it has been necessary to invest in equipment that needs to stay in the countryside permanently and is susceptible to robbery. This risk of losing their investments is one of the biggest obstacles that prevent farmers from bringing newer and more expensive technologies to the sector, and it is the problem that is going to be addressed in this project.

Some examples of equipment that is susceptible to theft are solar panels, different parts of irrigation systems, copper from transformers or cables, water pumps, diesel generators, tools, etc.

In this project, an anti-theft device that could be placed in the countryside is going to be designed. This device will be equipped with different sensors. Also, it will be connected to an IoT platform, where the data is going to be analyzed to detect a theft and warn the farmer. Since there exist a lot of different equipment that may require different anti-theft devices, this project is going to be centered in designing one device to protect a diesel generator. However, one of the objectives of the project will be to make it adaptable to protect other types of equipment. Finally, a market study is going to be conducted to study if it is profitable to launch the product, and what is the best strategy to do so.

In this paper, the first part will go over a research of existing solutions and technologies that can be useful to use in the project. Then, the objectives of the project are going to be stated and the schedule and work breakdown used to fulfill the objectives is going to be explained. The next step is to design the device. For this, a general vision of the design is explained first, followed by a design of one prototype and a design of the algorithms that are going to be executed in the cloud. This prototype is going to be designed, built and tested in a real generator in the countryside. Then, a market study is going to be conducted to analyze the viability of launching the designed product. Based on the experience obtained

from the prototypes and the results obtained in the market study, some recommendations and optimizations are going to be carried out to obtain the optimal commercial product.

## 2. State of the art

### 2.1. Solutions to thefts in the agricultural sector

Currently, there are different solutions to the problem of thefts in the agricultural sector. However, none of them solves it completely.

Most of the solutions that exist now are mechanical systems that try to hamper the theft. For example, most farmers place the equipment that is susceptible to robbery locked in small huts. There are also more ingenious solutions like fuel filler caps that prevent the thieves from stealing fuel [1], or galvanized steel profiles that protect the electric cables of the center-pivot irrigation systems [2].

Other solutions are connected to the Internet or the telephone network and can notify the farmer in real time in case of robbery. However, they are not widely used due to its high price compared to the price of the equipment that they protect.

The company Traxco® sells an anti-theft system that consists of some sensors (accelerometers) that are connected to a central transmitter which sends an SMS message in case a theft is detected. It also uses a 120dB alarm to dissuade the thief. This system with just one sensor costs 252€, and each additional sensor costs 24€ [3]. The same company offers as well some more complex sensors to detect shots (to place in hunting reserves for example), copper robbery, vehicle trespass, etc. equipped with a GSM transmitter for 360€ to 546€ [4].

The Italian company Naria Security [5] sells a system that consists of an optic fiber cable which can be tied around all the equipment and machinery that need to be protected. The system can detect when the cable is cut or is heavily bended and can be connected to an external alarm transmitter to warn the owner.

Other solutions are the installation of security cameras, or the placing of GPS sensors. However, the cameras are not effective most of the times since they can be easily damaged by the thieves and are useless if they go with their face covered. As for the GPS sensors, they have a limited battery duration, they can be detected by the thieves and they are useless to prevent robberies of copper or small batteries.

Also, there are technologies that are being used with other purposes and could be employed to solve the problem of the robberies. For example, some state-of-the-art irrigation systems are equipped with digital irrigation timers that are connected to the Internet or the telephonic network. These timers can be controlled remotely, and some sensors can be added to warn the farmer in case of failure (for instance, if the pressure measured in a pipe is smaller than its expected value). Furthermore, sensors that detect trespass can be installed in the system. One of the leader companies in Spain in this sector is Sistemas Electrónicos Progrès [6]. Its irrigation timer Agrónic 4000 has three different alarm outputs that can be programmed to activate when the signals coming from the sensors take some particular values [7]. These timers could be effective in the prevention of thefts. Nevertheless, its high price makes them worthwhile only when their primary purpose is to control the irrigation. The company METOS® [8] also employs similar technologies to send data from meteorological and biological sensors to the cloud. From the analysis of these data, it is possible to predict the appearance of diseases or to minimize the use of water in irrigation. They use LoRa, NB-IoT and GSM communication technologies in their products. They also sell two types of tracker devices [9]. The first one is designed to be mounted in a tractor and needs to be connected to its battery. It is especially useful for farmers that have several tractors, to have a control on where and where they have been working. The second one is designed to be placed in static equipment and it has an internal battery with capacity for more than 2000 position transmissions. Both allow the farmer to detect a robbery using the GPS position. They are sold in the market for 350€.

## 2.2. Solutions to thefts of portable generators

Currently, there exist solutions specifically designed to protect portable generators. The company 'Swag Off Road' sells a security enclosure that prevents the thieves from stealing the generator or the gasoline in the fuel tank [10]. However, a new design is needed for every different generator, so this product is barely used.

Other solutions that can be used in generators that were discussed before are chains and lockers or GPS trackers. The tracker device sold by METOS is the most similar to the one that is going to be designed in this project. Although in

their webpage there is no mention to their application in portable generators, it seems that it could be used for this purpose. These devices detect a possible theft from the position data of GPS, by establishing an invisible fence. If the device trespasses that fence and leaves the area where it is expected to be, a warning is sent to the user.

Another product that exist in the market are the monitoring systems for diesel generators. They can detect when the generators are working, how much power they are generating or what is the fuel level in the diesel tank. They also have sensors that generate data from which mechanical problems or high temperatures in the generator can be detected. Some of these products are also equipped with a GPS sensor to detect the position of the generator. These products usually come already built in the generator when it is acquired. Most of the generators that use this solution are big generators used in applications that require high power. Although a robbery can be detected with these products, their main objective is to analyze the operation of the generator for predictive maintenance, fuel monitoring (including fuel theft detection) or efficiency increase [11].

### 2.3. IoT Communications

The Internet of Things (IoT) is a concept that refers to the interconnection of quotidian objects to the Internet. Given the special characteristics of the IoT networks, some technologies are more suitable for this application than others. This project needs of these technologies to send the data gathered by the device to the platform. In this section, some of the existing technologies are going to be discussed and compared, and their advantages and disadvantages are going to be studied.

#### 2.3.1. Communication Networks

The lack of Wi-Fi in the countryside areas makes it necessary to use other technologies to send the data to the cloud. Some solutions that are employed nowadays in IoT designs are:

- GPRS/GSM networks: GSM stands for Global System for Mobile communications and it is the most widespread communication technology in the world. GSM operates on two frequency bands: 900 MHz and 1800

MHz. GPRS stands for General Packet Radio Service and it is an upgrade of GSM that allows faster communications (56 to 114 kbps) [12].

- 3G/4G/5G networks: these technologies allow the transmission of bigger amounts of data, but their price is higher compared to the GPRS /GSM technologies. Since this project does not require a lot of data to be transmitted, these technologies will not be further considered.
- LPWAN (low power wide-area networks): these technologies provide low power consumption and a long range in the communications. They are especially suitable for IoT projects. The most used LPWAN technologies are:
  - o Sigfox: Sigfox is a LPWAN network operator that offers end-to-end IoT connectivity solution based on its patented technologies. The end devices use binary phase-shift keying (BPSK) modulation to transmit the information in an ultra-narrow band (100 Hz) using some of the unlicensed ISM bands below 1 GHz. For example, in Europe, the information is transmitted in the 868 MHz band. The main advantages of Sigfox are its low cost, low energy consumption, low interferences, and high coverage. Its main drawback is the limited number of messages that can be transmitted using this technology. Sigfox supports bidirectional communications, but with some restrictions. The uplink (from the end device to the data station) is limited to 140 messages per day, being each message maximum length of 12 bytes. The downlink communication supports 4 messages of 8 bytes per day at most, and they must be always preceded by an uplink message. Each uplink message is transmitted multiple times over different frequency channels. The base station can receive messages at the same time in multiple channels, so the device can choose randomly the channels to transmit the messages. This makes the communication really robust and simplifies the design of the end device [13].
  - o LoRa: LoRa is a wireless data communication technology that uses a chirp spread spectrum (CSS) modulation technique, also in the sub-GHz ISM bands [13]. This modulation technique allows long

range communication of small amounts of data and high immunity to interference, while minimizing power consumption [14]. The maximum payload length of each message is 243 bytes. LoRa defines the lower physical layer of the network, while LoRaWAN is the standard that defines the upper layers [15]. LoRaWAN supports various classes of end devices to address the different requirements of a wide range of IoT applications: bidirectional end devices (class A), bidirectional end devices with scheduled receive slots (class B) or bidirectional end devices with maximal receive slots (class C). Class A devices are the most power-efficient and can only receive a downlink message after an uplink transmission [13].

- **NB-IoT**: NB-IoT is a technology that uses licensed frequency bands and it can coexist with GSM and LTE at the same bands. The data rate is limited to 200 kbps for the downlink and to 20 kbps for the uplink. The maximum payload size for each message is 1600 bytes [13].

All these technical characteristics result in different performances of the technologies. Figure 1. Comparison among LPWAN technologies. shows a summary of different factors of the technologies, that is helpful to compare them and choose the optimal one depending on the application.

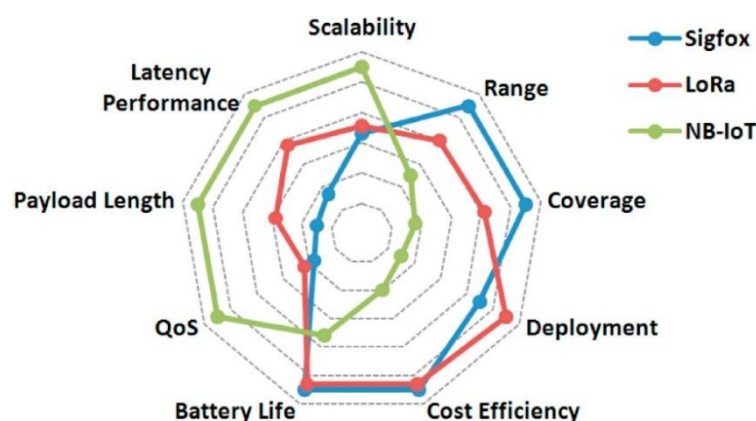


Figure 1. Comparison among LPWAN technologies [13].

Given that our device is going to be in the countryside, a wide coverage is the most important factor that our technology needs. Also, the cost efficiency is vital to launch a product that is profitable for the user. Therefore, Sigfox and LoRa are

the LPWAN technology that fit best in this project. However, the LoRaWAN® infrastructure has not been fully deployed in Spain at the time this paper was written and most of the rural areas do not have coverage yet [16]. Therefore, this technology is not going to be considered in this project.

### 2.3.2. IoT Communication Protocols

A communication protocol is a standard that is defined to allow two or more devices to communicate and understand each other. The machine-to-machine (M2M) communications in the Internet of Things must keep some requirements, which makes the regular communication protocols not optimum for this application. Some of these requirements are the need to connect a huge number of devices, the need for scalability, low processing requirements, security requirements, etc. [17].

Given these requirements, some protocols have been developed to cope with IoT communications. Some of them are MQTT (Message Queue Telemetry Transport), AMQP (Advanced Message Queuing Protocol), WAMP (Web Application Messaging Protocol), CoAP (Constrained Application Protocol), STOMP (Streaming Text Oriented Messaging Protocol), XMPP (Extensible Message and Presence Protocol), WMQ (WebSphere MQ). In this project, MQTT is going to be used, since it is light and easy to implement, and it is appropriate for devices with low power requirements.

MQTT is a Message Service Pub/Sub protocol. The Pub/Sub methodology allows the sender devices to assign a topic to each message that they send. The devices that are interested in receiving the messages of a certain topic can subscribe to that topic and they will receive them. The Broker handles the distribution of the messages from the senders to the receivers. Since it is a Message Service, it distributes immediately the messages to the subscribers. If they are not connected at that moment, the messages get lost, since the Broker is not designed to store big amounts of data in a queue.

### 2.4. The cloud

The cloud allows for providing better services to the user without increasing too much the cost of the device. For example, the cloud allows for data storage and statistics generation, without the need of using a ROM memory in every IoT



device. It also reduces the data processed in the device, resulting in lower power consumption and cheaper processors. However, there is a tradeoff here, since the some LPWAN technologies like Sigfox or LoRa have very limited payload lengths and few messages are allowed per day. Therefore, in some cases, some degree of data preprocessing is going to be needed in the device to reduce the amount of data sent. Also, the power needed to send the messages may be bigger than the power saved in data processing.

Nowadays, there are many companies that offer cloud computing services, some of them specifically for IoT applications. One of them is Altair®, whose cloud platform is going to be used in this project. This platform has two access gates: by HTTP REST requests and MQTT. In this platform, the different devices are called “things”. According to the World Wide Web Consortium (W3C) and its work on the Web of Things (WoT) [18], each thing may have some “properties”, some “actions” and some “events” defined. The physical device, by sending information to the cloud, can update the “properties” of the thing and can activate the “events”. Also, by using the “actions” defined in the platform, the user can send messages to the physical devices, for example, to change the value of a variable or to set the device in stand-by. All of them (“properties”, “actions” and “events”) are defined using a JSON structure. The Web of Things provides an Application Layer to the Internet of Things by providing architectural styles and programming patterns to allow real-world objects to be part of the World Wide Web [19].

### 2.5. Positioning systems

It is important to know where the device is located when a theft is detected. To do so, a sensor that retrieves the position of the device is needed. Two technologies can be used to know the position of a device outdoors: those that use signals from satellites (Global Navigation Satellites Systems, GNSS) or those that use signals from communication antennas.

In the first category, the most common system is the GPS, which uses US satellites, but other systems exist, like GLONASS or Galileo, which are developed by Russia and the European Union respectively. The first system to be deployed was the GPS, which currently uses 24 satellites and is the most used GNSS. The satellites send signals with information about the exact time at which they were

sent, that is obtained from the atomic clock that is inside each of the satellites. The receiver can triangulate its position when it receives signals of at least three satellites. The position is calculated from the Time Difference of Arrival (TDOA). The biggest number of satellites that the receiver is listening to, the more precise the measure will be. A parameter that is commonly used to show the inaccuracy of a measurement is called DOP (Dilution of Precision). This value is always higher than one (ideally it is equal to one) and, when it is multiplied by the accuracy of the device, it results in the inaccuracy of a particular measurement [20].

In the second category, Sigfox offers a location service that does not need extra hardware. It uses the Received Signal Strength Indicator (RSSI) instead of the TDOA technology and it computes the most likely location of the device from the signals received by different stations, based on their strength. This technology provides an accuracy of 1 to 10 km [21]. The LoRa alliance also offers a geolocation technology based on the LoRaWAN® infrastructure. It provides two methods for geolocation determination: one based on RSSI and the other one based on TDOA, which is more accurate. The first one determines the position with an accuracy of 1000-2000 m, while the second one has an accuracy of 20-200 m [22].

Compared to GPS, the Sigfox and LoRaWAN® solutions offer the advantage of working both in indoor and outdoor environments, while the GPS technology is very limited indoors. They also offer lower cost (no extra hardware required) and lower battery consumption. However, these technologies have a worse precision than GPS technology. For the current project, the precision of LoRa and Sigfox geolocation technologies may not be enough to find a generator that has been stolen. However, these technologies can be used as a back-up in case the generator is stored in an indoor location and the GPS sensor does not receive any signal, especially if Sigfox or LoRaWAN® are used to transmit the data, since no extra hardware is required. A comparison of some aspects of these geolocation technologies is shown in Table 1.

.

Table 1. Geolocation technologies comparison

	<b>Coverage</b>	<b>Cost</b>	<b>Precision</b>	<b>Power consumption</b>
<b>GNSS</b>	Outdoors	Module (5 - 40€)	<3 m	High
<b>Sigfox</b>	Indoors & Outdoors	2.42 €/device/year	1-10 km	Low
<b>LoRaWAN® TDOA</b>	Indoors & Outdoors	No extra cost	20-200 m	Low
<b>LoRaWAN® RSSI</b>	Indoors & Outdoors	No extra cost	1-2 km	Low



### 3. Objectives of the project

The main objectives of the project are the following:

- Design of a device that is accurate and precise to detect the theft of a portable generator located in the country.
- Optimization of the cost of this device so that it can be sold for less than 200 € to be competitive in the current market.
- Design of a device that is flexible and could be utilized to prevent thefts from other agricultural equipment with small or no modifications.
- Study of the actual market to launch the designed product in it.



*Figure 2. Diesel generator*



## 4. Project planning

To achieve the objectives stated above, the project is going to be divided in different tasks. These tasks are going to be distributed over the time that is available, leaving some time free in case unforeseen circumstances occur. This way, the project is ensured to be completed on time. Table 2 and Table 3 summarize the division of tasks and the schedule that is going to be followed.

Table 2. Division of tasks.

	Tasks
DESIGN	1.a - Research of existing technologies and solutions.
	1.b - Design of the device (sensors, algorithms, communication protocols...).
	1.c - Design of the algorithms executed in the IoT platform.
CODING & ASSEMBLY	2.a - Collection of hardware material.
	2.b.i - Assembly and coding. Design and 3D printing of the enclosing case.
	2.b.ii - Assembly and coding. Connections and assembly of the hardware.
	2.b.iii - Assembly and coding. Coding of the device (sensors an communications).
	2.b.iv - Assembly and coding. Coding of the IoT platform.
	2.c.i - Validation. Validation of the device.
	2.c.ii - Validation. Validation of the platform.
BUSINESS PLAN	3.a - Cost model.
	3.b - Analysis of the competition.
	3.c - Revenue model.
	3.d - Product sales forecast.

Table 3. Task planning

Month	February				March					April				May				June				July	
Week	W1	W2	W3	W4	W1	W2	W3	W4	W5	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2
1.a	█																						
1.b	█	█	█																				
1.c				█																			
2.a				█	█	█																	
2.b.i				█	█	█																	
2.b.ii					█	█	█																
2.b.iii							█	█	█														
2.b.iv												█	█										
2.c.i												█	█										
2.c.ii																	█						
3.a																							
3.b																							
3.c																							
3.d																							





## 5. Design overview

### 5.1. General design of the device

The actions that the device located in the countryside will complete are:

- Detection of a possible theft of the generator and detection of whether the generator is working or not. This task is divided into two different subtasks:
  - o Data acquisition: measurement of the acceleration of the generator and its GPS position.
  - o Data treatment: these measurements will pass through different algorithms that will determine whether the generator is working, it is being moved or it is off and motionless.
- Communication with the platform. The module will send information regularly about the current state of the generator (working, idle or moving) and its GPS coordinates in case the generator is moving.

To perform these tasks, the following components are going to be needed:

- A microcontroller will store the code with the algorithms, and it will receive, treat, and send information. It will be the component that connects to all the other components and will give intelligence to the device. Also, by treating the data from the sensors, it will reduce the amount of data that needs to be sent to the cloud.
- The acceleration of the generator will be measured with an accelerometer that will output the acceleration in the three axes. These measurements will be sent to the microcontroller via SPI or I2C.
- The GPS position of the generator will be measured using a GPS module. The information retrieved by this module will be sent to the microcontroller using asynchronous communication through a UART port.
- The communication with the cloud will be conducted by a GPRS/GSM module. The microcontroller will communicate with this module via UART. The GPRS/GSM module will send the information (state of the generator and GPS coordinates) to the server using the MQTT protocol. The election of the GPRS/GSM technology was mainly because it is a fully developed technology that offers a wide coverage in the countryside. This also allows a faster prototyping process. However, as it was described in *Section*

2.3.1, the Sigfox technology would be the most suitable technology for these devices. This project does not need a great amount of data to be sent, while it can benefit from the lower cost of Sigfox with respect to 2G technology. In the future, the design may be adapted to use Sigfox, but this is out of the scope of this project.

Figure 3 shows a diagram with the main blocks of the device, as well as the communications that take place amongst them:

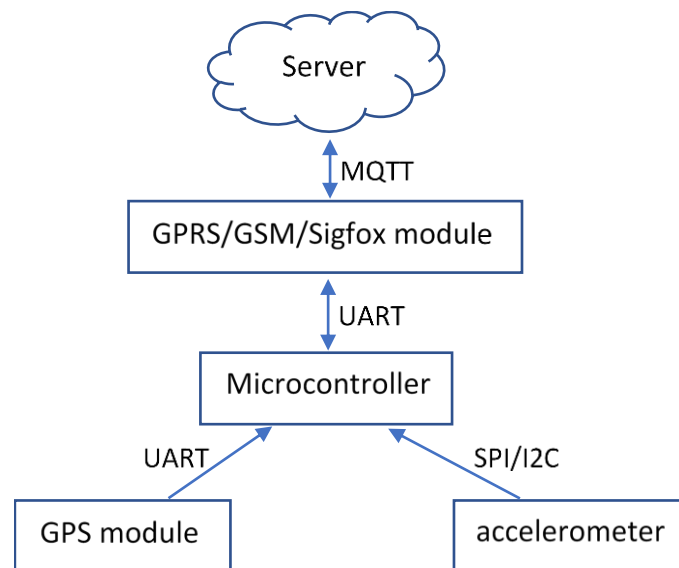


Figure 3. Diagram of the main blocks of the device.

## 5.2. Power supply

The device will be connected to the 12 V battery that the generator uses to start up. However, it will also need a backup battery to provide energy to the device in case the connection to the main battery is lost or the main battery is stolen. This second battery needs to be rechargeable and have a good energy density to reduce its size. These conditions are best fulfilled by lithium batteries [23]. However, these batteries have some problems that must be considered in the design of the device. If they get completely discharged or they stay fully charged for a long period of time, they will get damaged and will lose capacity fast. Also, high temperatures affect them. As a result, there must be some intelligence embedded in the device that controls the charging of the battery, also known as a Battery Management System (BMS). This is especially necessary to maintain

the battery at a highly enough SoC to be prepared to supply power to the device at any moment and for the maximum amount of time possible, but without keeping it at a level that may damage its capacity. To do so, it will be necessary to measure the State of Charge of the battery. Measuring the voltage at the terminals of the battery will allow to make an estimation of its State of Charge (SoC) from the discharge profile of the battery, as it is observed in Figure 4, which shows the discharge curve of a lithium-ion battery, the Panasonic NCA593446 [24]. However, the profile shown in this graph depends strongly on the discharge rate (Figure 4) and on temperature (Figure 5). The discharge rate can be predicted upfront if the energy consumption of the device is known, but the dependence on temperature makes it necessary to measure this variable to better estimate the SoC of the battery. This is especially necessary in this particular project, since the battery is going to be placed in the countryside where temperature changes are frequent.

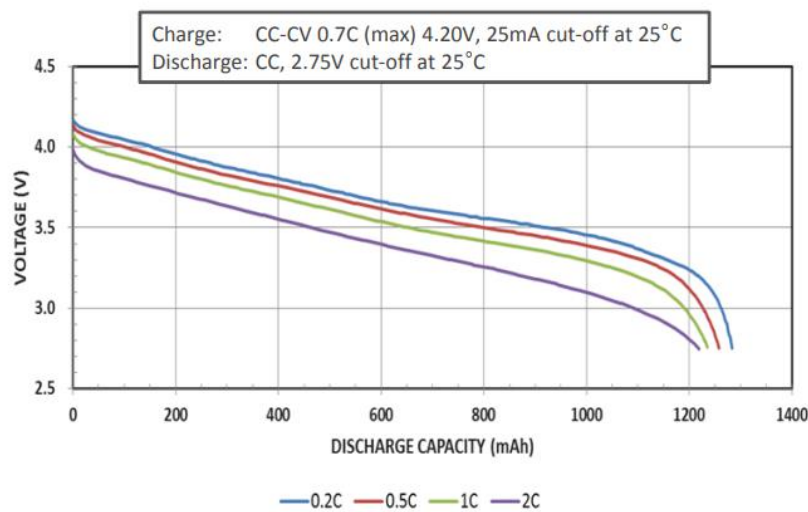


Figure 4. NCA593446 discharge characteristics by discharge rate [25].

