PROYECTO I+D+i

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Título del proyecto

Sistema remoto de inspección de torres eléctricas y telecomunicaciones basado en una plataforma IoT

Acrónimo

IOTOWER

Contenido del proyecto

Las técnicas de evaluación de la salud estructural abordan el problema de la identificación de daños a través de cambios observados en los parámetros medidos o estimados con respecto al sistema monitoreado. Se pueden clasificar como métodos de detección locales y globales. Los métodos se basan en los cambios medidos en la respuesta vibratoria espacio-temporal inducida en las estructuras. La respuesta a la vibración depende de las propiedades físicas de una estructura (masa, amortiguación y rigidez) que pueden verse alteradas cuando surge un daño. Estos cambios pueden servir como un indicador de la aparición temprana de daños para la evaluación estructural. En las últimas décadas, se han realizado una cantidad considerable de contribuciones en el campo de los métodos de END (ensayos no destructivos) basados en la vibración.
Estos métodos se pueden clasificar según:

- El nivel de identificación pretendido,
- Basados en modelos finitos, o experimentales
- La correlación del dominio utilizado, según 3 categorías de dominio
  - Respuesta espacio-Temporal
  - Respuesta espectral-Espacial
  - En las formas de deflexión operacional

En cuanto al alcance, la identificación del daño se puede abordar como un proceso de 4 pasos: identificar la existencia de daño, determinar su ubicación geométrica, evaluar la gravedad de los daños y predecir la vida útil restante de la estructura.
En general, la bibliografía revisada revela numerosos enfoques, métodos y esquemas, y demuestra claramente que no existe un acuerdo generalizado sobre el método óptimo para realizar el diagnóstico.

Objetivos principales

Desarrollo de un nuevo Sistema basado en una plataforma IoT (Internet of Things) para evaluar de manera autónoma, remota y en tiempo real, la integridad de torres eléctricas y de telecomunicaciones a partir de su comportamiento vibratorio.

Fases del proyecto

I. Gestión y Coordinación del Proyecto
II. Evaluación de la seguridad estructural mediante la correlación del patrón espectral de vibración
III. Diseño de un sistema basado en la plataforma IoT para la evaluación autónoma de la integridad estructural.
IV. Validación del sistema en una torre de telecomunicaciones.

Resultados y conclusiones

Se han conseguido monitorizar varias torres de forma remota, pudiendo así observar correlaciones entre varios factores ambientales y la salud estructural de las mismas. Se ha observado que hay un cambio detectable en la inclinación de las torres y se ha podido correlacionar tanto con los vientos como con la temperatura. Los resultados se han podido consultar en un portal que permitía fácil acceso a los datos. Pese a que el proyecto requiere ser pulido y alimentado con más datos, sobre todo respecto a posibles daños, se ha alcanzado un estadio en el que no falta mucho para su viabilidad comercial.

IO TOWER – Digitalización torres de comunicación y eléctricas

E3 Metodología final de medición

Proyecto	IOTOWER	**Código de proyecto**	COMRDI15-1-0036
Entregable	E3	**Fecha**	Marzo 2021
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Contenido

1 Introducción

El objetivo principal de este documento es detallar qué algoritmos y procedimientos se siguen durante la adquisición y el procesamiento de los datos adquiridos por el prototipo hasta su envío. Dentro de estos algoritmos se pueden encontrar tres tipos básicos: los de adquisición de datos del sensor a una placa Arduino, que pueden incluir una parte de procesado para prepararlos para ser enviados a una Raspberry Pi; los de recepción dentro de la Raspberry Pi, que se encargan de recoger los datos enviados desde los Arduinos para poder ser procesados; y los de procesado de datos, que se encargan de preparar los datos para ser enviados externamente.

Los tres tipos de algoritmos anteriormente citados se replican en dos grupos de sensores: los acelerómetros y los sensores de clima, incluyendo anemómetro, veleta y sensor de temperatura. Cada caso tiene, obviamente, particularidades que serán exploradas y explicadas con el detalle necesario a lo largo del documento presente.