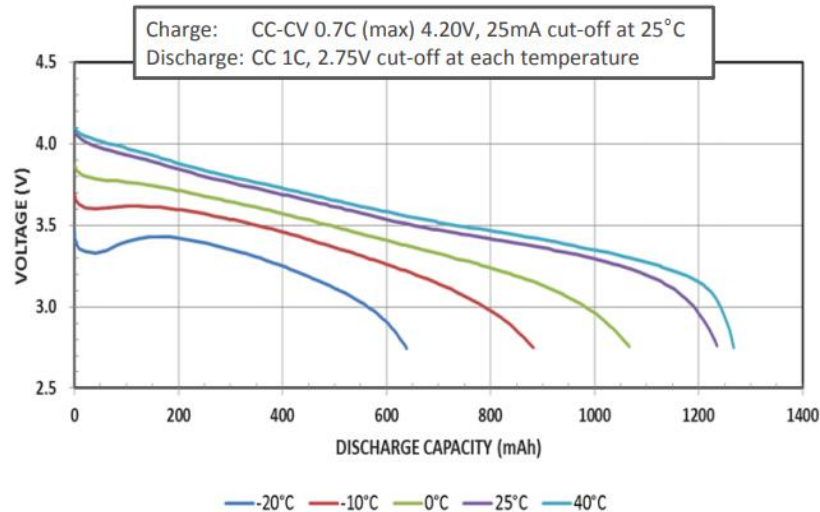


Figure 5. NCA593446 discharge characteristics by temperature [25].

Also, batteries must not be charged at extreme temperatures. It is not recommended to charge a lithium battery below 0°C or above 45°C [26]. Finally, the BMS must include some overvoltage and overcurrent protection. All this is extremely important because lithium batteries may explode and inflame if they are not managed correctly. This is a risk for the user and for the generator, but in this project in particular, it also poses a risk for the environment because a burning battery in the countryside may provoke a wildfire.

For a better performance in an outside environment, the device will need to be as hermetic as possible. The only connector that will be accessible from the outside will be the DC jack that will be connected to the generator battery. Also, it cannot have an ON/OFF switch since that would allow the thieves to turn it off and the device would be useless. Therefore, the battery will be mounted inside the case during the fabrication and it should not be accessible anymore. To avoid the discharge of the battery during periods when the device remains unused, it is necessary to include a method to turn the device on and off remotely. However, if it needs to be waiting for a message to turn itself on, at least the GSM module must stay always on, still consuming power. The solution proposed in this project is to start with the device completely off, including the GSM module. It will turn on automatically when the external power supply is connected, and it will remain on in case it is disconnected (the internal backup battery would supply the power in this case). To turn it off again, a message will need to be sent via GSM/GPRS.

### 5.3. Communications overview

In terms of communications, there will be three entities that will send and receive messages: the user (the farmer), the platform, and the device located on the generator. A diagram of the communication flux is shown in Figure 6.

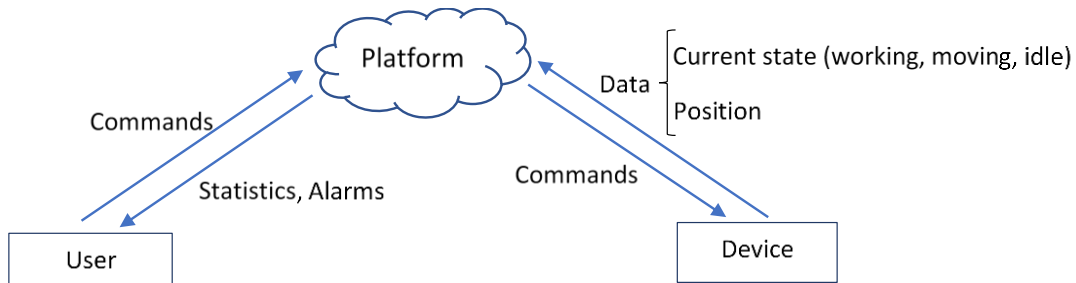


Figure 6. Communications flow.

The communications between the module and the platform will go in both directions. The module will send information about the current state of the generator ('working', 'moving' or 'idle'), and its GPS coordinates in case the state is 'moving'. The module will receive commands to change its settings or to turn itself off.

The communications between the user and the platform will also go in both directions. The user can request statistics about the usage of the generator or about its position. Also, the platform will alert the user in case the generator is being moved, in case the connection between the device and the generator is lost, or in case any other problem happens. The user will also receive statistics about the usage of the generator once a week, once a month, or when requested.

### 5.4. The platform

The platform will perform three tasks:

- Storage of data.
- Data processing. The module will generate statistics about the utilization of the generator, and it will track it in case of robbery.
- Communication center. The platform will receive data from the module, it will receive requests from the user, and it will send alarms and statistics to the user.



## 6. Design of the prototype

To test the design and optimize it before launching a commercial product, a prototype is going to be built. In this prototype, Wi-Fi is going to be used to communicate between the platform and the device. Since this technology will not be available in the countryside, where the final design is going to be located, the final product should be equipped with a different wireless data communication technology, as discussed in *Section 2.3.1* and *Section 5.1*. However, the testing of the communication technology is not the priority of this prototype. The design of the algorithms of the prototype will take the limitations of these networks into account, such as their limited bandwidth. The objectives of this prototype are:

- Send data from an accelerometer to the microcontroller.
- Design and test an algorithm to detect movement and vibrations in a diesel generator, and to differentiate these two situations. The input to this algorithm will be the data of the accelerometer.
- Receive data in the GPS sensor, understand the messages the GPS sends using UART and test the GPS sensor in the environment where the commercial device is going to be used.
- Connect to the cloud and receive data from the device.

### 6.1. Hardware

To fulfill the objectives stated above, this prototype will need a microcontroller, an accelerometer, a GPS sensor and a WiFi module. Given these requisites, an optimal board for this prototype is the 'Arduino NANO 33 IoT'. Arduino is an open-source hardware and software company that designs and manufactures single-board microcontrollers and microcontroller kits for fast prototyping [27]. One of the boards that they sell is the 'Arduino Nano 33 IoT'. It is a small board with built-in Wi-Fi, Bluetooth and a 6-axis IMU (a 3-axis accelerometer plus a 3-axis gyroscope). All this makes this board very appropriate for this prototype, since it concentrates the accelerometer, the microcontroller and the communications in a 45x18 mm board. The price of this board with headers is \$20 and all its technical specs are summarized in Annex E [28].

With this Arduino, the only extra feature needed to be included in the prototype is the GPS. There exists a wide supply of GPS modules in the market, with all

kind of features and prices. However, the two following models are some of the most popular and the ones that fit the best in the actual project:

- The 'Ublox NEO-6M' is a GPS module with up to 5 Hz update rate, 50 channels (22 tracking), -161 dBm navigation sensitivity and up to 2.5 meters accuracy. It needs a voltage from 3V to 5V and consumes 50 mA on average. However, the chip allows a reduction in power consumption to 11mA by activating a Power Save Mode (PSM) (not available with NEO-6P, NEO-6T and NEO-6V) [29]. Its price is one of the lowest in the market and they can be found for less than \$5.
- The 'Adafruit Ultimate GPS Breakout V3' is a GPS module with up to 10 Hz update rate, 66 channels, -165dBm sensitivity and around 3 meters accuracy. It consumes 20 mA during navigation and an ENABLE pin is available to turn it off using any microcontroller and save power. The input supply voltage can be from 3 to 5 V, but it needs to be stable. Although this module has better features than 'Ublox NEO-6M', its price is also bigger. It is sold by the manufacturer for \$39.95 [30].

Finally, the module chosen for this prototype was the Ublox NEO-6M, mostly due to its lower price.

When it is tested in the real diesel generator, the power for the prototype will come from the battery that it uses to start up. The standard in the industry is to use 12 V lead-acid batteries for this purpose. Therefore, a voltage regulator will be needed to convert from the 12 V of the generator battery to a voltage between 3.3V and 5V to run the GPS module and the Arduino. Both the GPS and the Arduino boards have their own voltage regulators and they accept a supply voltage in that range, although the electronics inside the modules work at 3.3 V. The voltage regulator used was the L7805CV, that converts an input voltage from 10 to 35 V to 5 V at the output. It allows an output current of 1.5 A, much bigger than the current needed in this project. As it is recommended in the datasheet, the converter was connected with two capacitors to ground, one at the input and another one at the output (Figure 7), to attenuate noise and sharp changes in voltage [31]. The connection from the battery to the prototype happens through a DC jack with positive polarity on the inside and grounded on the outside.



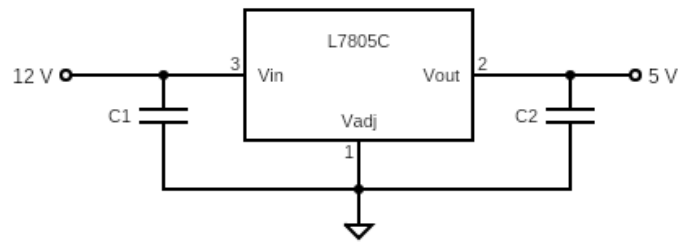


Figure 7. Connection of the voltage regulator

The circuit diagrams, with the connections between all the modules and with the voltage regulator, can be consulted in Annex A. The prototype was soldered on a standard solder-able breadboard. The case employed was a standard IP55 case used for electric connections. The prototype soldered and built in this case is shown in Figure 8.

Furthermore, a PCB and a custom-made case have been designed. The plans of the PCB are shown in Annex B. The plans of the case that will contain the PCB and all the electronics can be found in Annex C.



Figure 8. Picture of the first prototype built.

## 6.2. Software

The code was written in Arduino language, which is based in C++, and it can be found in Annex D. The main task of the software is to estimate the state of the generator from the data measured by the accelerometer. It also reads the data sent from the GPS module and manages the Wi-Fi connectivity to send the data

periodically to a server using MQTT. To write more legible code, the project was divided in four code files: the main file and three function files, with their corresponding header files.

- The file “accelerometer.cpp” manages the accelerometer and performs the estimation of the estate of the generator.
- The file “gps.cpp” contains all the code related to the GPS sensor.
- The file “wifi.cpp” and the final one manages the WiFi module and the MQTT protocol.
- A file called “credentials.h” keeps sensible passwords all together in a different file and avoid sharing them accidentally.
- The main file (“Prototype.ino”) uses high level functions defined in the other files to perform the different actions. This way, it is easier to understand and debug the code.

In the following sections, the working principles of each of these three function files (“acceleromer.cpp”, “gps.cpp” and “wifi.cpp”) are going to be explained.

#### 6.2.1. Reading accelerometer data. State of the generator

The file ‘accelerometer.cpp’ contains all the functions to control the accelerometer and to perform the estimations of the state of the generator from the acceleration measured.

The IMU is controlled using a built-in Arduino library named ‘`Arduino_LSM6DS3.h`’. To measure the acceleration in the three axis the function ‘`IMU.readAcceleration(x, y, z);`’, which is available in that library, is used.

The estimation of the state of the generator (‘idle’, ‘working’ or ‘moving’) is done in the device and not in the cloud to reduce the amount of data sent, since the bandwidth of the LPWAN technologies is limited. The algorithm is not continuous, but it is applied discretely at a frequency that in this paper is called “frequency of estimations”. The process to estimate the state of the generator is the following:

- 1- **Measure the acceleration** in the three axes.
- 2- **Store the measurements** in the next position of three different arrays. Repeat these two steps until the arrays are full. At the end of this step  $N_{data}$  values will have been recorded for each of the three axes.  $N_{data}$

must be high enough to detect a good number of oscillations when the generator is working. However, if it is too high, the battery consumption and time spent may increase. A value for  $N_{data}$  to detect from 50 to 100 oscillations would be appropriate, so it will depend on the sampling frequency and the generator frequency.

- 3- **Modify the arrays** by subtracting to each element the average of the  $N_{ave}$  previous elements, as shown in (1). This algorithm cannot be applied to the  $N_{ave}$  first elements of the arrays, which will be only used to calculate the average that is subtracted to the following ones. Therefore, from now, the length of the modified arrays will be  $N_{mod} = N_{data} - N_{ave}$ . This step filters out the acceleration of the gravity and sets the average of the signal to zero in steady state. This algorithm is a simple high-pass filter known as ‘moving average filter’ [32]. A high-pass filter like this is needed because the position of the device is not known beforehand, so it is not possible to predict the contribution that the gravity is going to have in each of the axes.

$$a[k] = a_{raw}[k + N_{ave}] - \frac{1}{N_{ave}} \sum_{j=k}^{j=k+N_{ave}-1} a_{raw}[j] \quad (1)$$

$N_{ave}$  must be high enough to contain several oscillations when the generator is working, so that the average calculated is as close as possible to the steady-state average. However, the highest it is, the more values will be measured and not used in the following steps. An appropriate value for  $N_{ave}$  is about a 20% of  $N_{data}$ .

- 4- **Calculate the integral** of the values in the resultant arrays for each of the three axes. The results represent something similar to the change in velocity in that axis during the period of time stored in the vector, as shown in (2):

$$\Delta v = \sum_{k=0}^{k=N_{mod}-1} a[k] \cdot T_s \quad (2)$$

Where,  $T_s$  is the sampling period and  $N_{mod}$  is the length of the vectors. In the code shown in Annex D,  $T_s$  was not used. However, the value of  $\Delta v$  obtained is proportional and it represents the same information.

- 5- **Calculate the RMS value** of the vectors, using (3):

$$a_{rms} = \sqrt{\frac{1}{N_{mod}} \cdot \sum_{k=0}^{k=N_{mod}-1} (a[k])^2} \quad (3)$$

6- **Calculate the maximum** absolute value of  $\Delta v$  and  $a_{rms}$  in each of the axes (4).

$$a_{rms\_max} = \max\{|a_{rms\_x}|, |a_{rms\_y}|, |a_{rms\_z}|\}$$

$$\Delta v_{max} = \max\{|\Delta v_x|, |\Delta v_y|, |\Delta v_z|\} \quad (4)$$

7- From these two parameters, **estimate the state** of the generator by comparing them to some threshold values. If there is a significant change in velocity ( $\Delta v_{max} > \Delta v_{threshold}$ ), then the generator is being moved. Otherwise, if the RMS value of the acceleration is bigger than another threshold value, the generator is working. If none of these conditions is fulfilled, the generator is idle (Figure 9).

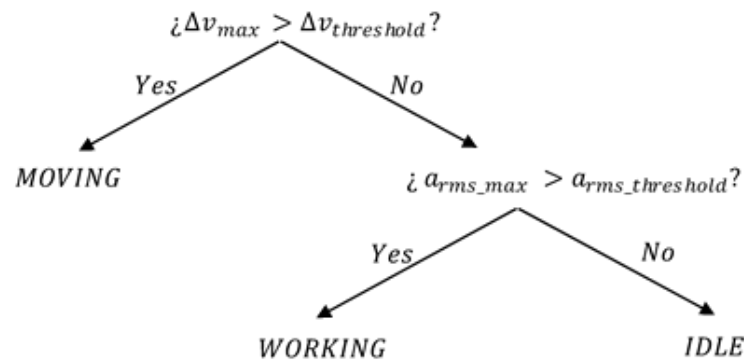


Figure 9. Decision tree used in the estimation

8- This estimation is passed through **another filter** that uses the last estimations, which are stored in an array, to reduce errors. The filter follows these conditions:

- If the state is WORKING, the filtered state will be:
  - IDLE if any of the previous estimations is different from WORKING.
  - WORKING if all the previous estimations in the array are WORKING.
- If the state is different from WORKING, the filtered state will be that same state (MOVING or IDLE).

This filter is necessary because it was observed that in the transitions from MOVING to IDLE, the algorithm sometimes detected WORKING wrongly. It is enough to use an array with three elements (the current estimation and two previous estimations) to avoid this problem. The main downside of the filter is that it adds a delay in the detection of a generator WORKING, but it is small, and it does not pose a big problem in this application. This delay is directly dependent on the number of estimations used in the filter and inversely dependent on the frequency of estimations.

The case of a generator being moved while it is working will not be considered because it is not likely to happen. However, the state estimated in this case would be 'moving', which has a higher priority than 'working' because it could mean a robbery of the generator.

In the step 4 of this algorithm, a vector with the instantaneous velocity could have been created by using (5), and the condition of robbery could have been set to having an average velocity different from zero for a small period of time.

$$v[k] = v[k - 1] + a[k] \cdot T_s \quad (5)$$

However, this method would have been prone to drifting error, since each value of the velocity is calculated from the previous one. Therefore, a small offset in the measurement of the acceleration would lead to an increasing error in the estimation of the velocity. Nevertheless, with the method chosen, this drifting error in the velocity is minimized. A constant velocity movement of the generator is not going to be detected with the method used, but this is not a problem since the robbery is always going to be detected. It is impossible to steal a generator at a constant velocity and some acceleration is needed to reach that velocity anyways.

The sampling frequency is also a delicate decision. For a 2-poles induction machine, the shaft of the generator is going to be spinning at a frequency of 50 Hz (3000 rpm) when it is working. For a 4-poles machine, the spinning frequency will be 25 Hz (1500 rpm). It is not common to find generators with more poles in the agricultural sector. Also, they would allow a smaller sampling frequency, so it would not be a problem. According to the Nyquist theorem, the sampling frequency needs to be at least two times the frequency of the signal that we want

to capture. Following this theorem, it will be necessary to measure at a frequency higher than 100 Hz in this application. However, the algorithm designed does not depend on to the frequency measured, it only depends on its RMS. In other words, it does not estimate the frequency of the vibrations, but it differentiates a vibration from a movement. If the sampling frequency is smaller than the Nyquist frequency, the sensed frequency might be different from the real frequency, but it may still represent a vibration. Therefore, this algorithm would still work with sampling frequencies smaller than the Nyquist frequency as soon as they are not divisors of the spinning frequency (sampling at 50 Hz, 25Hz, 12.5 Hz... must be avoided). In that case, a constant with zero RMS would be sensed. In the prototype, the sampling frequency chosen will be 104 Hz.

A MATLAB script was created to test the algorithm and experiment with different parameters. This script creates the vibration signal for each of the axes as a sinusoidal. Then, it samples the signal at the specified sampling frequency, it adds some gaussian noise and it applies the algorithms explained above. The MATLAB code can be found in Annex F. Two plots showing the real, sampled and filtered signals in the simulation are shown in Figure 10 and Figure 11. In these graphs, each of the colors (red, yellow and blue) corresponds to one of the axes (x, y and z).

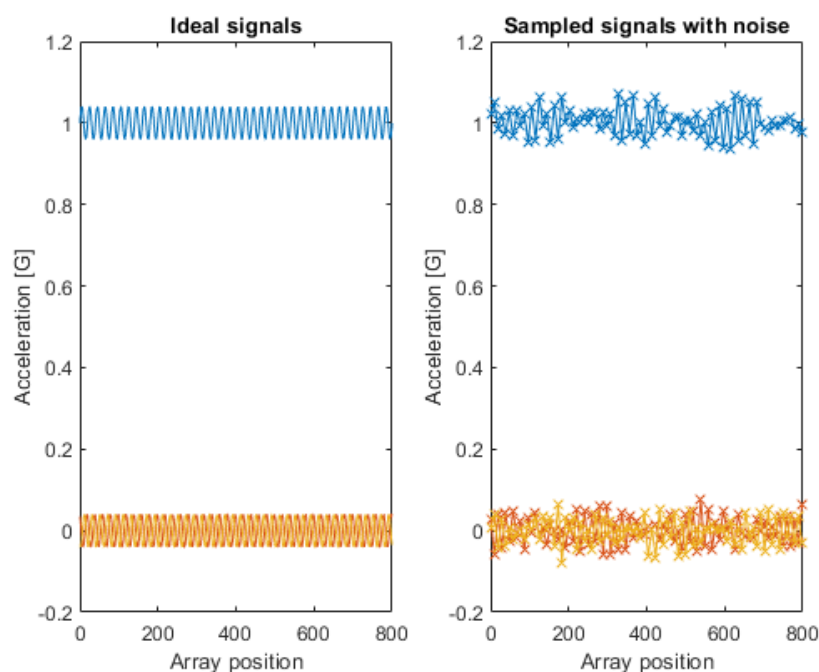


Figure 10. Real ideal signals vs. the sampled signals

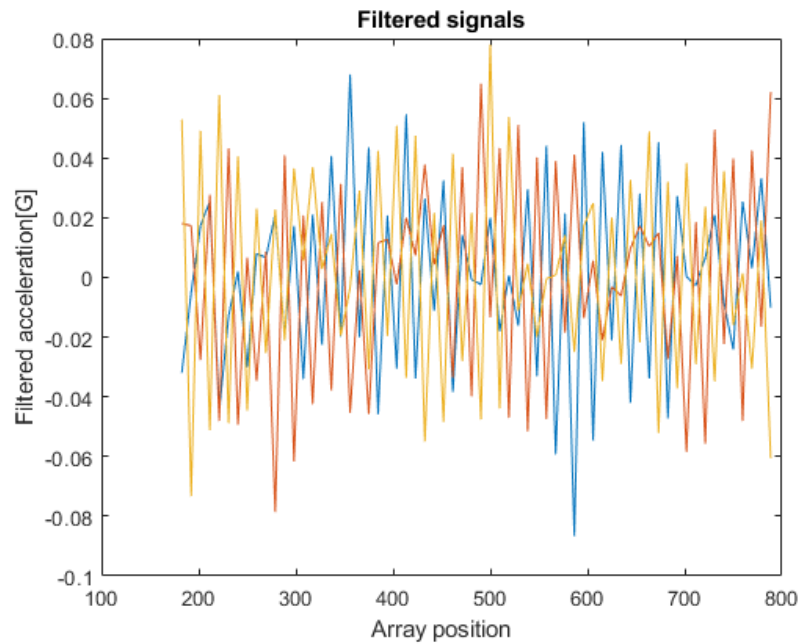


Figure 11. Signals after the moving average filter

In this particular simulation, the output of the algorithm was:

```
Results:
delta_v_max = 5.925876e-04, a_rms_max = 3.482423e-02
```

Apart from the sampling frequency, there are two other frequencies involved in the algorithm:

- The frequency of estimations, which is the frequency at which the algorithm is applied.
- The frequency at which the information is sent to the platform.

To determine the frequency of estimations, the following considerations must be taken into account. It is possible to apply the algorithm at the same frequency as the sampling frequency (104 Hz). This would mean that every time a new acceleration value is measured, the existing values in the array are shifted one position and the algorithm is applied. However, the state of the generator does not change so fast, so it is not necessary to do this at such a high frequency. A reasonable frequency to apply the algorithm would go from once every 10 seconds to once every 30 seconds. Due to the limited RAM memory, all the acceleration data collected during this time cannot be stored all together to apply the algorithm to the whole series once every 10 to 30 seconds. Also, it is not necessary, and some power could be saved by taking less measurements. The

solution proposed is to take measurements during a small portion of these time periods. For example, the acceleration could be measured for 2 seconds every 20 seconds. In this range, it is very unlikely to miss a theft in the portion of time the sensor is idle.

To determine the frequency at which the information is sent, the cost and limitations of the communication networks must be considered. Wi-Fi does not imply any limitation on the amount of data sent, but other technologies like Sigfox do. Also, if GSM is used, each message may represent a cost for the user depending on the contracted fee. Furthermore, independently of the technology, more messages sent means higher power consumption. To make the program suitable for these technologies, the frequency of communication must be smaller than the frequency at which the algorithm that measures the acceleration is applied. If a message was sent every time the algorithm is applied, too many messages would be sent, or the algorithm would be applied too few times. To solve this problem, a Finite State Machine (shown in Figure 12) will be created in the device and messages will be sent only in three cases:

- 1- When there is a transition of state, with information about the new state.
- 2- Every 2 hours or so to check that the device is working, independently of the state of the generator.
- 3- In the Alarm state, messages need to be sent more frequently with information about the GPS position. For instance, every 5 minutes.

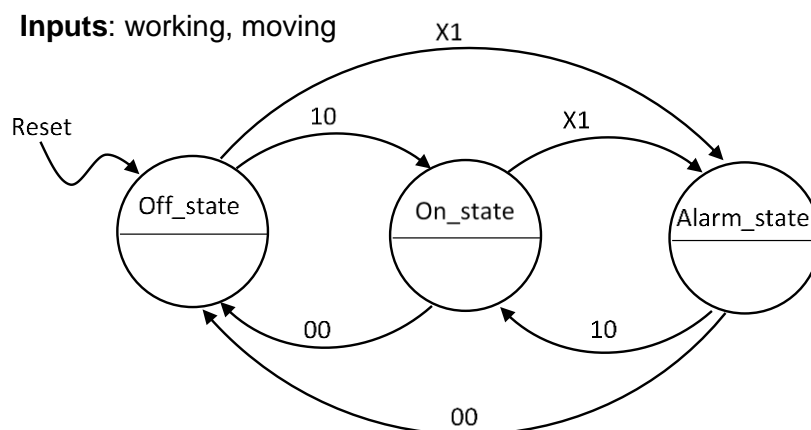


Figure 12. FSM executed in the device.



### 6.2.2. Reading GPS data

The GPS sensor communicates with the Arduino NANO by UART. Every time it performs a measurement, it sends an array of characters containing all the information obtained in that measurement. This sentence is codified using the NMEA protocol. To parse this sentence and obtain the numerical values needed, an Arduino library called “TinyGPS++” was used. This library creates a C++ “gps” object, looks for all the different parameters in the NMEA sentence, and stores their values in the different attributes of that object. From here, it is really easy to access any of these parameters, like the altitude, latitude, longitude, the number of satellites perceived by the sensor, the exact time, the velocity and direction, etc. [33].

The Arduino NANO 33 IoT uses the Atmel SAMD21G microcontroller, which allows for I/O multiplexing. This means that various serial functions can be selected for most of its pins, by configuring the SERCOM ports. In this project, a UART port was configured on pins 5 (PA05) and 6 (PA04). To do so, the following lines of code were added at the beginning of the script [34], [35]:

```
#include <Arduino.h>
#include "wiring_private.h"

// Configure serial port to the GPS
Uart gpsSerial (&sercom0, 5, 6, SERCOM_RX_PAD_1, UART_TX_PAD_0);

// Attach the interrupt handler to the SERCOM
void SERCOM0_Handler() {
    gpsSerial.IrqHandler();
}

// Reassign pins 5 and 6 to SERCOM alt
pinPeripheral(5, PIO_SERCOM_ALT);
```

### 6.2.3. Managing embedded WiFi module

To control the WiFi module in the Arduino NANO 33 IoT, the “WiFiNINA.h” library was used. This library allows to create a WiFiClient C++ object that can be used to accept incoming connections as a server or make outgoing ones as a client. In this project, the Arduino was used as client, but the MQTT library managed this. The only thing that was done using the WifiNINA library was to declare the WiFiClient object and to connect to a WiFi network with the following lines of code:

```
WiFiClient my_wifiClient;  
  
status = WiFi.begin(ssid, password);
```

To manage the MQTT communications, the “PubSubClient.h” library was used. This library created another C++ object of the class PubSubClient. To initialize it, the WiFiClient object was attached to it, and the URL and port of the server was stored in it. Some other information like the client ID, the username and the password for the MQTT connection was used to connect to the server. To publish a message or to subscribe to a topic there are also built-in functions that simplify this process.

### 6.3. Testing the prototype

This first prototype was tested on a real generator in the countryside. Figure 13 shows the device (at the bottom-left) mounted on the generator.



*Figure 13. Testing of the prototype on the ground*

From this test, some conclusions were drawn:

- The GPS works well. Placing the antenna inside the case does not hurt the precision significantly. Figure 14 shows 24 measurements of the position on the map. They are all within 2m of the actual position of the device.

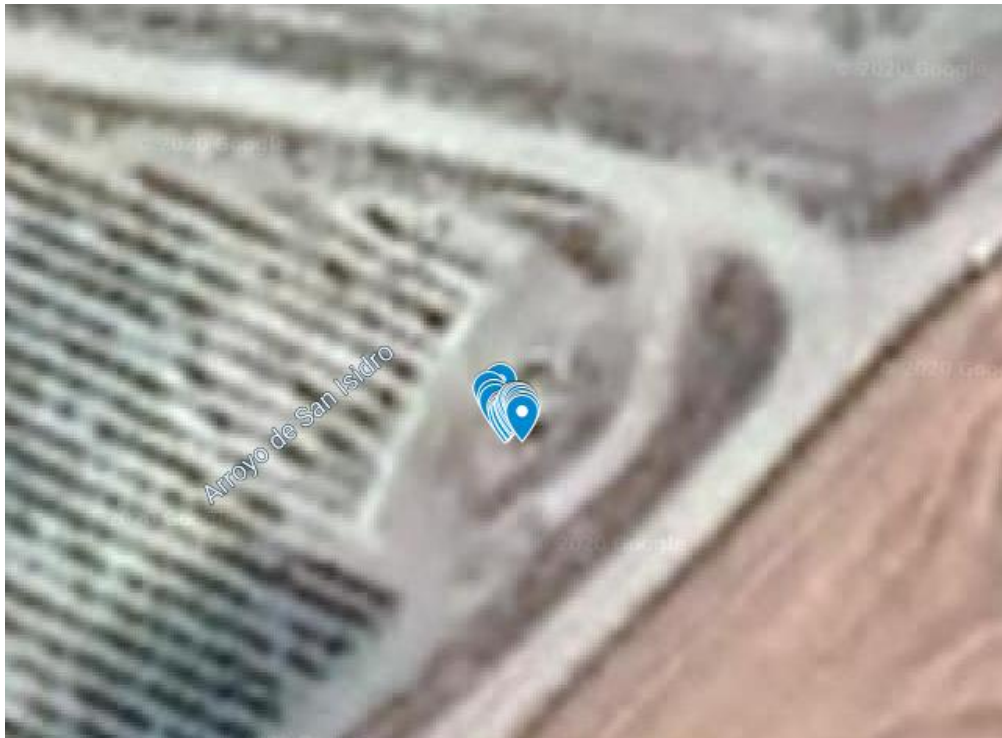


Figure 14. GPS testing results

- The generator shakes more when it starts working and when it stops. When it is working constantly, the vibration gets smaller. Figure 15 shows a plot with the measurements of  $a_{rms\_max}$  and  $\Delta v_{max}$  obtained during three starts and stops of the generator.

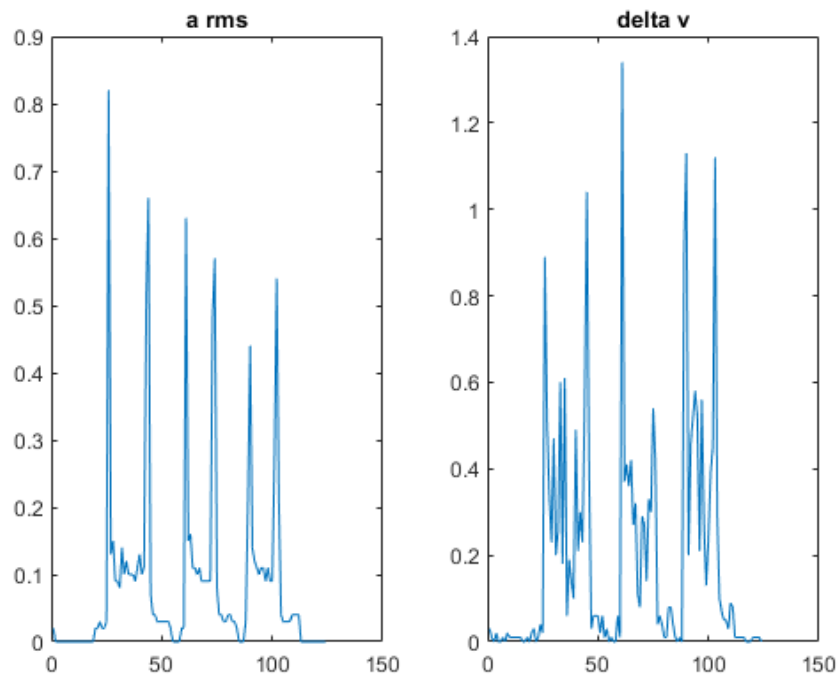


Figure 15. Results of the test on the ground

From these graphs, the threshold values for  $a_{rms}$  and  $\Delta v$  can be calculated. From the graph on the right,  $\Delta v_{threshold}$  needs to be around 1.5 to detect as 'movement' the measurements whose  $\Delta v$  exceed this value. From the graph on the left,  $a_{rms\_threshold}$  needs to be below 0.1 (0.05 would be an adequate value).

## 7. Design of the platform algorithms

In the platform, there will be an entity called a 'thing' that will receive data periodically, with information about the state of the generator and/or its position, It will store this data automatically with information about the time at which it was received, which will allow for statistics generation. As it was explained in 5.4, the 'thing' will be defined in the platform as a JSON structure, with 'properties', 'actions' and 'events' fields. The JSON structure written for this project is shown in Annex K.

The properties of the 'thing' will be:

- Latitude: the last latitude observation of the device, calculated by the GPS sensor.
- Longitude: the last longitude observation of the device, calculated by the GPS sensor.
- HDOP: the horizontal dilution of precision, which indicated the precision of the last geolocation measurement. It is also calculated by the GPS sensor.
- Moving (Boolean): a boolean variable that will be 1 when the device is moving, according to the last data received by the platform. Otherwise, it will be 0.
- Working (Boolean): a boolean variable that will be 1 when the device is working, according to the last data received by the platform. Otherwise, it will be 0.

The actions of the 'thing' will be:

- Disconnect: it will send the message to turn off the device as discussed in 5.2. If the device is not connected to the external battery, it will turn itself off and, to activate it again, it will be necessary to connect the external battery physically. If the external battery is connected, it will reset the device. Since this action cannot be undone, a password will need to be introduced to avoid activating it unintentionally.
- Standby on: it will set the device in stand-by mode to save power. In this mode, the device will only listen to the incoming messages until a 'standby off' message is sent, but it will not perform the other tasks like theft detection or GPS measurements.

- Standby off: it will set the device back in full functionality mode from standby mode.

The 'events' of the thing will be:

- Start working: the generator has started to work.
- Start moving: the generator has been moved.
- Stop working: the generator has stopped working.
- Stop moving: the generator has stopped being moved. These four events correspond with the transitions of states in the FSM shown in Figure 12.
- On: the device has been turned on. This event will be sent every time the device is turned on by connecting the external battery.
- Off: the device has been turned off. This event will be sent by the device just before it turns itself off. This event will contain a variable to know the reason for the device to turn off. This code can take the following values:
  - o 0 if the device is about to turn itself off after receiving the 'Disconnect' action (in case it is not connected to the external battery).
  - o 1 if the device is about to turn off because the external battery is not connected, and the internal battery level is too low.
  - o 2 if the device is about to turn off because the temperature of the battery is too high.
- GPS working: the GPS has started to receive signal.
- GPS not working: the GPS has stopped receiving signal.
- Power lost: the external battery is not supplying the device anymore.
- Power retrieved: the external battery has started to supply the device again.

With the first four events, the platform will be able to know in which state the generator is at each moment. There will be four possibilities, since each generator can only be at one state at a time: Working, Moving, Idle or No Signal Received. The last case will happen if the platform does not receive the periodical message discussed in *Section 6.2.1*.

To take advantage of the full functionality of the platform, it is planned to develop an API and a smartphone app with a user interface. This would allow to use the

data in the cloud to provide statistics to the user when he/she demands them and to warn the farmer in case a robbery is detected. More in detail, the application will provide the user the capability to:

- 1- Customize the application to receive statistical reports annually, monthly or weekly. The statistics included in the reports are:
  - Number of hours working, and percentage of time working.
  - Number of hours idle, and percentage of time idle.
  - Average working time per day.
  - Number of movements of the generator detected.
- 2- Reset the start time for statistics collection, so that the previous data is not used for this purpose. This may be useful if the device is used to protect a different generator and the farmer do not want the data to get mixed with the data obtained for the previous one.
- 3- Request the current state of the generator and its GPS position, as well as the time these messages were received in the platform.
- 4- Receive a notification when a movement of the generator is detected. A security radius and expected position coordinates can be also introduced so that the farmer can receive another notification if the generator leaves that radius from the expected position. All this will be customized in the application.
- 5- Send commands to the device. These commands will be the same as the 'actions' described in the JSON structure (disconnect, stand-by on and stand-by off).

It is important to create a simple and user-friendly smartphone application to perform all these tasks. New technologies do not have such a big penetration in the countryside as they have in the city, so a complex application may result a barrier and may result detrimental to the introduction of the product in this market. It would also be advisable to have a different way of warning and informing those users that do not have a smartphone, through SMS and phone calls.





## 8. Market study and business model

This section is going to study if an investment in this product is profitable, and what is the optimal strategy to follow. The study is going to follow this structure, which can be iterated several times:

- Design of the business model.
- Sales forecast.
- Cost analysis.
- Price fixing and income analysis. To do this, three aspects are considered:
  - o The price of the products offered by the competition.
  - o The cost that the product has for the company
  - o The price that the client is willing to pay (study of the demand).
- Profit forecast.

With this structure, each of the steps depend on the previous ones. The cost of the devices depends on the amount of them sold. Therefore, their price depends both on the cost and on the sales forecast. Finally, the profit forecast, which is calculated from the total costs and the total incomes, depends on all the previous steps. From the yearly profit, the IRR and NPV indicators are going to be calculated to analyze the viability of the investment. The investment period considered will be 5 years.

### 8.1. Design of the business model

The target population, that live in the countryside, have some characteristics that must be considered to decide the strategy used to reach them. There is not a big density of potential clients anywhere, but they are widespread all over the territory. Also, some of them do not use social media regularly. This makes it really expensive to reach them directly and requires using intermediate agents that already have a good contact network with potential clients in the area. For example, stores that sell agricultural equipment or companies that conduct services for a lot of farmers would be good agents to associate with.

As it will be explained later, the number of devices that are expected to be sold are below 20.000. Therefore, it is not profitable to buy manufacturing equipment

for the PCB and the case, and these services are going to be ordered to other companies.

The business plan is to sell some devices in Year 0 to some reliable farmers at a low price and not collecting any fee for the cloud services. This would give the company really valuable feedback to improve the product and detect possible flaws. This year, a simple webpage offering the product is going to be set up and the mobile application is going to be developed by an external software developer. In Year 1, the product is going to be launched to the market. In the middle of Year 2, a worker is going to be hired. In Year 4, the company is going to hire an extra worker and the company will start to explore other markets outside Spain. As it has been explained, most of the work of the company is going to be outsourced. The company is going to buy the materials, it is going to assemble the devices, pack them up, and in most of the cases, sell them to a retailer or other agent. The development and maintenance of the webpage is going to be done using an online web developing tool. The develop of the mobile application is going to be ordered to an external company, which is also going to do the maintenance until the company hires the first worker in Year 2. The owner of the company is going to be working on the project without earning a salary because that would increase too much the costs at the start of the project. However, this withdrawal allows him to benefit from the future profits of the company.

## 8.2. Sales forecast

Most of the diesel generators placed in the countryside, at least in Spain, are used to pump water out from wells. Therefore, it is possible to estimate the number of potential generators where the device designed could be used from a study of the existing wells in Spain.

In Spain, there exist more than 500.000 wells officially [36]. However, this number does not reflect the reality, since half of more of the wells in Spain are illegal, so they are not registered in the official statistics [37]. Therefore, the number of wells in Spain exceeds the million. A portion of these wells are in inhabited areas and are used for water supply to homes and villages. From the ones located in the countryside, four cases can be distinguished:

- The wells that have a power transmission line close to them take the electricity from a **transformer**.
- A small portion of the wells use **solar panels** to generate electricity to pump the water out.
- Others are not currently in use because they may have been **depleted**.
- The rest of them use a **diesel generator**, and they are the target of this project. It is estimated that the number of wells that use a diesel generator in Spain are around 150.000. This represents the maximum number of devices that could be potentially sold in Spain.

Table 4 shows an estimation of the number of each of the previous types of wells in Spain.

*Table 4. Estimation of the number of wells in Spain*

Total number of wells		1.000.000
Wells for domestic usage		500.000
Wells for irrigation	Currently not used	175.000
	Electricity obtained from the grid (transformer)	125.000
	Electricity obtained with solar panels	50.000
	Electricity obtained with diesel generators	150.000

A positive estimate is to sell 20% of all these devices, which would mean to sell 30.000 devices. A more pessimistic estimate is to reach a 5% and sell 7.500 devices. This number of devices could be sold every 15 years, which is the expected lifetime of the device.

Also, it is possible to estimate the number of clients that this would represent. It is estimated that a farmer has in average 1.5 wells susceptible for the use of this technology. Therefore, the number of clients could go from 13500 to 3500 in Spain, using the previous estimations.

The number of devices sold yearly will increase in time, as more agents start to distribute the product. Following the strategy explained in 8.1, the sales forecast for each year is shown in Table 5:

Table 5. Sales forecast during the first 5 years.

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
<b>Salaried employees</b>	0	0	0.5	1	2	2
<b>Number of devices sold</b>	10	100	300	700	1300	2500

All the devices sold are going to be connected to the platform and have access to the mobile application. Some clients may prefer not to use the mobile application and receive the alerts by SMS or phone calls. For the company, the cost of the device without access to the app is slightly smaller, but the price of the product sold is going to be the same. In this study, no distinction is going to be made between both type of products.

### 8.3. Profit model

The business model outsources the manufacturing of all the parts used in the device. PCB fabrication and assembly are going to be ordered to an external company, and the case and other parts are going to be bought to another company. Therefore, the tasks that are going to be done by the company are going to be the assembly and packaging of the parts, and the sale of the product to a distribution agent, which is the best sales strategy considering the characteristics of the target population, as it has been discussed. The company is going to have five departments, each of them with different type of costs:

- **Supplies:** materials and salaries of the people that search and treat with the suppliers.
- **Assembly and packaging:** packaging material and salaries.
- **Sales:** salaries of the people that treat with the distribution agents.
- **Distribution:** shipping cost to the distribution agents.
- **Maintenance:** salaries to assist customer requests, maintenance of the mobile app and webpage.

The incomes for the company will come from two different lines: the sale of the devices and the incomes from a cloud services fee that is going to be collected from all the active clients.

The costs of these two products for the company are going to be studied below. Then, the incomes associated are going to be analyzed and the expected profit is going to be calculated.

### 8.3.1. Cost analysis

The costs that the company has to cover can be organized by the step in the production chain at which they are covered. Since the production chain of all the devices sold is the same, the costs are going to be considered without making this distinction. However, Table 6 shows a qualitative representation of this cost attribution:

*Table 6. Qualitative attribution of costs*

	<b>Supplies</b>	<b>Assembly</b>	<b>Sales</b>	<b>Distribution</b>	<b>Maintenance and customer attention</b>
<b>Materials</b>	xxx	x	-	-	-
<b>Salaries</b>	x	x	xxx	-	x
<b>Shipping</b>	-	-	-	x	-
<b>Web &amp; app</b>	-	-	-	-	xxx

The following subsections will study each of the different costs (materials, salaries, shipping, web & app).

#### 8.3.1.1. Material costs

Material costs can be divided in costs of the materials used to build the device and costs of the materials used to package the device.

In the first category, the PCB is going to be manufactured and assembled by an external company, the case is going to be manufactured by another company, and the screws needed to mount the device on the generator are going to be bought externally. Table 7 shows two estimates of the costs per device, one more optimistic, and the other one more pessimistic. The reasoning taken to reach these numbers is explained below.

Table 7. Device material costs.

Device material costs		
Cost	Lower estimate (€)	Higher estimate (€)
Electronic components	24	30
PCB fabrication	0.5	1
PCB assembly	2.5	5
Case	1	3
Screws, nuts and washers	0.5	0.5
Cable and connectors to 12V battery	1.5	1.5
TOTAL	30	41

The second prototype designed (*Section 9.1*) already has all the functionalities of the final device. Therefore, the cost of the materials used in this prototype can be used as a reference to estimate the cost of the materials in the commercial device.

The cost of the electronic components can be estimated from the cost of the components for the second prototype, shown in Annex J. Due to scale economies, and the cost reduction that may result from substituting the modules used in the prototype, like the Arduino, by single components and IC's, the cost can be reduced to half. Therefore, the cost of the electronic components is estimated to be from 24€ to 30€.

The PCB needed is simple. It only has two layers and it does not require high precision. The PCB designed for prototype 2 has 66 cm<sup>2</sup>. If the Arduino, GPS and GSM modules are substituted by single components and chips, the size can be reduced to half. If the battery is moved away from the PCB and assembled directly to the case, the size can be reduced to one third or one quarter. With this size and characteristics, the PCB can cost from 0,50€ to 1€.

The assembly cost of the components to the PCB can be reduced if SMD components are used, since it is possible to automatize its soldering process. It may cost from 2,5€ to 5€.

From the dimensions of the PCB, it is estimated that the case will need around 30cm<sup>3</sup> of plastic. The plastic is inexpensive. If the case is made of ABS, the case would represent 32,1g of material. Since it can be found for 2,5€/Kg, the plastic for each case would cost 8 cents. However, the fabrication of this case may result

more expensive. Injection molding, which is the most common process of thermoplastic manufacturing is economical only for large production quantities, since a personalized mold is expensive. Therefore, the cost of the case will depend a lot on the production quantity. If it is not very large, it may be cheaper to adapt the design of the PCB to a case that exist in the market. Depending on this, the cost of the case may go from 1€ to 3€.

Eight screws, two nuts and two washers are going to be needed. This will cost 0,5€.

The connectors and the cable that go to the generator 12V battery will cost around 1.5€.

Adding everything, the cost of the materials needed to build the device will go from 30€ to 41€ per device.

These estimations have been done considering that a big amount of materials is bought together. However, at the start of the investment, the number of devices sold is going to be smaller and, therefore, their unitary cost is going to be higher. For the first devices, the unitary material cost is estimated to be 80€. The following years, it will decrease as shown in Table 8.

#### *8.3.1.2. Salaries*

The cost of an employee for a company is estimated to be 50.000 € per year. The company is expected to have no salaried employees until the middle of Year 2. At that time, one employee is going to be hired. A second employee is going to be hired at Year 4. Most of the time of the employees is going to be devoted to establishing new clients. They are also going to spend some time treating with the suppliers, assembling and packaging the products, and treating with the clients that may have requests or concerns. The time devoted to assembly and packaging is estimated to be 5 minutes per device, so according to Table 5, the time dedicated to this task is going to be less than 9 hours per month during the most busy year (Year 5). The total cost in salaries for the companies can be consulted in Table 8.

#### *8.3.1.3. Shipping costs*

The shipping cost from the suppliers is included in the cost of materials. The shipping cost to the distribution agents (or final clients) is considered here. The

first devices will cost 2,4€ per device, which is the cost of sending the device through a post office, but this cost will decrease as bigger quantities are sent, as shown in Table 8.

#### 8.3.1.4. Cost of the cloud services, the webpage, and the mobile application

Each device that is connected to the cloud costs to the company 2€ per month. This service is externalized, so the maintenance of the platform does not represent a cost for the company. The total cost for the company is proportional to the number of active devices in the market.

A webpage is going to be created to exhibit the benefits and possibilities of the product, and to provide the contact information of the company. This webpage is going to be developed using an online web developing tool, which will cost 500€ yearly, including the cost to renew the domain.

A mobile application that connects to the platform, shows the data in an intuitive way and sends notifications to the farmer is also going to be needed. Its development cost is estimated to be 5.000€ and it is going to be outsourced. The estimated maintenance cost is estimated to be 1.000€/year until the first worker is hired. From then, the maintenance will be done by him, so its cost is contained in the salaries cost.

#### 8.3.1.5. Summary of costs

Table 8 shows a summary of all the costs of the company yearly:

Table 8. Summary of costs.

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Salaries	0	0	25000	50000	100000	100000
Number of devices sold	10	100	300	700	1300	2500
Unitary cost of the device	80	60	50	40	35	30
Total cost of the devices	800	6000	15000	28000	45500	75000
Unitary package cost	1	1	0.7	0.5	0.4	0.3
Total packages cost	10	100	210	350	520	750
Unitary distribution cost	2.4	2	1.8	1.5	1.5	1
Total distribution cost	24	200	540	1050	1950	2500
Web development and maintenance	500	500	500	500	500	500
Mobile app development & maintenance	5000	1000	500	0	0	0
Number of active devices	10	110	410	1110	2410	4910
Infrastructure cost	240	2640	9840	26640	57840	117840
Total cost	6334	7800	41750	79900	148470	178750
Unitary cost	633.4	78	139.1667	114.1429	114.2077	71.5



### 8.3.2. Price analysis

To set the price of the products, three factors need to be considered: what are the costs for the company, what is the price of the competition, and what is the benefit for the farmers that buy this product.

From the costs for the company, the lowest price to reach the break-even point can be set. In this case, it is around 105€. The lowest fee for the cloud services is 24€/year (2€/month).

#### 8.3.2.1. Analysis of the competition

The device designed in this project is not found in the actual market, although the technology used is not new. There are three solutions in the actual market that are similar to the one designed in this project:

- Diesel generator monitoring systems. They can detect when the generators are working, how much power they are generating or what is the level of the diesel tank. They can also detect mechanical problems or high temperatures in the generator. Some of these products are also equipped with a GPS sensor to detect the position of the generator. These products usually come already built in the generator when it is acquired. Most of the generators that use this solution are big generators used in industrial applications. Although a robbery can be detected with these products, their main objective is to analyze the operation of the generator for predictive maintenance, fuel monitoring (including fuel theft detection) or efficiency increase.
- Tracker devices. Most of them are generic GPS devices that can be attached anywhere and are not designed to be used in diesel generators specifically. The only tracker devices that are designed to be used in the countryside are those sold by Metos®. These devices can be used to track tractors (they are specially designed for farmers that have several tractors) or to track static equipment that do not have a battery. They are connected to the company platform, but none of them can be used to detect when a generator is working [9]. They cost 350€, plus a subscription fee to the cloud.

- Generic GSM alarms. These products send a warning message when a movement is detected, or when any sensor is triggered. They are designed to be placed in the countryside, but not on generators. They would not detect when the generator is working, and they are not connected to a platform. The cheapest one found was 256€ (*Section 2.1*).

Therefore, the competition already employs the technology used in this project, but not all together with the purpose of theft prevention. There is no patent or state-of-the-art technology involved. This means that any of these companies could develop the product designed in this project in a short time, using their previous experience with the same technologies.

In Spain, the thefts in agricultural areas are more common than in other developed countries, like the US and northern Europe. This creates a need in the Spanish farmers that may not be detected by companies that do not operate in Spain. This may be an advantage with respect to the foreign competition, where there are multiple IoT companies that could easily develop a similar product. In Spain, the IoT companies dedicated to the agricultural sector are not focused in theft prevention, but their main business are smart sensors and solutions to increase crop production using precision agriculture.

In terms of the price of the device designed in this project to be competitive in the market, it should be sold for less than 300€ to the final client (with access to the mobile app). Considering that the distribution agent keeps a 20% of this, the price at our company should be less than 250€.

#### *8.3.2.2. Benefits and costs from the farmer's perspective*

The generators that are used in the countryside are medium-size generators, that cost around 5.000€. The farmers could benefit from the theft detection of the devices, that gives them security in their investments. If a generator is stolen, the farmer does not only lose the generator, but the whole harvest is put at risk if this happens during the summer. Also, this product would allow them to increase their productivity and reduce their costs. For example, from the statistics generated during the previous months or years, they could understand better their costs in diesel, and they could forecast how much diesel are they going to need in the future. Also, since the time when the generator is working coincides with the time

when the irrigation system is watering, these data could be useful to draw conclusions about the optimal time to irrigate, or the relation between weather conditions and water usage. Finally, if some improvements are done in the final product, the generator could be turned on and off automatically, saving time and money to the farmer, or the device could be used for predictive maintenance of the generator as well.

The cost for the farmer is the price of the device, plus the price of the SIM card and the cloud services fee. As it has been discussed, the price of the device needs to be below 300€ to be competitive in the market. The cloud services fee may cost them around 30€ annually, and a SIM card with 50MB per month could cost them 60€ annually [38], or less if the generator is not used in winter and they use a pre-paid card.

Therefore, these devices are profitable for the farmer in most of the cases. Assuming that it takes 15 minutes for a farmer to go to the field to turn the generator on and off, and he/she needs to irrigate the field 30 days per year, this device would save him/her 15 hours yearly, which represents more than 150€ and exceeds the yearly cost. Also, even a small increase in production, like a 1%, would generate a profit that exceeds the costs of the device.

#### 8.3.2.3. Price election

Table 9. Summary of the previous price analysis

From the demand analysis	<500€
From the competition analysis	<250€
From the unitary costs (break-even)	>105€

From this analysis, the price of the device with access to the mobile app is going to be set at 180€. This would allow the retail price to be around 216€. This price is in the middle between the limit fixed by the competition and the limit fixed by the break-even analysis. A higher price would mean more unitary profit, but less units sold. At least during the first years, the price difference with the competition needs to be high because otherwise, the consumers would choose a brand that is already known. Also, a low price allows a higher margin for the retailer, which represents an incentive for him to sell this product.

The first two years, the price is going to be 130€, since at this time the product would still be in a developing stage (see Table 10).

### 8.3.3. Profit forecast

With the prices set, and the costs and sales forecasted, it is possible to estimate the profit of the investment yearly. It was considered that the company pays a 25% of the gross profit on taxes and that negative profits are deducted from the profits of the following years that pay taxes.

Table 10. Incomes and total profit

Price	130	130	180	180	180	180
Device sales income	1300	13000	54000	126000	234000	450000
App income	0	3600	14400	39600	86400	176400
Total income	1300	16600	68400	165600	320400	626400
Total cost	6334	7800	41750	79900	148470	178750
Gross profit	-5034	8800	26650	85700	171930	447650
Taxes	0	941.5	6662.5	21425	42982.5	111912.5
Net profit	-5034	7858.5	19987.5	64275	128947.5	335737.5

From here, the IRR and NPV indicators can be calculated:

$$IRR = 301 \%$$

$$NPV = 330.417,18 \text{ € (using an interest rate of 0,1)}$$

The gross profit and net profit per worker have been also calculated for the duration of the investment (Table 11):

Table 11. Profit per worker

Gross profit per worker	-5034	8800	17766.67	42850	57310	149216.7
Net profit per worker	-5034	7858.5	13325	32137.5	42982.5	111912.5

## 9. Optimizations and indications for the final product

### 9.1. Second prototype

Based on the prototype previously built and tested, a second prototype has been designed. This one uses a GSM/GPRS module for communications and a backup battery for energy storage. The objective of this prototype is to incorporate all the functionalities of the final product, so that it can get tested in the countryside without the need of a Wi-Fi network. In the following sections, the design of this prototype is going to be explained.

#### 9.1.1. Electronic circuit. Power supply and backup battery.

Since this prototype is going to use an internal battery, it will need some electronics controlling the charge and discharge of that battery. This battery management system needs to fulfill some requirements that were discussed in *Section 5.2*. This, and the fact that the GSM module does not tolerate 5V as a supply voltage, made it necessary to design a new circuit for this prototype. A partial diagram of the circuit that was designed is shown in Figure 16, which will be used to explain its working principles. The complete diagram is shown in Annex G.

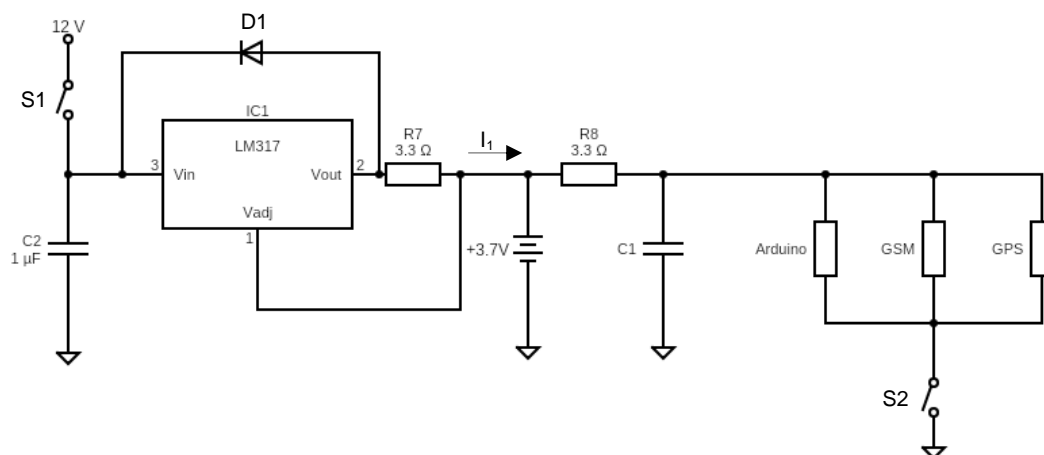


Figure 16. Prototype 2. Diagram of the power circuit.

The circuit works as follows:

- In normal conditions, the circuit is connected to the external 12 V battery.

- The switch S1 controls whether current from the external battery can flow into the circuit or not. When current flows into the circuit, the internal battery will charge. Therefore, S1 controls whether the internal battery is being charged or not.
- The LM317 integrated circuit is a linear adjustable voltage regulator. It fixes a difference of 1,25 V between the  $V_{out}$  and  $V_{adj}$  pins. Therefore, with this configuration, it will supply a constant current  $I_1$ , flowing into the battery and the rest of the circuit. The LM317 needs to have at least 3 V more at the input than at the output. Therefore, with this configuration, the input needs to be at least 4,25V higher than the voltage of the internal battery. The calculation of the output current is simple (6), and it is fixed by the value of the resistance  $R_7$ . In this case, this resistance is chosen so that the battery is being charged at around 0,1 C, which means that the charging current is around 260 mA with the 2600mAh battery used. That 260 mA are the difference between the current that leaves the LM317 and the current that is consumed by the Arduino, GPS and GSM modules. The current consumed is estimated to be around 150 mA, as it is explained in the next bullet point.

$$I_1 = \frac{1.25}{R_7} = 380mA \quad (6)$$

In the LM317 datasheet [39], it is recommended to add an input capacitor (C2) to reduce any ripple that may appear in the input voltage. Also, a protection diode is recommended to provide a current path in case the voltage at the output gets higher than the voltage at the input, especially given that there is a battery at the output and the IC may get damaged if the input becomes around 1V below the voltage of that battery.

- The battery will be a lithium-ion battery cell, with a nominal voltage of 3,7V, although it can reach 4,2V when it is fully charged and around 3,2V when it is almost fully discharged. The power consumption of the GSM/GPRS module is difficult to estimate because it depends a lot on the functions that it performs and it draws current in short pulses, but 50 mA in average is a good estimate [40]. The GPS also consumes 50 mA in average, and it can be estimated that the Arduino consumes another 50 mA. In total, the device consumes around 150 mA from the internal battery. In this second

prototype, a 2600mAh Li-ion battery is going to be used. Assuming the battery is at 80% of its charge capacity when the external battery supply is lost, it will be able to supply the circuit for 14 hours. This is enough for testing purposes, although the final product would require the battery to last at least two or three days.

- The battery will feed the Arduino, the GSM/GPRS module and the GPS module when S2 is closed. By opening S2, the device can be turned off.
- Since the GSM/GPRS and the GPS module input currents are not constant, a big capacitor (C1) is going to be connected at the input of these modules, so that it can supply high current pulses for short periods of time, keeping the current that charges the battery almost constant. A small resistance ( $R_8$ ) can also be added between the battery and the capacitor for the same purpose.

In the circuit, S1 and S2 are going to be two transistors operated by the microcontroller, which require some extra electronics. Also, some circuitry will be needed to sense the voltage of the internal battery or the voltage at the input from the external battery, to decide if the transistors should be open or closed. A diagram of the complete circuit is shown in Annex G. In that diagram,  $R_1(33k\Omega)$  and  $R_2(10k\Omega)$  form a voltage divider that is used to measure the input voltage. The external battery is a lead-acid 12 V battery, so it can reach 14 V when it is fully charged. In that case, the voltage sensed by the microcontroller ADC at the divider will be 3,26 V, which is just below the limit of 3,3V at the pins of the microcontroller. This way, the measurement of the voltage will use the full range of the ADC. With this measurement it can be detected if the external battery is connected or not, and also the State of Charge of that battery can be estimated. If it is too low in a way that further discharging may endanger the next start of the generator, S1 (see Figure 16) should be opened. In a similar way,  $R_3(2.7k\Omega)$  and  $R_4(10k\Omega)$  will allow the microcontroller to measure the internal battery voltage. When the voltage of this battery is 4,2V, the microcontroller will sense 3,3V at one of its analog pins. From this voltage, the SoC of the internal battery can be estimated. The LM317 will be providing a constant current into the battery when S1 is closed. Therefore, when the estimated SoC is too high (around 90 to 95% SoC), S1 will be opened. When gets below a certain value (for example, 60%

SoC), it will close again, so that the battery will be kept always between these two values, ready to power the device if the external battery is lost at any moment. A temperature sensor will be also connected to the Arduino and it will be placed in contact with the battery cell. It will allow to make more precise estimations of the SoC of the battery, as it was discussed in *Section 5.2*. Also, if the temperature of the battery is higher than the maximum safety temperature, S1 can be opened to stop the charging of the battery or S2 can be opened to shut the device off.

S1 in Figure 6 represents Q2 in the complete diagram shown in Annex G. This transistor is a P-type MOSFET transistor, and it is operated using an NPN BJT transistor (Q1) in a previous stage, since the microcontroller cannot set the gate of the PMOS at 12V directly. When the voltage at pin number 7 (D4) of the Arduino is set to 3,3V, Q1 will be saturated and the voltage at the collector of Q1 will be almost 0V. Therefore, the gate of Q2 will be almost grounded and it will be closed, allowing the current to flow into the LM317. When the pin in the Arduino is set to 0V, Q1 will open. The gate-to-source voltage of Q2 will be 0V, so it will also open. This is the situation when the Arduino device is started for the first time. It will need power to start, but the connection with the external battery will be closed unless the Arduino opens it, so the power used to start up the microcontroller cannot come from the external battery. Therefore, the internal battery will need to be charged, at least slightly, for the Arduino to start working and close these transistors. The resistance  $R_5$  ( $2,7k\Omega$ ), at the base of Q1, guarantees with a security factor of 2,5 that this transistor is going to be in saturation when the microcontroller sends 3,3V, as it is shown in (7) and (8):

$$i_{c\_sat} = \frac{12 - 0,2}{10} = 11,98 \text{ mA} \quad (7)$$

$$i_{b\_min} = \frac{i_{c\_sat}}{\beta_{min}} = \frac{11,98}{30} = 0,4 \text{ mA} \rightarrow R_{b\_max} = \frac{3,3 - 0,7}{0,4} = 6,5k\Omega \quad (8)$$

S2 in Figure 6 represents Q3 in the complete diagram shown in Annex G. This is a logic-level N-type MOSFET. This means that it is an N-MOS that can be operated with low voltages, so no other transistor is needed previously as a driver. This transistor can connect or disconnect the ground to all the modules in the circuit, so it is able to turn all the circuit off. It will be opened when a problem occurs and when the device is stored or it is not being used, to reduce the battery



consumption. As it was discussed in *Section 5.2*, the device will be turned off using a signal from the microcontroller and it will be turned on again when the external power supply is connected. Therefore, it will not be possible to turn the device off when the external battery is connected to it. When the external power supply is connected, the voltage divider formed by  $R_{10}(100k\Omega)$  and  $R_{11}(39k\Omega)$  will set 3,3V at the gate of the transistor, so it will open, allowing current to flow through the Arduino and turning it on. At this time, the pin number 6 (D3) of the Arduino, will be set high (3,3V). If the external battery is disconnected, the Arduino will depend on the power supplied by the internal battery, and it will be able to turn itself (and the other modules) off by setting its pin number 6 low. If this pin is set low (0V) while the external battery is connected, it will turn the Arduino off, but it will be turned on automatically immediately after. Therefore, this action will reset the microcontroller, and it may be also useful in some cases. The resistance  $R_9(470\Omega)$  limits the current that may flow through the Arduino pin to charge or discharge the gate-to-source capacitance in the MOSFET when there is a transition from 0 to 3.3V or vice versa. It limits this current to 7mA (9), which is the maximum in the Arduino NANO 33 IoT pins.

$$\frac{3.3V}{R_9} = \frac{3.3V}{470\Omega} = 7mA \quad (9)$$

#### 9.1.2. GSM/GPRS module

The GSM/GPRS module chosen for this prototype uses the SIM800L chip. A picture of it is shown in Figure 17. It is a miniature GSM modem that can send SMS text messages, make and receive phone calls or connect to the Internet through GPRS and TCP/IP. The module supports quad-band GSM/GPRS network, so it can work almost anywhere in the world [41].



Figure 17. SIM800L module used in the second prototype [42].

The power supply for this module must be between 3,4V and 4,4V and it may be able to provide up to 2A during transmission burst. If it is directly connected to 5V, it may get damaged. The microcontroller and the module communicate through a UART port. The module supports baud rates from 1200bps to 115200bps with Auto-Baud detection [41]. The type of messages that are sent to control and configure the module are called AT commands, since they all start with these two letters, which have their origin in the word 'attention' [43]. For example, to make an HTTP request, the following commands need to be sent through the UART port to the GSM/GPRS module [44], [45]:

```

AT+CFUN=1           //Set full functionality (1 by default)

AT+CPIN=1234       //Introduce the PIN number

AT+CGATT=1        //Start GPRS service

AT+CSTT="airtelwap.es","wap@wap","wap125" //Set the APN address,
user and password (This example works for Vodafone SIM cards, but it changes
depending on the phone operator). [http://www.apn.com.es/]

AT+CIICR          // Bring Up Wireless Connection with GPRS

AT+CIFSR          // Get Local IP Address

AT+CIPSTART="TCP","www.web-adress.com","80" // Start up TCP
connection. The address and port are specified.

```

```
AT+CIPSEND=75 //Specify the length of the HTTP request string. The HTTP request would be sent right after this command, with some delay. To signal that the request has ended, a "ctrl+z" character (26 in decimal or 0x1A in hexadecimal) needs to be sent.
```

In the code, some delay would be added after each of the commands to ensure that the process started has finished before the next command is sent.

If MQTT is going to be used, instead of HTTP, the procedure is almost the same, but the message sent after the `AT+CIPSEND` command needs to follow the MQTT standard [46]. However, developing this from scratch would require a deep knowledge of this protocol and some time. By using the "PubSubClient.h" library, the developing time may be reduced. This library requires a web Client C++ object since the PubSubClient C++ object is associated with it when it is created. For example, this web Client object can be a WifiNINA Client or an Ethernet Client. In this case, the "GSM.h" library allows to create a GSM Client that can be associated with the PubSubClient instance. Therefore, it is possible to use the "PubSubClient.h" and "GSM.h" libraries at the same time to manage GSM communications and the MQTT protocol without the need of a deep knowledge of them. In fact, all the code related to the MQTT protocol can be kept as in Annex D, but the functions in the "GSM.h" library will substitute the "WifiNINA.h" ones.

#### 9.1.3. PCB design

As in the first prototype, a PCB was designed for this second prototype. The plans of the PCB can be consulted in Annex H.

To design the PCB, both SMD and THT components were used. Except for  $R_7$  and  $R_8$ , all the resistances used are SMD 0805 (0.08 inches x 0.05 inches), which can dissipate up to 0,125 Watts. For  $R_7$  and  $R_8$ , the PCB was designed so that a THT resistance of up to 1-Watt fits in the holes. The complete list of components that are going to be mounted in the PCB is shown in Annex J.

#### 9.1.4. Case design

A case for this second prototype has also been designed. The plans and isometrics of this case can be consulted in Annex I. It was designed custom-made to the PCB. With respect to the case designed in the previous prototype, this one

is bigger, mainly due to the electrolytic capacitor (C1) and the internal battery. The case is composed of two different parts that are assembled using four M3x12mm screws. These screws are placed in the flared holes at the sides of the parts. The PCB will be also screwed to the top part using four M3x10mm screws. This part has a 1x1mm gap to place a rubber O ring in it and seal the junction. A detail of it is shown Figure 18. The bottom part has a 9x11mm rectangular hole where the female DC jack will fit. It also includes two protrusions to fasten the device to the generator. This can be done using a pair of screws through the M5 holes or using a belt though the slots. A render of the assembly is shown in Figure 19. A list of all the pieces mentioned before is shown in Table 12.

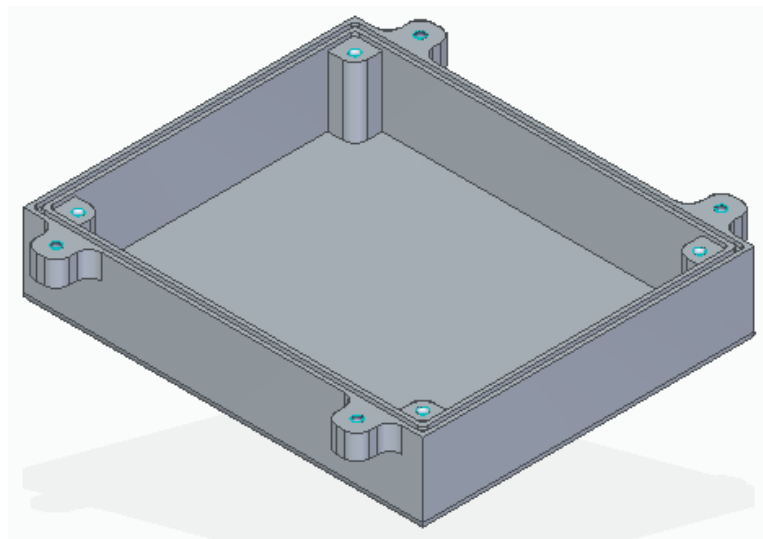


Figure 18. Top part of the case (upside down).

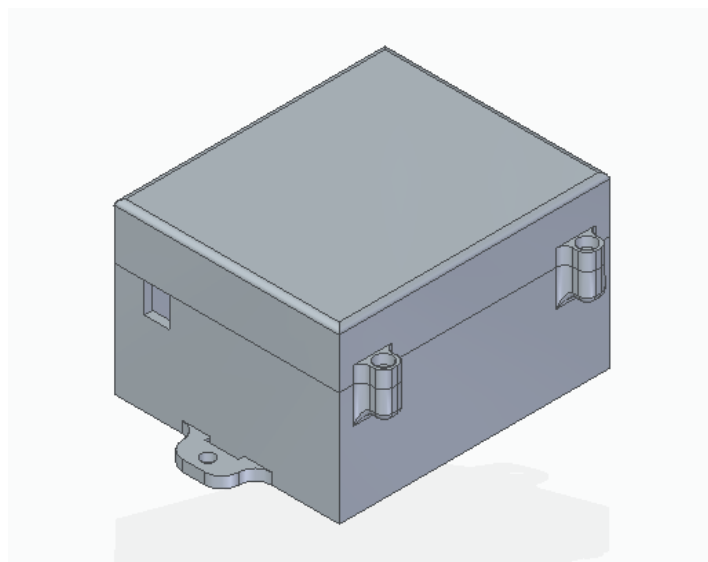


Figure 19. Assembly of the case

Table 12. List of pieces needed for the second prototype.

Piece	Amount
Case top part	1
Case bottom part	1
Allen screw M3x12 DIN912	4
Allen screw M3x10 DIN912	4
Socket button screw M5x12 ISO7380	2
Hexagonal nut M5 DIN934	2
Medium split lock washer M5 DIN127-B	2

## 9.2. Battery

The internal battery of the second prototype can provide power to the device for around 14 hours. In the final product, this time needs to be larger, to give more flexibility to the user if a problem occurs (around two days is enough). One procedure to do this is to modify the hardware and software to turn off parts of the device when they are not needed. For example, a transistor may be placed before the GPS module to turn it on only if a movement of the generator is detected. To send information about the GPS is useless when no movement has been detected. Also, the GSM/GPRS module has options to reduce its power consumption by dispensing with some functionalities. The configuration of this

module can be set to be prepared to receive GPRS messages at certain times in the day, and a buffer in the platform can be created to store the messages and send them only at those times, since none of the messages sent to the device is critically urgent. If GSM/GPRS is substituted with Sigfox communication, power will be further saved. Also, the power consumption of the MCU and accelerometer in the final product will be smaller than the power consumption of the Arduino in the prototype, since it includes components that are not needed in the design and are consuming power constantly. If the power consumption was reduced to 50mA in average, the 2600mAh cell would last around 2 days. Finally, if these optimizations were not enough, the battery cell could be replaced with another one with more capacity, or more than one cell could be connected in parallel, but it needs to be taken into account that the battery represents an important part of the cost of the device.

To use these devices to protect other equipment that do not have a battery available, the internal battery would need to last longer. It has been estimated that the minimum that would make the device viable in the market would be 3 months. Otherwise, the user would need to recharge the devices too often and he may have the feeling that the product gives him more work than it saves him. To achieve this, more than one cell will be probably needed, and the device will need to cut back some functionalities, like its ability to receive GPRS messages or even the GPS sensor. A good solution in some situations may be to add a small solar panel to charge the battery during the day.

### 9.3. Autoconfiguration

The algorithm implemented generates two values from the arrays of accelerations measured and it compares these values with two threshold values to estimate if the generator is working, is idle, or it is being moved. These threshold values may be different for different generators. For example, if the threshold values are calibrated in a generator that works smoothly, the device may mistakenly detect a robbery in a generator that shakes more. Also, if it is calibrated in a generator that vibrates a lot, it may not detect when a smoother machine is working. Therefore, with the actual algorithm it is recommended to test the device in the generator that is going to be used previously, see the values of  $a_{rms\_max}$  and  $\Delta v_{max}$  that are detected with the generator working, and decide

the threshold values that detect the state the best. This needs to be done by a person that understands how the algorithm works. Having workers hired to move around the countryside doing this task would be costly and inefficient. This task can be easily automatized. It would be possible to have an autoconfiguration mode implemented in the device to set these parameters automatically. In this mode, the device would collect data when the generator is working. Then it would send that data to the cloud, where an algorithm decides the values that classifies the state of the generator optimally. The data obtained by the accelerometer when the generator is being moved or idle does not depend on the type of generator, so it does not need to be sent for every generator.

To start this mode, the user would start the generator with the device mounted, and he would press a button in the device or in the mobile application to start measuring the acceleration.

#### 9.4. Classification algorithm

Following with the discussion on the estimation of the estate of the generator, what was done in this project was to use a classification tree. The space that results of plotting  $a_{rms\_max}$  versus  $\Delta v_{max}$  is divided as shown in Figure 20.

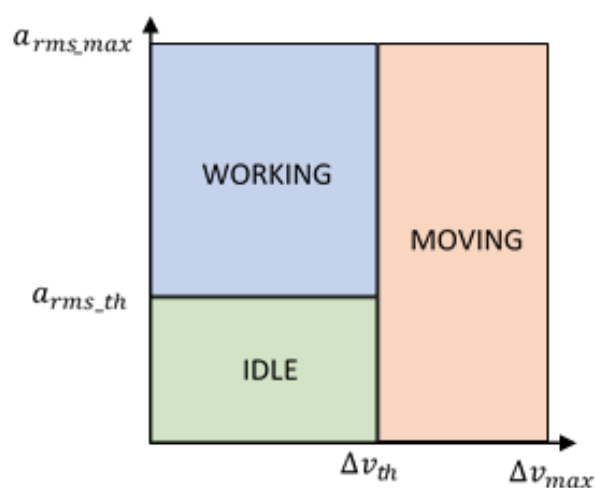


Figure 20. Classification algorithm plot

However, there may be more optimal classification algorithms. It would be insightful to study if this classification tree is better than a Linear Discriminant Analysis algorithm, for example. To decide the optimal classification algorithm, statistic and Big Data analysis can be applied to the data obtained in different types of generators.





## 10. References

- [1] Adaico, "Antirrobo de gasoil con rosca scania," [Online]. Available: <https://www.adaico.com/es/1-15010020.html>.
- [2] Riegos de Duero, S.A., "Antirobber Riegos del Duero," [Online]. Available: <http://www.riegosdelduero.com/idi/antirobber-riegos-del-duero#.XuXyE0UzblU>.
- [3] Traxco, "Sistema Antirrobo," [Online]. Available: <https://www.traxco.es/tienda/sistema-antirrobo>.
- [4] Traxco, "Avisador telefónico GSM," [Online]. Available: <https://www.traxco.es/tienda/avisador-telefonico-gsm>.
- [5] Naria Security, [Online]. Available: <https://www.nariasecurity.it/en/>.
- [6] Sistemas Electrónicos Progrès, [Online]. Available: <https://www.progres.es/>.
- [7] Sistemas Electrónicos Progrès, "Catálogo Agrónic 4000," [Online]. Available: [https://www.progres.es/sites/default/files/public/2221\\_folleto\\_agronic\\_4000.pdf](https://www.progres.es/sites/default/files/public/2221_folleto_agronic_4000.pdf).
- [8] Metos, [Online]. Available: <http://metos.at/es/>.
- [9] Metos, "iMetos Trackers," [Online]. Available: <http://metos.at/es/imetos-trackers/>.
- [10] Swag Off Road, "Security for your \$1,000 portable generator by Swag Off Road :Overland Expo 2015," [Online]. Available: <https://www.youtube.com/watch?v=iv4f9PUejn4>.
- [11] IoT Connect, "Smart Diesel Generator Monitoring Solution," [Online]. Available: <https://www.iotconnect.io/diesel-generator-monitoring.html>.
- [12] L. Blasco, "Cuáles son las diferencias entre E, GPRS, 3G, 4G, 5G y esas otras redes a las que se conecta tu celular," *BBC Mundo*, 05 09 2016.

- [13] K. Mekki, E. Bajic, F. Chaxel and F. Meyer, "A comparative study of LPWAN technologies for large-scale IoT deployment," *ICT Express*, vol. 5, no. 1, pp. 1-7, 2019.
- [14] "ESP32 with LoRa using Arduino IDE – Getting Started," [Online]. Available: <https://randomnerdtutorials.com/esp32-lora-rfm95-transceiver-arduino-ide/>.
- [15] Wikipedia, "LoRa," [Online]. Available: <https://en.wikipedia.org/wiki/LoRa>.
- [16] Madrid Business, "Redexia Nace En España La Primera Red Nacional LoRaWAN Dedicada Al IoT".*madridbusiness*.
- [17] L. LLamas, "Protocolos de comunicación para IoT," [Online]. Available: <https://www.luisllamas.es/protocolos-de-comunicacion-para-iot/>.
- [18] World Wide Web Consortium, "Web of Things at W3C," [Online]. Available: <https://www.w3.org/WoT/>.
- [19] Wikipedia, "Web of Things," [Online]. Available: [https://en.wikipedia.org/wiki/Web\\_of\\_Things](https://en.wikipedia.org/wiki/Web_of_Things).
- [20] Wikipedia, "Dilution of precision," [Online]. Available: [https://en.wikipedia.org/wiki/Dilution\\_of\\_precision\\_\(navigation\)](https://en.wikipedia.org/wiki/Dilution_of_precision_(navigation)).
- [21] Sigfox, "Geolocation technologies," [Online]. Available: <https://build.sigfox.com/geolocation-technologies>.
- [22] LoRa Alliance™ Strategy Committee, "Geolocation whitepaper," 01 2018. [Online]. Available: [https://lora-alliance.org/sites/default/files/2018-04/geolocation\\_whitepaper.pdf](https://lora-alliance.org/sites/default/files/2018-04/geolocation_whitepaper.pdf).
- [23] Battery University, "Comparison Table of Secondary Batteries," [Online]. Available: [https://batteryuniversity.com/learn/article/secondary\\_batteries](https://batteryuniversity.com/learn/article/secondary_batteries).
- [24] Battery University, "How to measure state of charge," [Online]. Available: [https://batteryuniversity.com/learn/article/how\\_to\\_measure\\_state\\_of\\_charge](https://batteryuniversity.com/learn/article/how_to_measure_state_of_charge).

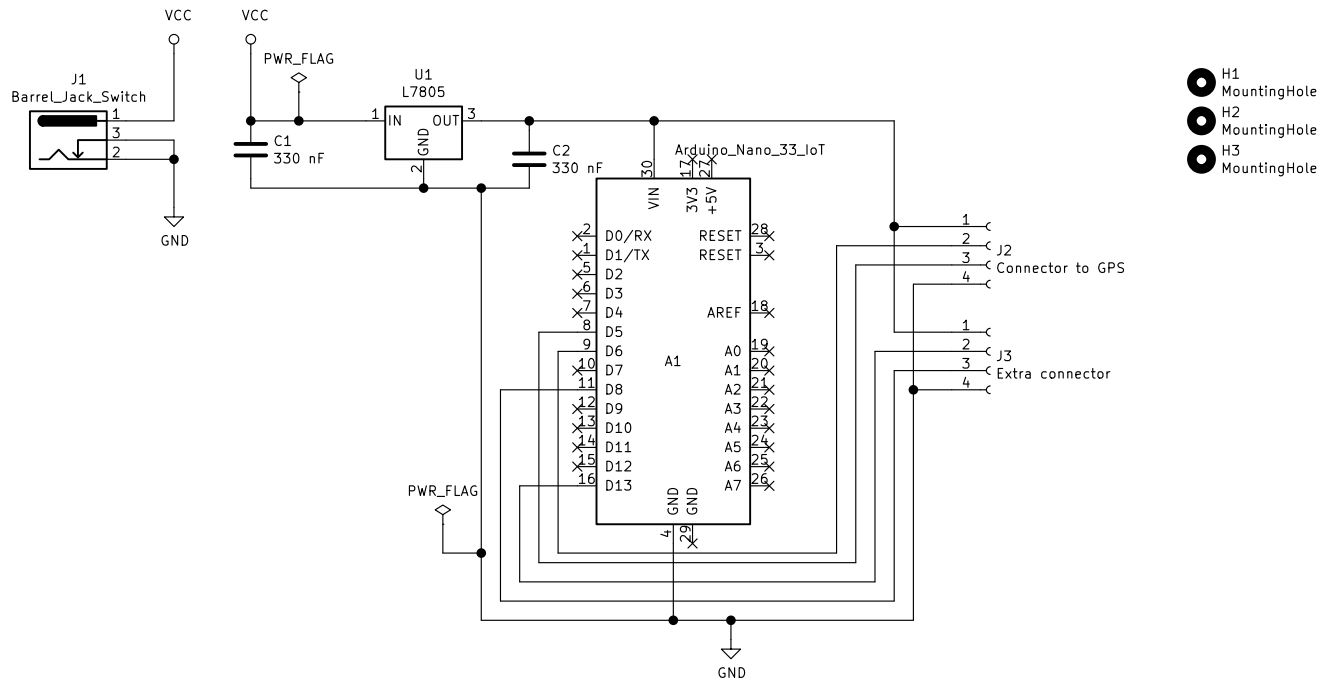
- [25] Panasonic, "NCA593446," June 2016. [Online]. Available: <https://actec.dk/media/documents/F28FE335B681.pdf>.
- [26] Battery University, "Charging batteries at high and low temperatures," [Online]. Available: [https://batteryuniversity.com/learn/article/charging\\_at\\_high\\_and\\_low\\_temperatures](https://batteryuniversity.com/learn/article/charging_at_high_and_low_temperatures).
- [27] Wikipedia, "Arduino," [Online]. Available: <https://en.wikipedia.org/wiki/Arduino>.
- [28] Arduino, "Nano 33 IoT with headers," [Online]. Available: <https://store.arduino.cc/usa/nano-33-iot-with-headers>.
- [29] u-blox, "NEO-6 u-blox 6 GPS Modules datasheet," [Online]. Available: [https://www.u-blox.com/sites/default/files/products/documents/NEO-6\\_DataSheet\\_%28GPS.G6-HW-09005%29.pdf](https://www.u-blox.com/sites/default/files/products/documents/NEO-6_DataSheet_%28GPS.G6-HW-09005%29.pdf).
- [30] Adafruit, "Adafruit Ultimate GPS Breakout," [Online]. Available: [https://www.adafruit.com/product/746?gclid=Cj0KCQiA7aPyBRChARIsAJfWCgKPBsQDQtHTARvKtSjzNTgzjv7jyta68TGTgmm-fxRcjpGWmRWwEdcaApIHEALw\\_wcB](https://www.adafruit.com/product/746?gclid=Cj0KCQiA7aPyBRChARIsAJfWCgKPBsQDQtHTARvKtSjzNTgzjv7jyta68TGTgmm-fxRcjpGWmRWwEdcaApIHEALw_wcB).
- [31] ST Microelectronics, "L78 Datasheet," [Online]. Available: <https://www.st.com/resource/en/datasheet/l78.pdf>.
- [32] Wikipedia, "Moving average," [Online]. Available: [https://en.wikipedia.org/wiki/Moving\\_average](https://en.wikipedia.org/wiki/Moving_average).
- [33] M. Hart, "Arduiniana. TinyGPS++," [Online]. Available: <http://arduiniana.org/libraries/tinygpsplus/>.
- [34] "Arduino Nano 33 IoT - Ultimate Guide," [Online]. Available: <https://github.com/ostaquet/Arduino-Nano-33-IoT-Ultimate-Guide>.
- [35] Sparkfun, "Adding More SERCOM Ports for SAMD Boards," [Online]. Available: <https://learn.sparkfun.com/tutorials/adding-more-sercom-ports-for-samd-boards/all>.

- [36] Ministerio de Agricultura, Alimentación y Medio Ambiente, "Captación y regulación de aguas superficiales y subterráneas y balsas para regadío, diseño, construcción y explotación.," [Online]. Available: [https://www.miteco.gob.es/es/agua/temas/sistema-espaniol-gestion-agua/31captacionyregulaciondeaguassuperficialesysubterraneasybalsasp araregadiodisenonstruccionyexplotacion\\_tcm30-215754.pdf](https://www.miteco.gob.es/es/agua/temas/sistema-espaniol-gestion-agua/31captacionyregulaciondeaguassuperficialesysubterraneasybalsasp araregadiodisenonstruccionyexplotacion_tcm30-215754.pdf).
- [37] El Confidencial, "España cuenta con más de un millón de pozos subterráneos similares al de Totalán," 16 01 2019.
- [38] Things Mobile, [Online]. Available: <https://www.thingsmobile.com/es/business>.
- [39] Texas Instruments, "LM317 3-terminal adjustable regulator," [Online]. Available: <https://www.ti.com/lit/ds/symlink/lm317.pdf>.
- [40] G. Paller, P. Szármes and G. Éló, "Power consumption considerations of GSM-connected sensors in the AgroDat.hu sensor network," *Sensors & Transducers*, vol. 0, no. 0, 2015.
- [41] Last Minute Engineers, "Send Receive SMS & Call with SIM800L GSM Module & Arduino," [Online]. Available: <https://lastminuteengineers.com/sim800l-gsm-module-arduino-tutorial/>.
- [42] AZdelivery, "SIM800L GSM GPRS," [Online]. Available: [https://cdn.shopify.com/s/files/1/1509/1638/products/AZDelivery\\_SIM800L\\_GSM\\_GPRS\\_module\\_with\\_antenna\\_for\\_Arduino\\_1-1\\_500x.jpg?v=1573903801](https://cdn.shopify.com/s/files/1/1509/1638/products/AZDelivery_SIM800L_GSM_GPRS_module_with_antenna_for_Arduino_1-1_500x.jpg?v=1573903801).
- [43] Wikipedia, "Hayes command set," [Online]. Available: [https://en.wikipedia.org/wiki/Hayes\\_command\\_set](https://en.wikipedia.org/wiki/Hayes_command_set).
- [44] SIMCom, "SIM800 Series\_AT Command," [Online]. Available: [https://www.elecrow.com/wiki/images/2/20/SIM800\\_Series\\_AT\\_Command\\_Manual\\_V1.09.pdf](https://www.elecrow.com/wiki/images/2/20/SIM800_Series_AT_Command_Manual_V1.09.pdf).
- [45] Explore Embedded, "Setting up GPRS with SIM800L," [Online]. Available: [https://exploreembedded.com/wiki/Setting\\_up\\_GPRS\\_with\\_SIM800L](https://exploreembedded.com/wiki/Setting_up_GPRS_with_SIM800L).

- [46] P. Mbari, "mqtt\_NEW.ino," [Online]. Available: [https://bitbucket.org/mbari\\_peter/sim800-mqtt-ravi/src/master/mqtt\\_NEW.ino](https://bitbucket.org/mbari_peter/sim800-mqtt-ravi/src/master/mqtt_NEW.ino).
- [47] United Nations, "Suatainable Development Goals," [Online]. Available: <https://sustainabledevelopment.un.org/sdgs>.



## Annex A: Circuit diagram of prototype 1



-  H1 MountingHole
-  H2 MountingHole
-  H3 MountingHole

Senior Design Project – ICAI

**Mario Ayerra Basés**

Sheet: /

File: KICAD files.sch

**Title: Prototype 1 schematic**

Size: A4 Date: 2020-06-16

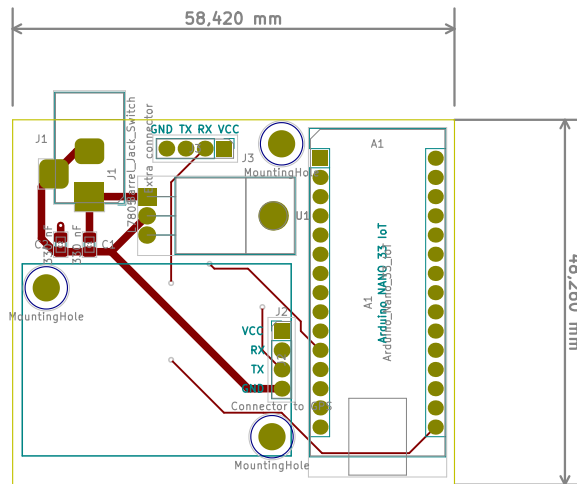
**Rev: 1**

KiCad E.D.A. kicad (2018-02-05 revision 1f487593f)-makepkg

Id: 1/1



## Annex B: PCB plans of prototype 1



Senior design project – ICAI

**Mario Ayerra Basés**

Sheet:

File: KICAD files.kicad\_pcb

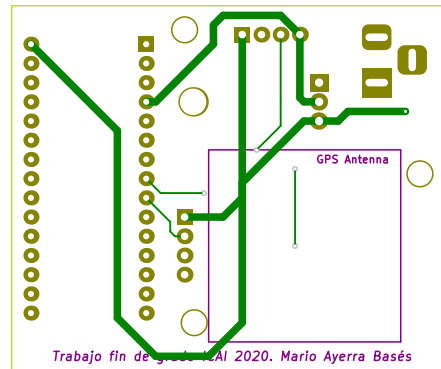
**Title: Prototype 1 front**

Size: A4 Date: 2020-06-16

KiCad E.D.A. kicad (2018-02-05 revision 1f487593f)-makepkg

**Rev: 1**

Id: 1/1



Senior design project – ICAI  
**Mario Ayerra Basés**

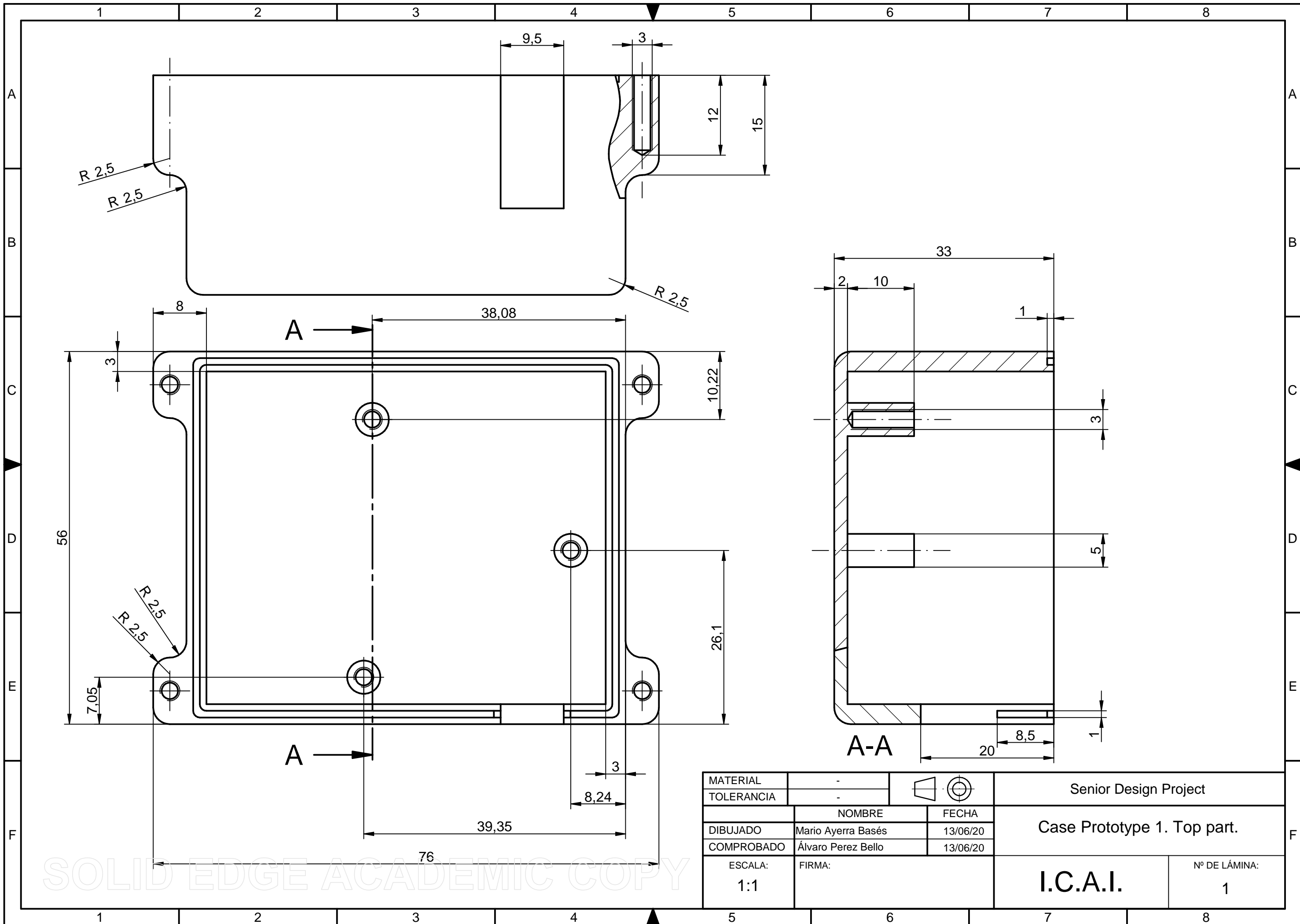
Sheet:  
File: KICAD files.kicad\_pcb

**Title: Prototype 1 back**

Size: A4      Date: 2020-06-16  
KiCad E.D.A. kicad (2018-02-05 revision 1f487593f)-makepkg

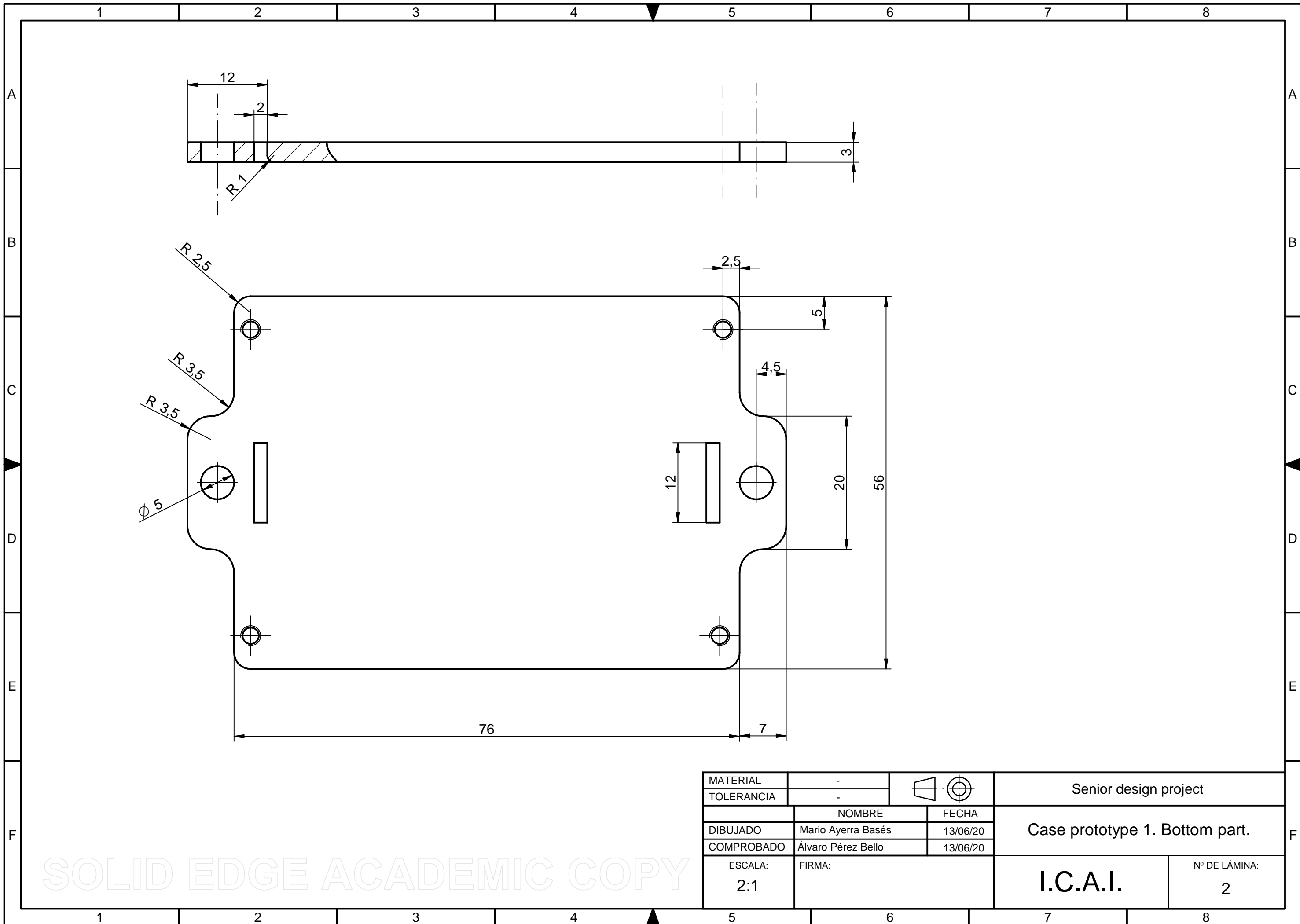
**Rev: 1**  
Id: 1/1

## Annex C: Plans of the case for prototype 1



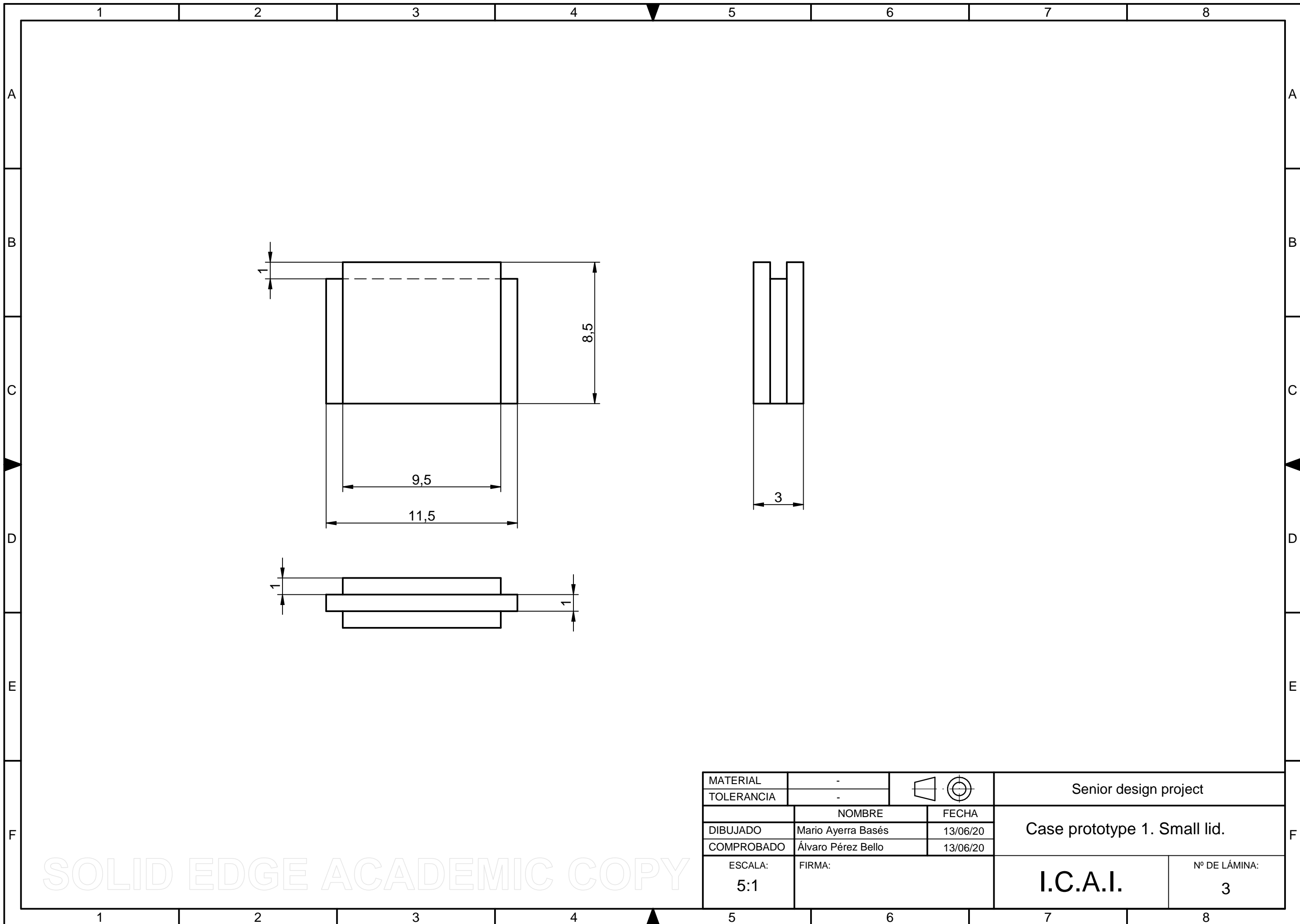
MATERIAL	-		Senior Design Project	
TOLERANCIA	-		Case Prototype 1. Top part.	
DIBUJADO	Mario Ayerra Basés	FECHA	13/06/20	I.C.A.I.
COMPROBADO	Álvaro Perez Bello	FECHA	13/06/20	
ESCALA:	1:1	FIRMA:		1

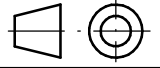
SOLID EDGE ACADEMIC COPY



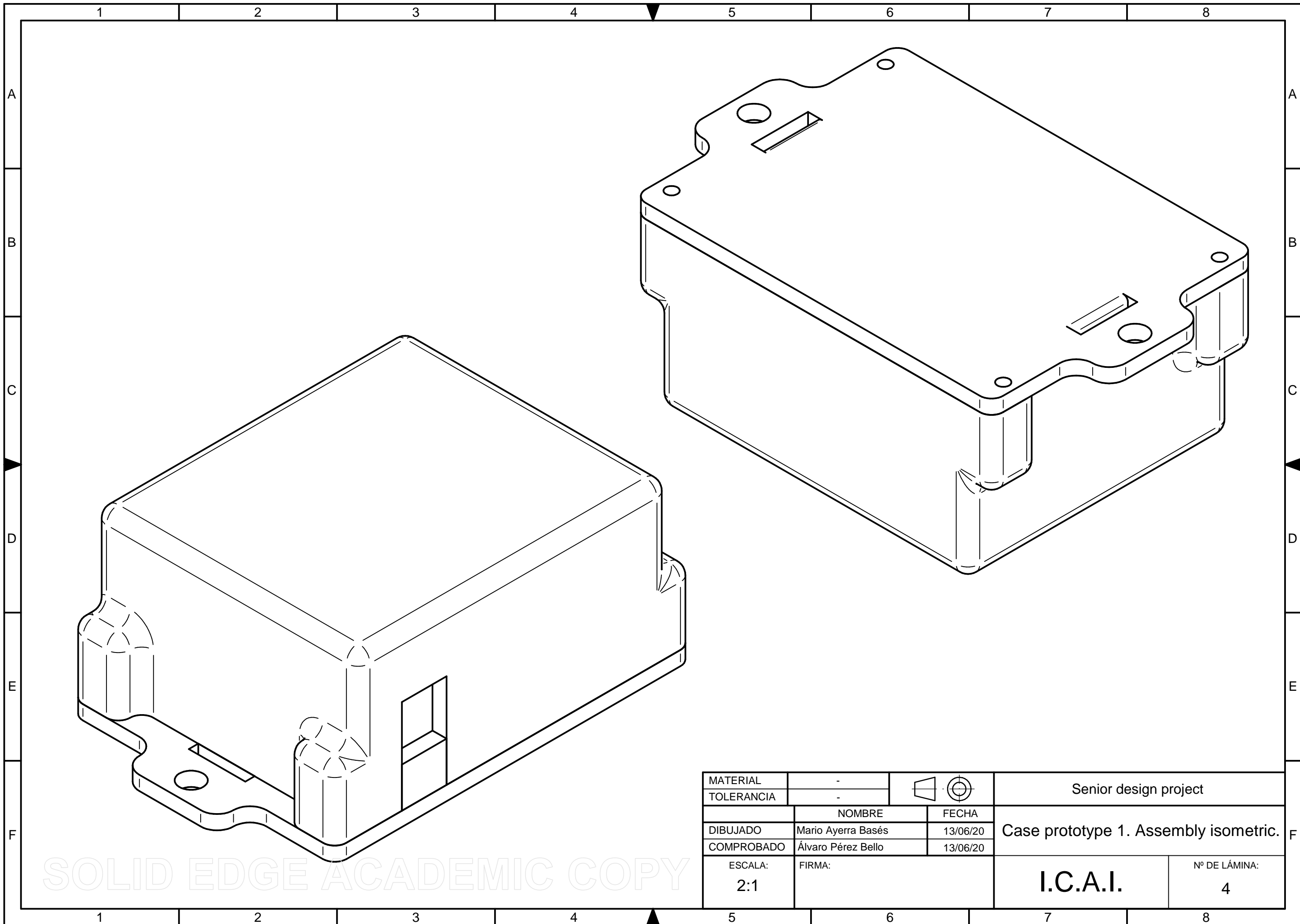
MATERIAL	-		Senior design project	
TOLERANCIA	-		Case prototype 1. Bottom part.	
	NOMBRE	FECHA	<b>I.C.A.I.</b>	
DIBUJADO	Mario Ayerra Basés	13/06/20		
COMPROBADO	Álvaro Pérez Bello	13/06/20		
ESCALA:	FIRMA:		Nº DE LÁMINA:	
2:1			2	

SOLID EDGE ACADEMIC COPY



MATERIAL	-		Senior design project	
TOLERANCIA	-		Case prototype 1. Small lid.	
	NOMBRE	FECHA	I.C.A.I.	
DIBUJADO	Mario Ayerra Basés	13/06/20		
COMPROBADO	Álvaro Pérez Bello	13/06/20	Nº DE LÁMINA:	
ESCALA:	FIRMA:		3	
5:1				

SOLID EDGE ACADEMIC COPY



SOLID EDGE ACADEMIC COPY

MATERIAL	-		Senior design project	
TOLERANCIA	-		Case prototype 1. Assembly isometric.	
	NOMBRE	FECHA		
DIBUJADO	Mario Ayerra Basés	13/06/20		
COMPROBADO	Álvaro Pérez Bello	13/06/20		
ESCALA:	FIRMA:		I.C.A.I.	Nº DE LÁMINA:
2:1				4



## Annex D: Arduino code prototype 1

In this Annex, the code implemented in the Arduino is shown. The code was divided in 4 files. The main one is Prototype.ino, and the other three ( accelerometer.cpp, wifi.cpp and gps.cpp) perform different tasks. Three extra files were created to include the headers of the code files, and another one to keep the all the passwords in the same file.

### prototype.ino

```
#include "accelerometer.h"
#include "gps.h"
#include "wifi.h"

#define MSG_FREQ 720000 // Time between messages in normal conditions
#define MSG_FREQ_ALARM 60000 // Time between messages in Alarm state
#define ACC_FREQ 100 // Time between estimation of the state of
the generator

unsigned long lastMsg = 0;
unsigned long lastAcc = 0;

enum FSM_state {Off_state, On_state, Alarm_state};
FSM_state current_state = Off_state;

void setup() {
  Serial.begin(9600);
  wifi_mqtt_init();
  mqtt_reconnect();
  gps_init();
  acc_init();
}

void loop() {
  int state;
  String gps_json_string;
  String json_string;
  char json_char[200];
  boolean state_change = 0;

  if((millis() - lastAcc) > ACC_FREQ){ //Wait for ACC_FREQ milliseconds
since the last state was estimated
    lastAcc = millis();
    state = estimate_state();

    if(current_state == Off_state){
      if(state == 2){ // MOVING
        current_state = Alarm_state;
        state_change = 1;
      }else if(state == 1){ // WORKING
        current_state = On_state;
        state_change = 1;
      }
    }else if(current_state == On_state){
      if(state == 0){ // IDLE
        current_state = Off_state;
      }
    }
  }
}
```

```
        state_change = 1;
    }else if(state == 2){
        current_state = Alarm_state;
        state_change = 1;
    }
}else if(current_state == Alarm_state){
    if(state == 0){
        current_state = Off_state;
        state_change = 1;
    }else if(state == 1){
        current_state = On_state;
        state_change = 1;
    }
}
}

// Generate a new JSON message
gps_json_string = read_gps();

String closing = "}";
String comma = ",";
String FSM_st = "\"FSM state\": ";
json_string = gps_json_string +
                FSM_st + String(current_state) + closing;

json_string.toCharArray(json_char, 200);

//Decide if a new message should be sent
if (((millis() - lastMsg) > MSG_FREQ) || state_change ||
((current_state == Alarm_state) && ((millis() - lastMsg) >
MSG_FREQ_ALARM))){
    lastMsg = millis();
    wifi_mqtt_send(json_char);
    Serial.println("New message sent:");
    Serial.println(json_string);
}
}
```

## accelerometer.cpp

```

#include <Arduino_LSM6DS3.h>

#define N_DATA 120          // Number of data to store per estimation
#define N_AVE 20            // Number of data to compute the moving average
#define N_MOD 100          // N_MOD = N_DATA - N_AVE
#define DELTA_V_LIMIT 0.5  // Threshold for delta_v
#define A_RMS_LIMIT 0.02   // Threshold for a_rms
#define N_PREVIOUS_STATES 3 // Number of previous states considered when
                             // filtering the estimation

// Check these input values at compilation time
#if (N_MOD != N_DATA - N_AVE || N_MOD <= 0)
#error "Error. N_MOD must be positive and equal to (N_DATA - N_AVE)"
#endif

int previous_states[N_PREVIOUS_STATES]; // Array used to filter the
state estimations
int next_state_pos; // Index in the array

//-----
// Calculates the summation from the element 'start' (included) to the
element ('start' + 'n')(not included) of the array 'numbers[]'
float summation(float numbers[], int n, int start){
    int i;
    float sum;
    sum = 0;

    for(i=start; i<(start + n); i++){
        sum += numbers[i];
    }
    return sum;
}

//-----
// Calculates the average from the element 'start' (included) to the
element ('start' + 'n')(not included) of the array 'numbers[]'
float average(float numbers[], int n, int start){
    float sum;
    float average;
    sum = summation(numbers, n, start);
    average = sum/n;
    return average;
}

//-----
// Calculate the rms value of an array ('numbers[]') with length 'n',
or the rms value of the first 'n' elements of 'numbers[]'
float rms(float numbers[], int n){
    int i;
    float current;
    float rms;
    float sum;
    sum = 0;

    for(i=0; i<n; i++){
        current = numbers[i]*numbers[i];
        sum += current;
    }
    rms = sqrt(sum/n);
}

```

```

    return rms;
}

//-----
// Initializes the IMU and the global variables
void acc_init(){
    int i;

    if (!IMU.begin()) {
        Serial.println("Failed to initialize IMU!");
        while (1);
    }
    Serial.print("Accelerometer sample rate = ");
    Serial.print(IMU.accelerationSampleRate());
    Serial.println(" Hz");

    // Initialize array to zero
    for(i=0; i<N_PREVIOUS_STATES; i++){
        previous_states[i] = 0;    // Initialize all to 0 (=Idle)
    }
    next_state_pos = 0;
}

//-----
// Measure the acceleration, treat the data and return the estimated
// current state of the generator
int estimate_state(){
    float x, y, z;
    unsigned long start_time;
    float acc_x[N_DATA], acc_y[N_DATA], acc_z[N_DATA];
    float acc_x_ave, acc_y_ave, acc_z_ave;
    float acc_x_mod[N_MOD], acc_y_mod[N_MOD], acc_z_mod[N_MOD];
    float a_rms_x, a_rms_y, a_rms_z, a_rms_max;
    float delta_v_x, delta_v_y, delta_v_z, delta_v_max;
    int i;
    int n;
    int state;
    int state_filtered;

    n = 0;

    // Record the accelerations in a vector:
    while(n < N_DATA){
        if (IMU.accelerationAvailable()) {
            IMU.readAcceleration(x, y, z);

            acc_x[n] = x;
            acc_y[n] = y;
            acc_z[n] = z;

            n++;
        }
    }

    //Modify the vectors by subtracting the average of the N_AVE previous
    //measurements (moving average):
    for(i=0; i<N_MOD; i++){
        acc_x_ave = average(acc_x, N_AVE, i);
        acc_x_mod[i] = acc_x[i+N_AVE] - acc_x_ave;
        acc_y_ave = average(acc_y, N_AVE, i);
        acc_y_mod[i] = acc_y[i+N_AVE] - acc_y_ave;
    }
}

```

```

    acc_z_ave = average(acc_z, N_AVE, i);
    acc_z_mod[i] = acc_z[i+N_AVE] - acc_z_ave;
}

//Compute delta_v and a_rms:
delta_v_x = abs(summation(acc_x_mod, N_MOD, 0));
delta_v_y = abs(summation(acc_y_mod, N_MOD, 0));
delta_v_z = abs(summation(acc_z_mod, N_MOD, 0));
delta_v_max = max(delta_v_x, delta_v_y);
delta_v_max = max(delta_v_max, delta_v_z);

a_rms_x = abs(rms(acc_x_mod, N_MOD));
a_rms_y = abs(rms(acc_y_mod, N_MOD));
a_rms_z = abs(rms(acc_z_mod, N_MOD));
a_rms_max = max(a_rms_x, a_rms_y);
a_rms_max = max(a_rms_max, a_rms_z);

// Estimate the state
if(delta_v_max > DELTA_V_LIMIT){
    state = 2; //Moving
}else if(a_rms_max > A_RMS_LIMIT){
    state = 1; //Working
}else{
    state = 0; //Idle
}

//Filter the estimation
previous_states[next_state_pos] = state;
if(state == 1){
    state_filtered = 1;
    for(i=0; i<N_PREVIOUS_STATES; i++){
        if(previous_states[i] != 1){
            state_filtered = 0; //Say that the generator is idle during the
transitions
        }
    }
}else{
    state_filtered = state; // 0 (Idle) or 2 (Moving)
}

next_state_pos = (next_state_pos + 1) % N_PREVIOUS_STATES;

Serial.print("a_rms_max = ");
Serial.print(a_rms_max);
Serial.print("  delta_v_max = ");
Serial.print(delta_v_max);
Serial.print("  State: ");
if(state == 0){
    Serial.print("IDLE");
}else if(state == 1){
    Serial.print("WORKING");
}else if(state == 2){
    Serial.print("MOVING");
}
Serial.print("  State filtered: ");
if(state_filtered == 0){
    Serial.println("IDLE");
}else if(state_filtered == 1){
    Serial.println("WORKING");
}else if(state_filtered == 2){
    Serial.println("MOVING");
}

```

```
    }  
    return state_filtered;  
}
```

## gps.cpp

```

#include <TinyGPS++.h>
#include <Arduino.h>
#include "wiring_private.h"

// Configure serial port to the GPS
Uart gpsSerial (&sercom0, 5, 6, SERCOM_RX_PAD_1, UART_TX_PAD_0);

// Attach the interrupt handler to the SERCOM
void SERCOM0_Handler() {
    gpsSerial.IrqHandler();
}

TinyGPSPlus gps;

//-----
void gps_init(){
    pinPeripheral(5, PIO_SERCOM_ALT);
    pinPeripheral(6, PIO_SERCOM_ALT);

    gpsSerial.begin(9600);
}

//-----
String read_gps(){
    while(gpsSerial.available() > 0){
        gps.encode(gpsSerial.read());
    }
    String GPS_latitude = String(gps.location.lat(), 6);
    String GPS_longitude = String(gps.location.lng(), 6);
    String GPS_altitude = String(gps.altitude.meters(), 1);
    String GPS_HDOP = String(gps.hdop.value());
    String opening = "{";
    //String closing = "}";
    String comma = ",";
    String latit = "\"latitude\": ";
    String longit = "\"longitude\": ";
    String altit = "\"altitude\": ";
    String HDOP = "\"HDOP\": ";
    String gps_json_string = opening +
        latit + GPS_latitude + comma +
        longit + GPS_longitude + comma +
        altit + GPS_altitude + comma +
        HDOP + GPS_HDOP + comma;
    return gps_json_string;
}

```

## wifi.cpp

```

#include <SPI.h>
#include <WiFiNINA.h>
#include <PubSubClient.h>
#include "credentials.h"

char pubTopic[] = "data/585"; // CHANGE THIS

const char* ssid = networkSSID;
const char* password = networkPASSWORD;
const char* mqttServer = mqttSERVER;
const char* mqttUsername = mqttUSERNAME;
const char* mqttPassword = mqttPASSWORD;

int status = WL_IDLE_STATUS;
WiFiClient wifiClient;
PubSubClient client(wifiClient);

//-----
void callback(char* topic, byte* payload, unsigned int length){
  Serial.print("Message arrived [");
  Serial.print(topic);
  Serial.print("] ");
  for (int i = 0; i < length; i++){
    Serial.print((char)payload[i]);
  }
  Serial.println();
}

//-----
void mqtt_reconnect()
{
  // Loop until we're reconnected
  while (!client.connected())
  {
    Serial.print("Attempting MQTT connection...");
    if (client.connect("mario_ayerra::585", mqttUsername,
mqttPassword)) //CHANGE THE CLIENT ID
    {
      Serial.println("connected");
      // ... and resubscribe
      //client.subscribe(subTopic);
    } else
    {
      Serial.print("failed, rc=");
      Serial.print(client.state());
      Serial.println(" try again in 5 seconds");
      // Wait 5 seconds before retrying
      delay(5000);
    }
  }
}

//-----
void wifi_mqtt_init(){
  while (status != WL_CONNECTED){
    Serial.print("Attempting to connect to SSID: ");
    Serial.println(ssid);
    // Connect to WPA/WPA2 network. Change this line if using open or
    WEP network:

```



```
    status = WiFi.begin(ssid, password);

    // wait 10 seconds for connection:
    delay(10000);
}
Serial.println("");
Serial.println("WiFi connected");
Serial.println("IP address: ");
Serial.println(WiFi.localIP());

client.setServer(mqttServer, 1883);
client.setCallback(callback);
}

//-----
void wifi_mqtt_send(char sentence[200]) {
    if (!client.connected()) {
        mqtt_reconnect();
    }
    client.loop();
    client.publish(pubTopic, sentence);
}
```

## accelerometer.h

```
int estimate_state();  
void acc_init();
```

## gps.h

```
void gps_init();  
String read_gps();
```

## wifi.h

```
void wifi_mqtt_init();  
void wifi_mqtt_send(char sentence[200]);  
void mqtt_reconnect();
```

## credentials.h

```
char networkSSID[] = "";  
char networkPASSWORD[] = "";  
  
char mqttSERVER[] = "mqtt.dev.altairsc.com";  
char mqttUSERNAME[] = "";  
char mqttPASSWORD[] = "";
```

## Annex E : Specs of the Arduino NANO 33 IoT

<b>Microcontroller</b>	SAMD21 Cortex® 32bit low power ARM MCU
<b>Radio module</b>	u-blox NINA-W102
<b>Secure element</b>	ATECC608A
<b>Operating voltage</b>	3.3V
<b>Input voltage (limit)</b>	21V
<b>DC Current per I/O pin</b>	7 mA
<b>Clock speed</b>	48 MHz
<b>CPU Flash memory</b>	256 kB
<b>SRAM</b>	32 kB
<b>EEPROM</b>	none
<b>Digital I/O pins</b>	14
<b>PWM Pins</b>	11
<b>UART</b>	1
<b>SPI</b>	1
<b>I2C</b>	1
<b>Analog Input Pins</b>	8 (ADC 8/10/12 bits)
<b>Analog Output Pins</b>	1 (DAC 10 bits)
<b>External Interrupts</b>	All digital pins
<b>LED_BUILTIN</b>	13
<b>USB</b>	Native in the SAMD21 processor
<b>IMU</b>	LSM6DS3
<b>Dimensions</b>	45 mm x 18 mm
<b>Weight</b>	5 grams



## Annex F: MATLAB code for algorithm testing

This Annex shows the MATLAB code used to test the algorithm and see the effect of changing different parameters on the output of the algorithm (`delta_v_max` and `a_rms_max`). The code also creates some graphs that can be found at the end of the Annex.

```

%% Simulation of the algorithms to estimate the state of the generator
% Author: Mario Ayerra
% Date created: 16/03/2020
% Last modified: 27/05/2020

%% Generation of the signals
% ----- %
% Input parameters
f_motor = 0.05;      % turning frequency of the motor [kHz]
f_sampling = 0.104; % sampling frequency [kHz]
vibr_amp = 0.04;    % amplitude of the vibrations [G]
t_span = 800;      % time duration of the simulation [ms]
noise_mag = 0.4;   % magnitude of the noise compared to vibr_amp
                  % (standard normally distributed noise)
working = 1;       % 0 or 1
% ----- %

% Time vector, with a value every 0.1 milliseconds:
t = linspace(0, t_span, 10*t_span+1); % t in milliseconds

% Vector with the sampling times:
t_sample = round(linspace(0, floor(t_span*f_sampling)/f_sampling,
floor(t_span*f_sampling)+1),1);

% Assuming that the accelerometer is placed with the x axis in the
vertical
% (gravity) direction:
acc_x_idle = ones(1, 10*t_span+1); % Accelerations in G (1G = 9.8 m/s^2)
acc_y_idle = zeros(1, 10*t_span+1);
acc_z_idle = zeros(1, 10*t_span+1);

% Assuming that the vibrations in the three axis three sinusoidal waves
with
% a phase shift of 120 degrees:
acc_x_working = acc_x_idle + working*vibr_amp*sin(2*pi*f_motor*t);
acc_y_working = acc_y_idle + working*vibr_amp*sin(2*pi*f_motor*t +
2*pi/3);
acc_z_working = acc_z_idle + working*vibr_amp*sin(2*pi*f_motor*t -
2*pi/3);

% Generate graph 1: Real signal vs. sampled signal
% Plot of the original signal
figure();
subplot(1,2,1);
plot(t, [acc_x_working; acc_y_working; acc_z_working]);
title("Ideal signals");
xlabel("Array position");

```

```

ylabel("Acceleration [G]");

% Discrete sample captured by the accelerometer:
acc_samp_x = acc_x_working(10*t_sample+1);
acc_samp_y = acc_y_working(10*t_sample+1);
acc_samp_z = acc_z_working(10*t_sample+1);

% Plot of the discrete sampled signal:
subplot(1,2,2);
plot(t_sample, [acc_samp_x; acc_samp_y; acc_samp_z], '-x');
title("Sampled signals without noise");
xlabel("Array position");
ylabel("Acceleration [G]");

Ns = length(acc_samp_x); % Number of elements in the sample

acc_samp_x_noise = acc_samp_x + noise_mag*vibr_amp*randn(1,Ns);
acc_samp_y_noise = acc_samp_y + noise_mag*vibr_amp*randn(1,Ns);
acc_samp_z_noise = acc_samp_z + noise_mag*vibr_amp*randn(1,Ns);

% Generate graph 2: Sampled signals with and without noise.
figure();
subplot(1,2,1);
plot(t_sample, [acc_samp_x; acc_samp_y; acc_samp_z], '-x');
title("Sampled signals without noise");
xlabel("Array position");
ylabel("Acceleration [G]");

subplot(1,2,2);
plot(t_sample, [acc_samp_x_noise; acc_samp_y_noise; acc_samp_z_noise],
'-x');
title("Sampled signals with noise");
xlabel("Array position");
ylabel("Acceleration [G]");

% Generate graph 3: Real signal vs. sampled signal with noise.
figure();
subplot(1,2,1);
plot(t, [acc_x_working; acc_y_working; acc_z_working]);
title("Ideal signals");
xlabel("Array position");
ylabel("Acceleration [G]");

subplot(1,2,2);
plot(t_sample, [acc_samp_x_noise; acc_samp_y_noise; acc_samp_z_noise],
'-x');
title("Sampled signals with noise");
xlabel("Array position");
ylabel("Acceleration [G]");

%% Test of the algorithm
% 1- Create new signals with the average of the last 'N_ave' samples
%   substracted:
%   a) For each element of the array, substract the average of the
%       elements that correspond to the previous 'N_ave' elements
%   b) Delete the first 'N_ave' elements of the array.
% 2- Calculate delta_v from this signals
% 3- Calculate a_rms from this signals
% 4- Estimate the state of the generator from delta_v and a_rms

```

```

% ----- %
% Parameters of the algorithm:
% t_ave = 50; % Amount of time used to compute the moving average [ms]
N_ave = 20; % Number of elements used to compute the moving average

% ----- %
% if(t_ave > t_span)
%     display('Error, the time used to compute the average needs to be
% bigger than the total time of the simulation');
% end

if(N_ave > Ns)
    disp('Error, the number of elements used to compute the average
needs to be smaller than the total number of elements in the vector');
end

% % Ns = length(acc_samp_x); % Number of elements in the sample
% Ns_mod = floor(Ns*(t_span - t_ave)/t_span); % Number of elements in
the modified vectors
% N_ave = Ns - Ns_mod; % Number of elements to compute the pseudo-
instantaneous average

Ns_mod = Ns - N_ave;

acc_x_mod = zeros(1, Ns_mod); % Initialize the modified vectors
acc_y_mod = zeros(1, Ns_mod);
acc_z_mod = zeros(1, Ns_mod);

for i = 1:Ns_mod
    acc_x_ave = sum(acc_samp_x_noise(i:(i+N_ave-1)))/N_ave;
    acc_x_mod(i) = acc_samp_x_noise(i+N_ave) - acc_x_ave;

    acc_y_ave = sum(acc_samp_y_noise(i:(i+N_ave-1)))/N_ave;
    acc_y_mod(i) = acc_samp_y_noise(i+N_ave) - acc_y_ave;

    acc_z_ave = sum(acc_samp_z_noise(i:(i+N_ave-1)))/N_ave;
    acc_z_mod(i) = acc_samp_z_noise(i+N_ave) - acc_z_ave;
end

delta_v_x = sum(acc_x_mod)/(f_sampling*1000); % [G/s]
delta_v_y = sum(acc_y_mod)/(f_sampling*1000); % [G/s]
delta_v_z = sum(acc_z_mod)/(f_sampling*1000); % [G/s]
delta_v_max = max([delta_v_x, delta_v_y, delta_v_z]);

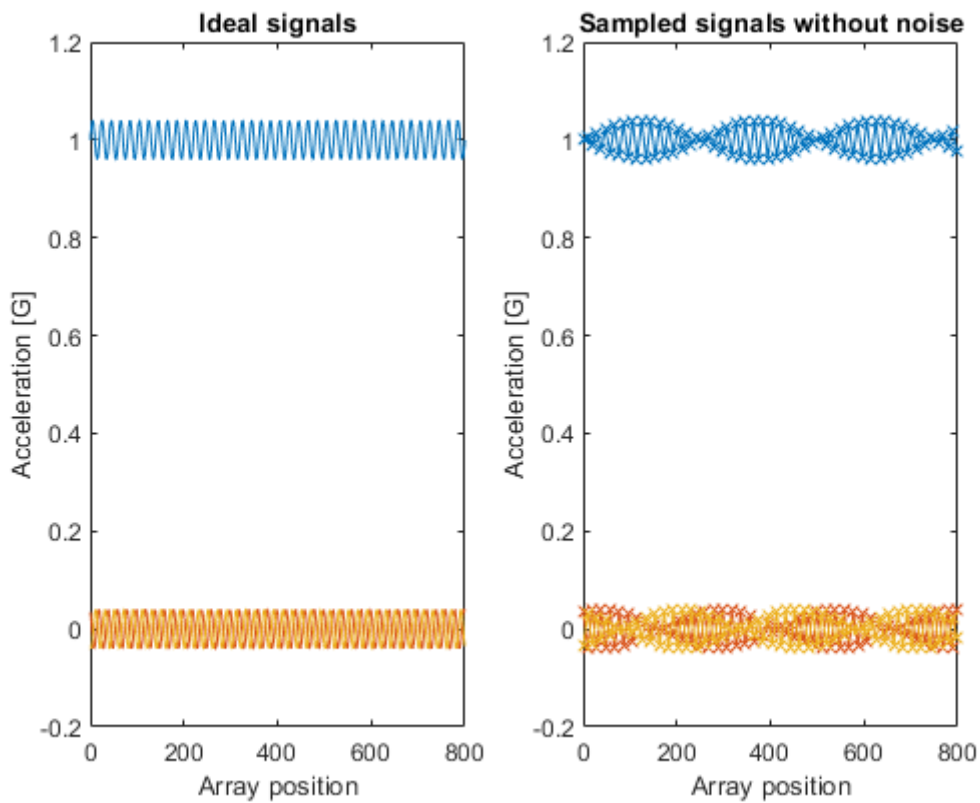
a_rms_x = sqrt(sum(acc_x_mod.^2)/Ns_mod);
a_rms_y = sqrt(sum(acc_y_mod.^2)/Ns_mod);
a_rms_z = sqrt(sum(acc_z_mod.^2)/Ns_mod);
a_rms_max = max([a_rms_x, a_rms_y, a_rms_z]);

% Generate graph 4: Filtered signals (after applying the moving average
filter).
figure();
plot(t_sample(N_ave:Ns-1), [acc_x_mod; acc_y_mod; acc_z_mod]);
title("Filtered signals");
xlabel("Array position");
ylabel("Filtered acceleration[G]");

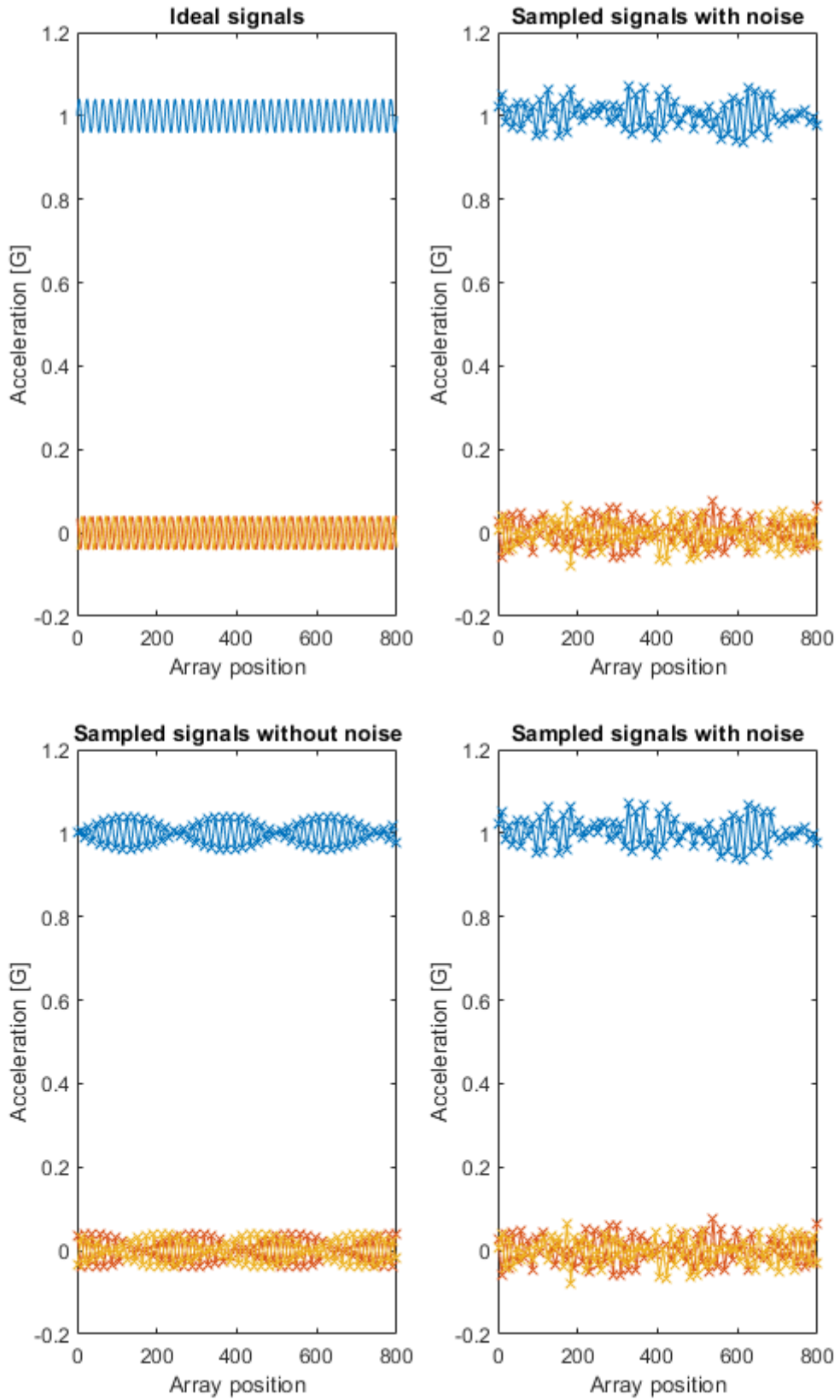
% Print the results of delta_v maximum and a_rms maximum.
fprintf('\nResults:\ndelta_v_max = %d, a_rms_max = %d\n', delta_v_max,
a_rms_max);

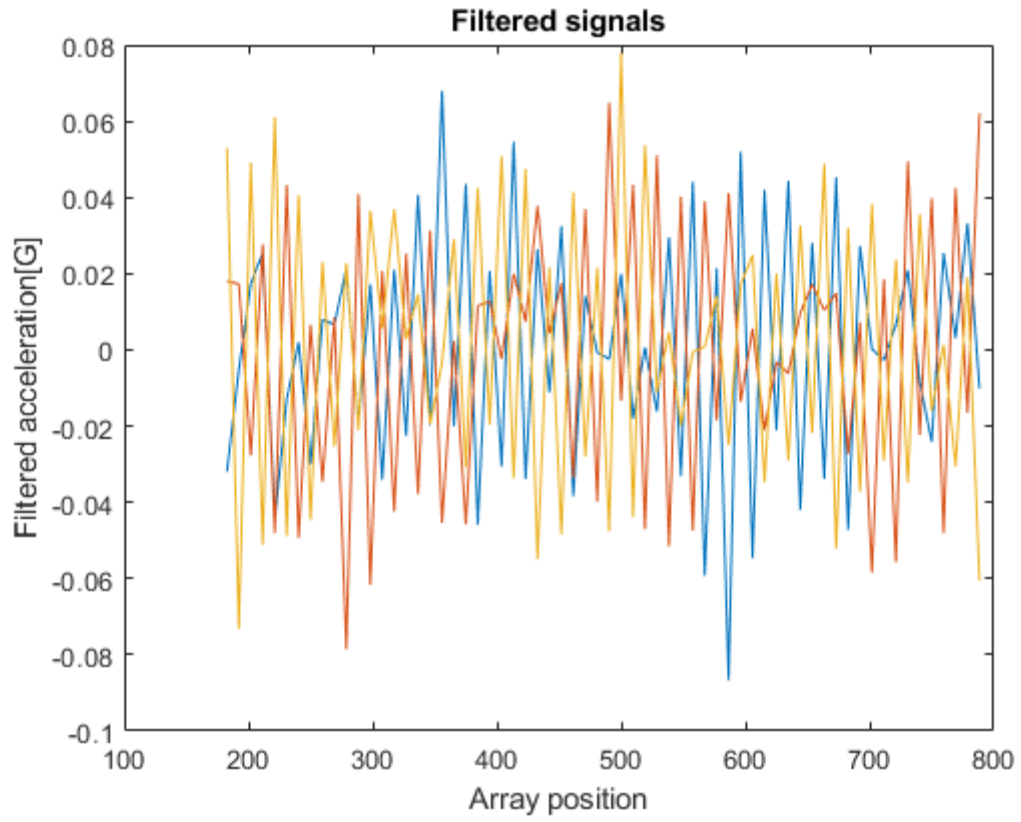
```

```
% Results with the following input parameters:  
% f_motor = 0.05;  
% f_sampling = 0.104;  
% vibr_amp = 0.02;  
% t_span = 600;  
% noise_mag = 0.4;  
% t_ave = 50;  
%  
% Results of four different simulations idle (WORKING = 0):  
% delta_v_max = [4.52e-5, 2.93e-5, 4.08e-4, 1.84e-6];  
% a_rms_max = [9.30e-3, 8.34e-3, 1.03e-2, 8.56e-3];  
%  
% Results of four different simulations working (WORKING = 1):  
% delta_v_max = [4.18e-4, 1.95e-4, 1.76e-4, 3.87e-4];  
% a_rms_max = [1.71e-2, 1.77e-2, 1.61e-2, 1.79e-2];
```

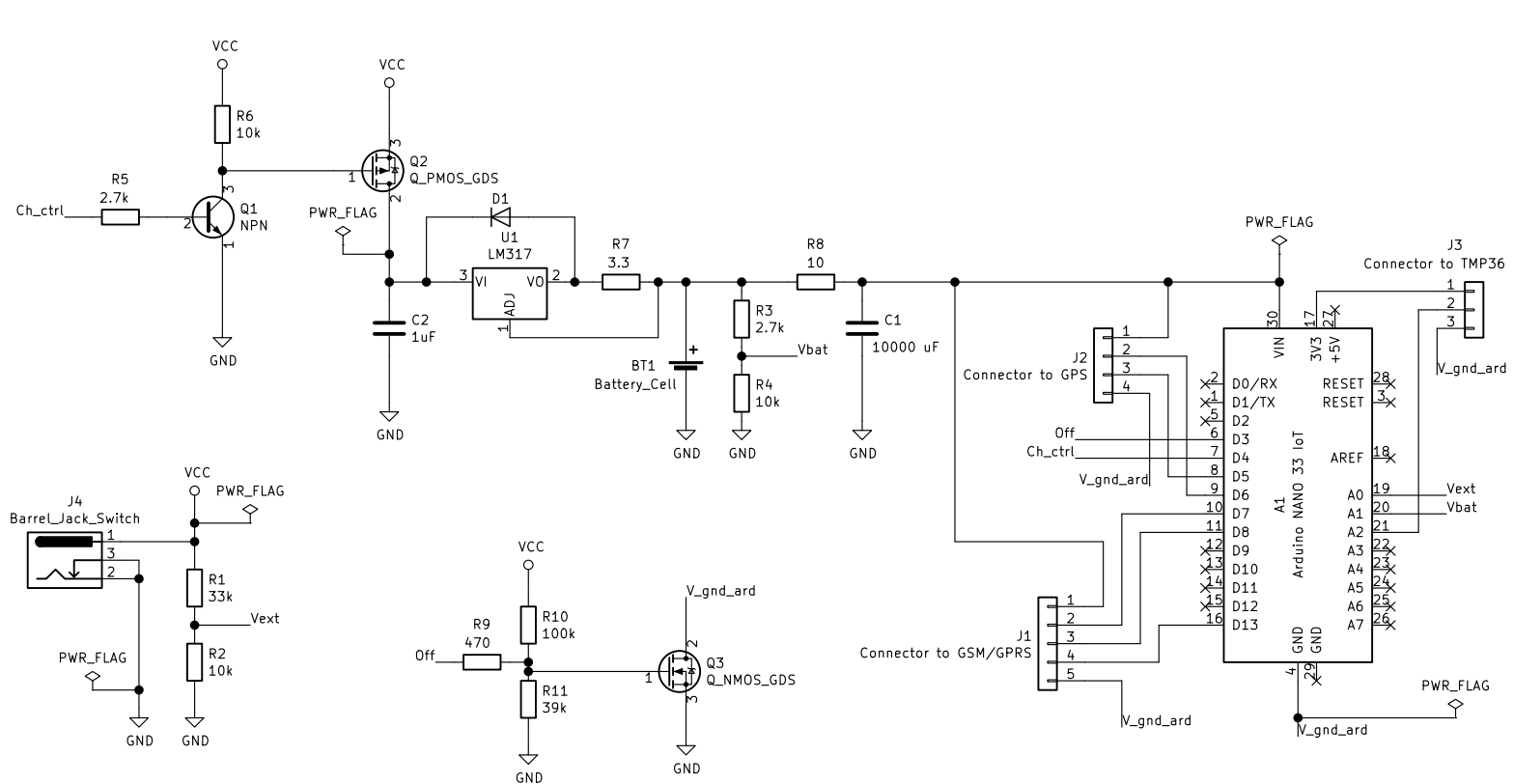








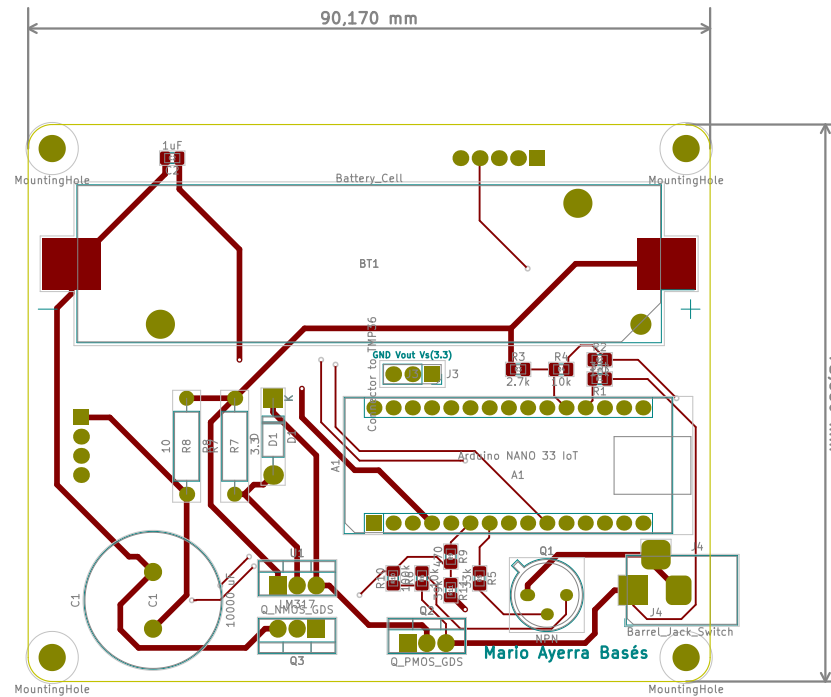
## Annex G: Circuit diagram prototype 2



-  H1 MountingHole
-  H2 MountingHole
-  H3 MountingHole
-  H4 MountingHole

Senior design project – ICAI	
<b>Mario Ayerra Basés</b>	
Sheet: /	
File: KiCAD prototype 2.sch	
<b>Title: Prototype 2 schematic</b>	
Size: A4	Date: 2020-06-16
KiCad E.D.A. kicad (2018-02-05 revision 1f487593f)-makepkg	Rev: 1
	Id: 1/1

## Annex H: PCB plans of prototype 2



Senior design project – ICAI

**Mario Ayerra Basés**

Sheet:

File: KiCAD prototype 2.kicad\_pcb

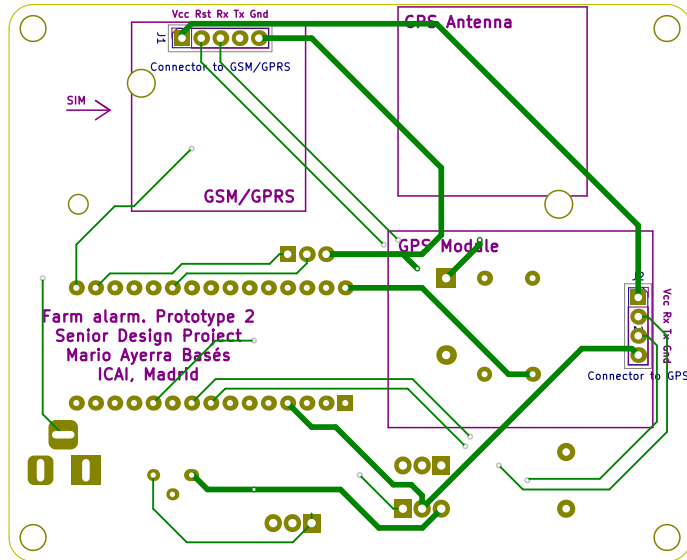
**Title: Prototype 2 back**

Size: A4 Date: 2020-06-16

KiCad E.D.A. kicad (2018-02-05 revision 1f487593f)-makepkg

**Rev: 1**

Id: 1/1



Senior design project – ICAI

**Mario Ayerra Basés**

Sheet:

File: KICAD prototype 2.kicad\_pcb

**Title: Prototype 2 back**

Size: A4

Date: 2020-06-16

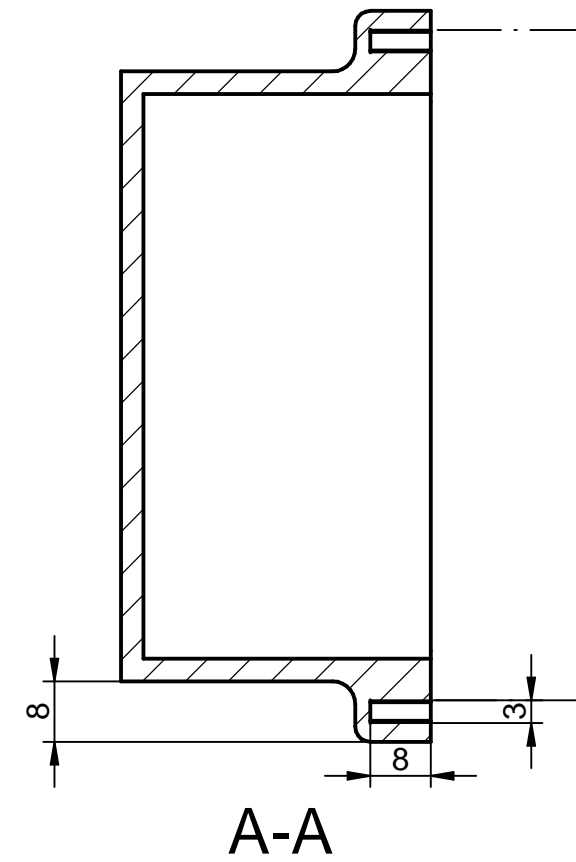
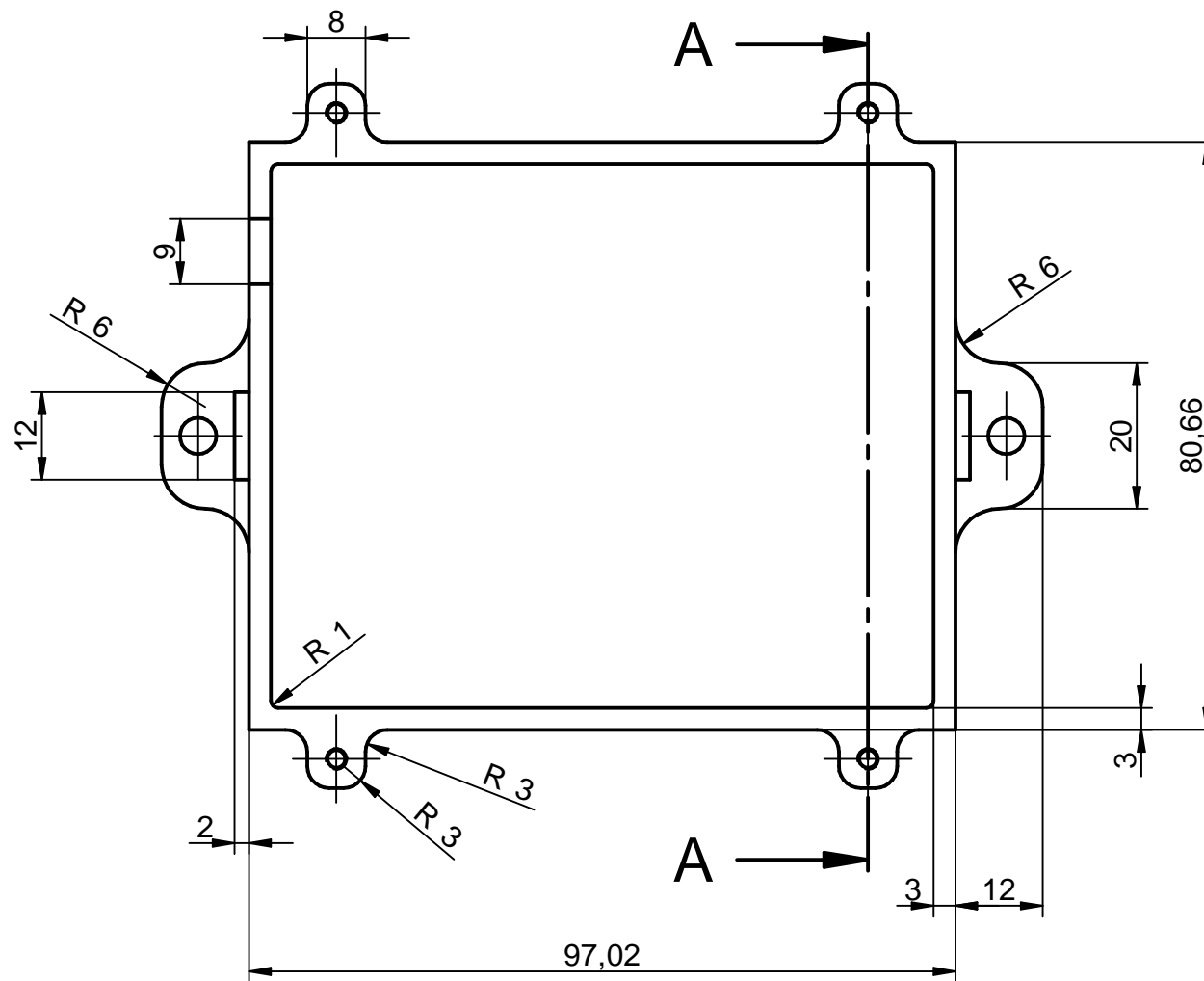
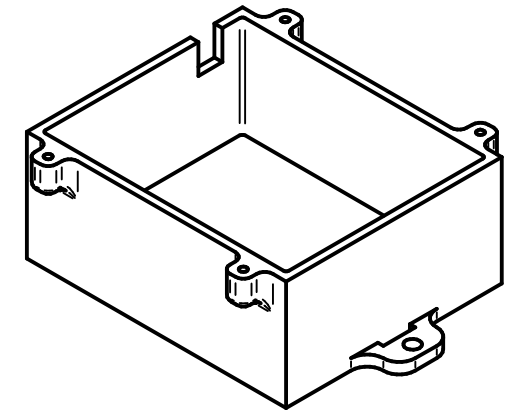
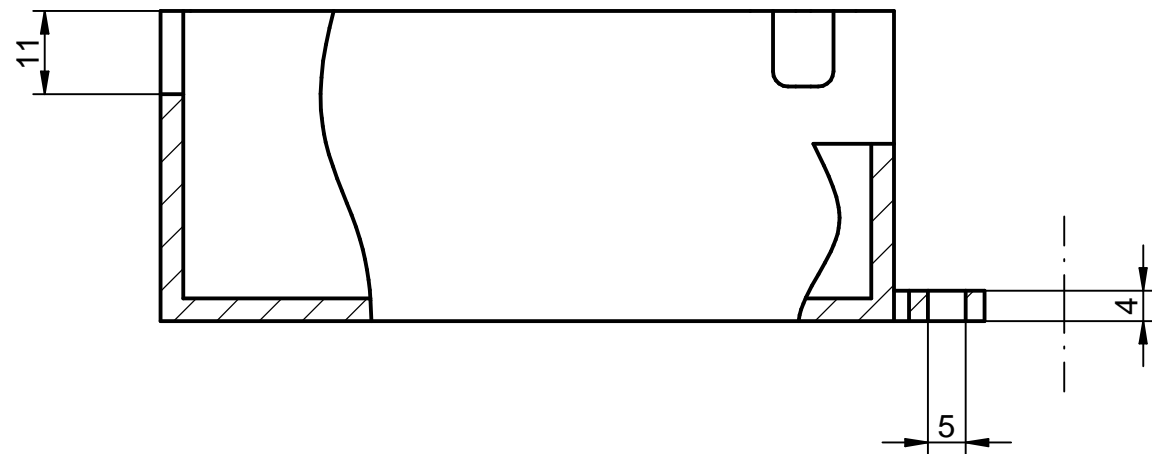
**Rev: 1**

KiCad E.D.A. kicad (2018-02-05 revision 1f487593f)-makepkg

Id: 1/1

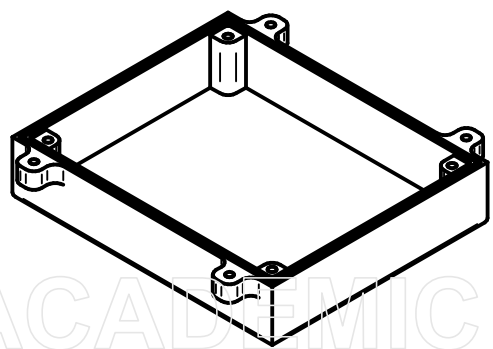
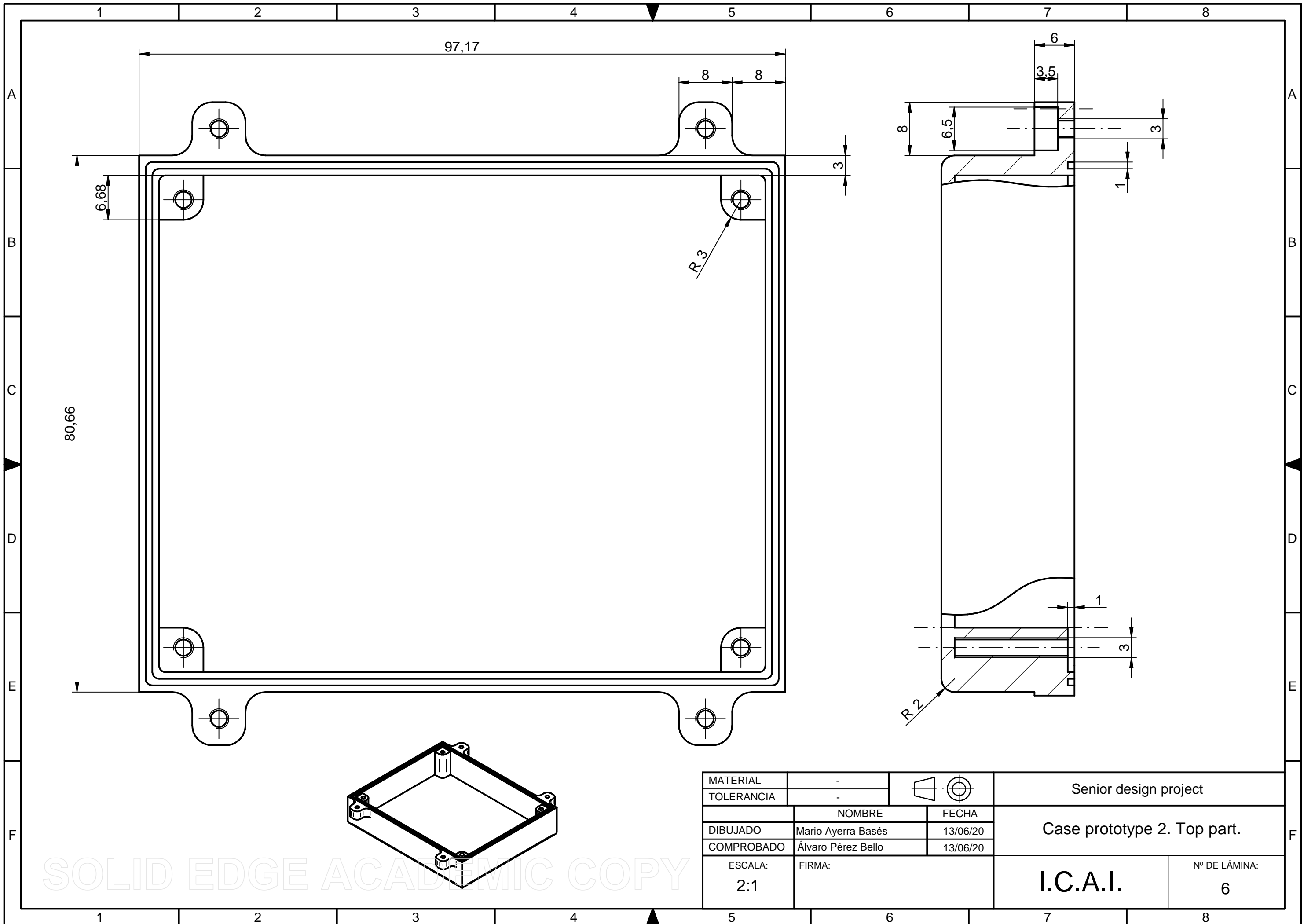
## Annex I: Plans of the case for prototype 2





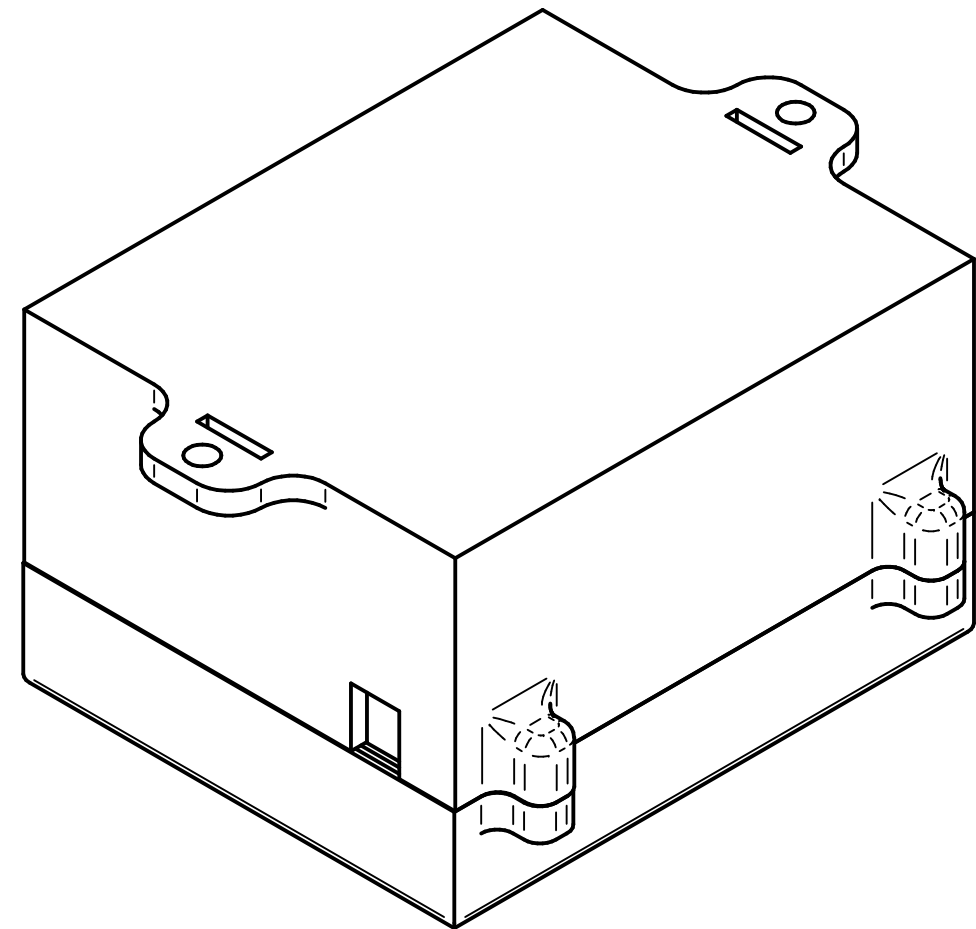
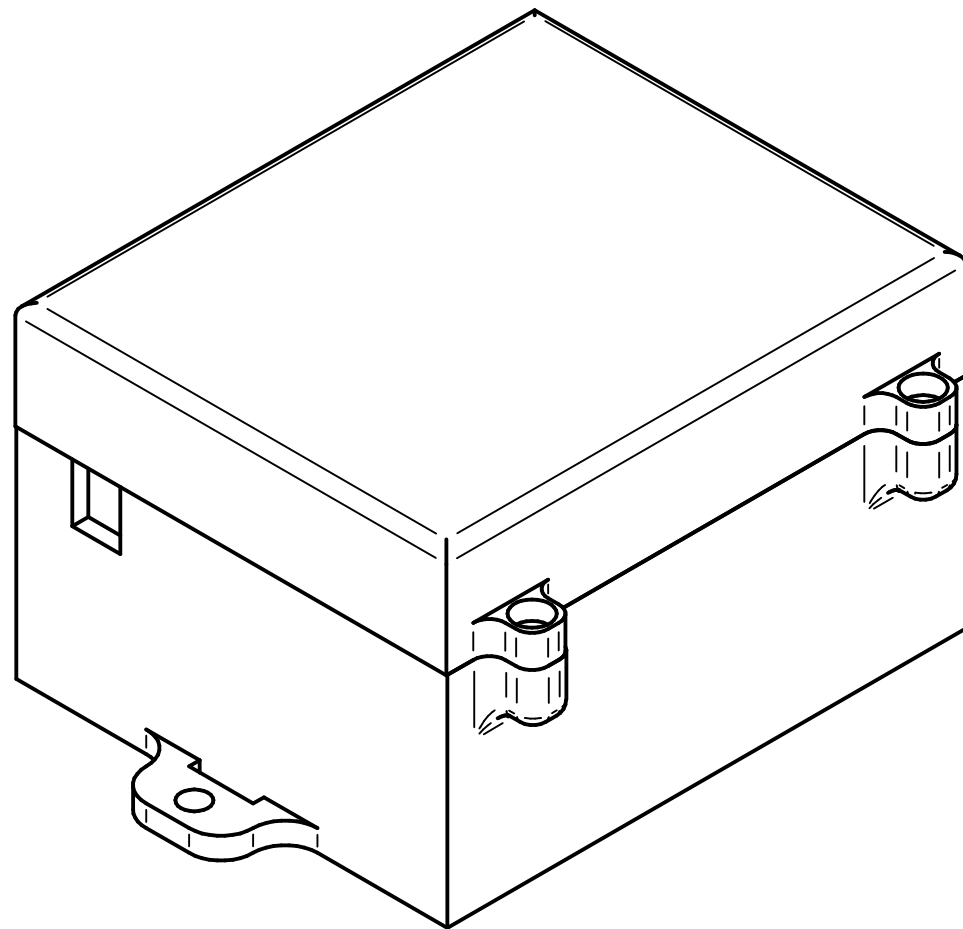
MATERIAL	-		Senior design project	
TOLERANCIA	-		Case prototype 2. Bottom part.	
	NOMBRE	FECHA		
DIBUJADO	Mario Ayerra Basés	9/06/20		
COMPROBADO	Álvaro Pérez Bello	9/06/20		
ESCALA:	FIRMA:			Nº DE LÁMINA:
1:1				5

SOLID EDGE ACADEMIC COPY



MATERIAL	-		Senior design project	
TOLERANCIA	-		Case prototype 2. Top part.	
	NOMBRE	FECHA	I.C.A.I.	
DIBUJADO	Mario Ayerra Basés	13/06/20		
COMPROBADO	Álvaro Pérez Bello	13/06/20	Nº DE LÁMINA: 6	
ESCALA: 2:1	FIRMA:			

SOLID EDGE ACADEMIC COPY



MATERIAL	-		Senior design project	
TOLERANCIA	-		Case Prototype 2. Assembly isometric.	
	NOMBRE	FECHA	I.C.A.I.	
DIBUJADO	Mario Ayerra Basés	13/06/20		
COMPROBADO	Álvaro Pérez Bello	13/06/20	Nº DE LÁMINA:	
ESCALA:	FIRMA:		7	
1:1				

SOLID EDGE ACADEMIC COPY

## Annex J: List of electronic components used in prototype 2

Components used in the PCB	Quantity	Unitary price (€)	Total price (€)
Arduino NANO 33 IoT	1	18	18
Battery cell Li-ion 2600mAh 18650	1	7.9	7.9
SMD 18650 keystone battery holder	1	2.76	2.76
10000uF electrolytic capacitor 6.3V THT (D18, H35.5)	1	2.1	2.1
1uF ceramic capacitor SMD 0805	1	0.022	0.022
THT diode 1N4007	1	0.05	0.05
NEO-6M Ublox GPS module (GY-GPS6MV2)	1	9.99	9.99
GSM/GPRS SIM800L module	1	8.99	8.99
TMP36GT9Z temperature sensor	1	2.05	2.05
2.54 mm pin socket 40 positions	2	0.95	1.9
DC jack connector female THT horizontal	1	0.4	0.4
LM317T linear voltage regulator THT TO-220	1	0.4	0.4
NPN transistor (2N2222)	1	0.75	0.75
PMOS GDS THT TO-220 (IRFZ44)	1	0.75	0.75
NMOS Logic Level THT TO-220 (IRL3705N)	1	1.55	1.55
Resistor 33kΩ SMD 0805	1	0.016	0.016
Resistor 10kΩ SMD 0805	3	0.016	0.048
Resistor 2.7kΩ SMD 0805	2	0.016	0.032
Resistor 470Ω SMD 0805	1	0.016	0.016
Resistor 39kΩ SMD 0805	1	0.016	0.016
Resistor 100kΩ SMD 0805	1	0.016	0.016
Resistor 3.3Ω THT	1	0.03	0.03
Resistor 10Ω THT	1	0.03	0.03
			<b>TOTAL</b>
			57.82



## Annex K: JSON 'thing' structure

```

-----PROPERTIES-----
{
  "latitude": {
    "links": [
      {
        "href":
"/things/123/properties/latitude"
      }
    ],
    "maximum": 90,
    "minimum": -90,
    "title": "Latitude",
    "type": "number"
  },
  "longitude": {
    "links": [
      {
        "href":
"/things/123/properties/longitude"
      }
    ],
    "maximum": 90,
    "minimum": -90,
    "title": "Longitude",
    "type": "number"
  },
  "HDOP": {
    "links": [
      {
        "href": "/things/123/properties/HDOP"
      }
    ],
    "maximum": 1000,
    "minimum": 0,
    "title": "HDOP",
    "type": "number"
  },
  "moving": {
    "links": [
      {
        "href": "/things/123/properties/moving"
      }
    ],
    "title": "Moving",
    "type": "boolean"
  },
  "working": {
    "links": [
      {
        "href": "/things/123/properties/working"
      }
    ],
    "title": "Working",
    "type": "boolean"
  }
}

```

```

-----ACTIONS-----
{
  "disconnect": {
    "title": "Disconnect",
    "description": "Turn off the device completely",
    "input": {
      "type": "object",
      "properties": {
        "securitykey": {
          "type": "integer",
          "minimum": 0,
          "maximum": 9999
        }
      }
    },
    "links": [{"href": "/things/123/actions/disconnect"}]
  },
  "stand_by_on": {
    "title": "Stand-by on",
    "description": "Set the device in stand by mode",
    "links": [{"href": "/things/123/actions/standby"}]
  },
  "stand_by_off": {
    "title": "Stand-by off",
    "description": "Set the device into full functionality",
    "links": [{"href": "/things/123/actions/standby"}]
  }
}

-----EVENTS-----
{
  "start_working": {
    "description": "The generator has started to work",
    "links": [{"href": "/things/123/events/start_working"}]
  },
  "start_moving": {
    "description": "The generator has been moved",
    "links": [{"href": "/things/123/events/start_moving"}]
  },
  "stop_working": {
    "description": "The generator has stopped working",
    "links": [{"href": "/things/123/events/stop_working"}]
  },
  "stop_moving": {
    "description": "The generator has stopped being moved",
    "links": [{"href": "/things/123/events/stop_moving"}]
  },
  "on": {
    "description": "The device has been turned on",
    "links": [{"href": "/things/123/events/on"}]
  },
  "off": {
    "description": "The device has been turned off",
    "input": {
      "type": "object",
      "properties": {
        "mode": {
          "type": "integer",
          "minimum": 0,
          "maximum": 5
        }
      }
    }
  }
}

```

```

        }
    },
    "links": [{"href": "/things/123/events/off_manually"}]
},
"off_battery": {
    "description": "The device has been turned off due to low
battety level or high battery temperature",
    "links": [{"href": "/things/123/events/off_battery"}]
},
"gps_working": {
    "description": "The GPS sensor has started to receive
signal",
    "links": [{"href": "/things/123/events/gps_working"}]
},
"gps_not_working": {
    "description": "The GPS sensor has stopped receiving
signal",
    "links": [{"href":
"/things/123/events/gps_not_working"}]
},
"power_lost": {
    "description": "The external battery is not supplying the
device anymore",
    "links": [{"href": "/things/123/events/power_lost"}]
},
"power_retrieved": {
    "description": "The external battery has started to
supply the device",
    "links": [{"href":
"/things/123/events/power_retrieved"}]
}
}

```





## Annex L: Alignment of the project with the Sustainable Development Goals



Figure 21. United Nations Sustainable Development Goals.

The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. At its heart are the 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all countries [47].

It is interesting to study how this project aligns with these objectives. One of the capabilities of the product designed is to help the farmers prevent thefts of their equipment. This promotes peace and justice, in line with goal number 16. Also, the devices designed monitor the diesel generators and collect data that allow the farmers to increase the production in their fields, save water and save money. The savings of water prevent water sources from being depleted, which would negatively affect the food supply and drinkable-water supply. Also, the increase in production is helpful to increase the food supply and help reduce the food scarcity in the world. Therefore, this project is also aligned with goals number 2 and 6.

The money savings and security that the farmers could obtain from using this product supports the primary sector that is necessary to have a developed and sustainable society. A primary sector that produces food efficiently is beneficial

for the whole society since it will be cheaper to satisfy their primary needs and less people will starve or depend on charity. This product promotes the innovation and the technology development in the countryside, allowing the farmers to produce higher quality food too. A primary sector that produces high-quality food is also beneficial for the whole society, that will be healthier and happier. The consequences mentioned along this paragraph are in line with goals number 2, 3, 8, 9 and 12.

Finally, in Spain one of the biggest social problems that exist currently is the depopulation of the rural areas. An efficient distribution of the population across the territory would reduce some of the problem of the actual society, like the extreme poverty and hunger present in some neighborhoods of the biggest cities, the excessive land disturbance in those areas, the waste of resources to transport food and supplies from the countryside to the cities, the lack of forest maintenance with the wildfire risk that this involves, etc. The product designed in this project would help to create the necessary conditions for the population to go back to rural areas, so it will help to achieve goals number 1, 10, 11 or 15.

In short, this project may help, directly or indirectly to achieve at least 11 of the 17 Sustainable Development Goals of the United Nations.