2 Captura de datos de aceleración

La captura de los datos de aceleración viene determinada por la configuración del acelerómetro en si mismo y por la cantidad de medidas de aceleración que se hagan. Poniendo la frecuencia de muestreo del acelerómetro a 200Hz y recogiendo 2000 medidas se consigue llegar a los 100Hz en como frecuencia máxima del espectro medido con una resolución frecuencial de 0.5Hz. Gran parte del código necesario para la adquisición de datos está relacionado con la calidad de los datos: asegurar que el tiempo de muestreo sea de 5ms como máximo y que se graben al menos 2000 mediciones de aceleración. Esos datos son los que luego se usan para el cálculo de ángulo de inclinación de la torre y de los picos de los espectros vibracionales.

2.1 Código de Arduino

El código de Arduino está próximamente relacionado con la adquisición de datos del acelerómetro directamente. Utiliza la biblioteca JY901 desarrollada por el fabricante del acelerómetro para, a partir de una interfaz serial, obtener los datos del acelerómetro y enviarlos a la Raspberry Pi. En este código es importante que el baudrate sea de 115200 (y que el acelerómetro esté configurado a ese mismo baudrate), para poder garantizar que los datos se envían a suficiente velocidad dentro del ratio de muestreo previamente mencionado. Del mismo modo, a ese baudrate no es recomendable enviar los datos en cadenas de texto de más de 17 caracteres, o la Raspberry Pi se vuelve incapaz de gestionar la recepción de datos.

2.2 Recepción de datos

Durante la recepción de datos, la Raspberry Pi se dedica a escuchar la comunicación serial del Arduino, recogiendo 2000 muestras y midiendo el tiempo que hay entre muestra y muestra. Si la media de esos tiempos no es muy cercana a 5ms entonces vuelve a empezar la medición de nuevo, hasta que la frecuencia de muestreo está por encima de 200Hz. Cuando se tiene un vector con valores de aceleración en las tres direcciones en las que mide el acelerómetro.

2.3 Procesado de datos

Lo primero que se hace con los datos es aplicar una transformación espacial de rotación sobre las medidas de aceleración. La primera vez que el dispositivo mide después de su instalación se crea un vector de calibración que contiene la información de cuanto tiene que girar el sistema de referencia (en radianes) para que la aceleración media se corresponda con la aceleración de la gravedad en uno de los ejes. Estos ángulos son los que se usan para girar el vector en cada medición. Una vez girado, se le resta el valor de la gravedad del eje alineado con la gravedad para dejar solo las medidas relacionadas con la vibración centradas en 0. A lo largo de estos datos de procesado se asegura, por supuesto, que las unidades de la medición estén en sistema internacional.

2.3.1 Cálculo de los ángulos

Una vez se dispone de un vector con la medida de aceleración en las tres direcciones del espacio girado según los ángulos de calibración, y antes de restar el valor de la gravedad, se vuelve a calcular el ángulo que se tendría que hacer que el vector de aceleración medio tendría que hacer para que la aceleración de la gravedad quedase contenida dentro del eje vertical. En definitiva esos deberían ser dos ángulos de euler solamente: uno para el giro en x y otro para el giro en z, si se asume que el eje y es el eje vertical (es decir: aproximadamente perpendicular al plano tangente con la superficie terrestre en ese punto). El giro en y se considera negligible. Esos giros son los giros que se pueden observar en la estructura. Si estos ángulos son considerables, entonces constituyen un claro indicador de que un daño ha ocurrido.

2.3.2 Cálculo de los picos

Para detectar los picos y si se mueven o no, se aplica una transformada de Fourier sobre cada una de las señales de aceleración de cada eje. La señal obtenida es una señal con considerable ruido, por lo que un algoritmo de búsqueda de picos sin un cierto calibrado es poco efectivo. Es por eso que se han estimado valores de significancia y distancia entre picos que se han considerado razonables, pero cuando se hayan obtenido suficientes espectros reales estos valores deben recalibrarse.

Una vez los datos han sido procesados de las formas mencionadas, están listos para ser enviados. Los algoritmos de procesado incluyen sendas maneras de asegurarse de que la calidad de los datos es la adecuada, retomando las medidas si es necesario. Pese a todo ello, el nivel de excitación de la estructura es clave en lo que a la calidad de la medida se refiere.

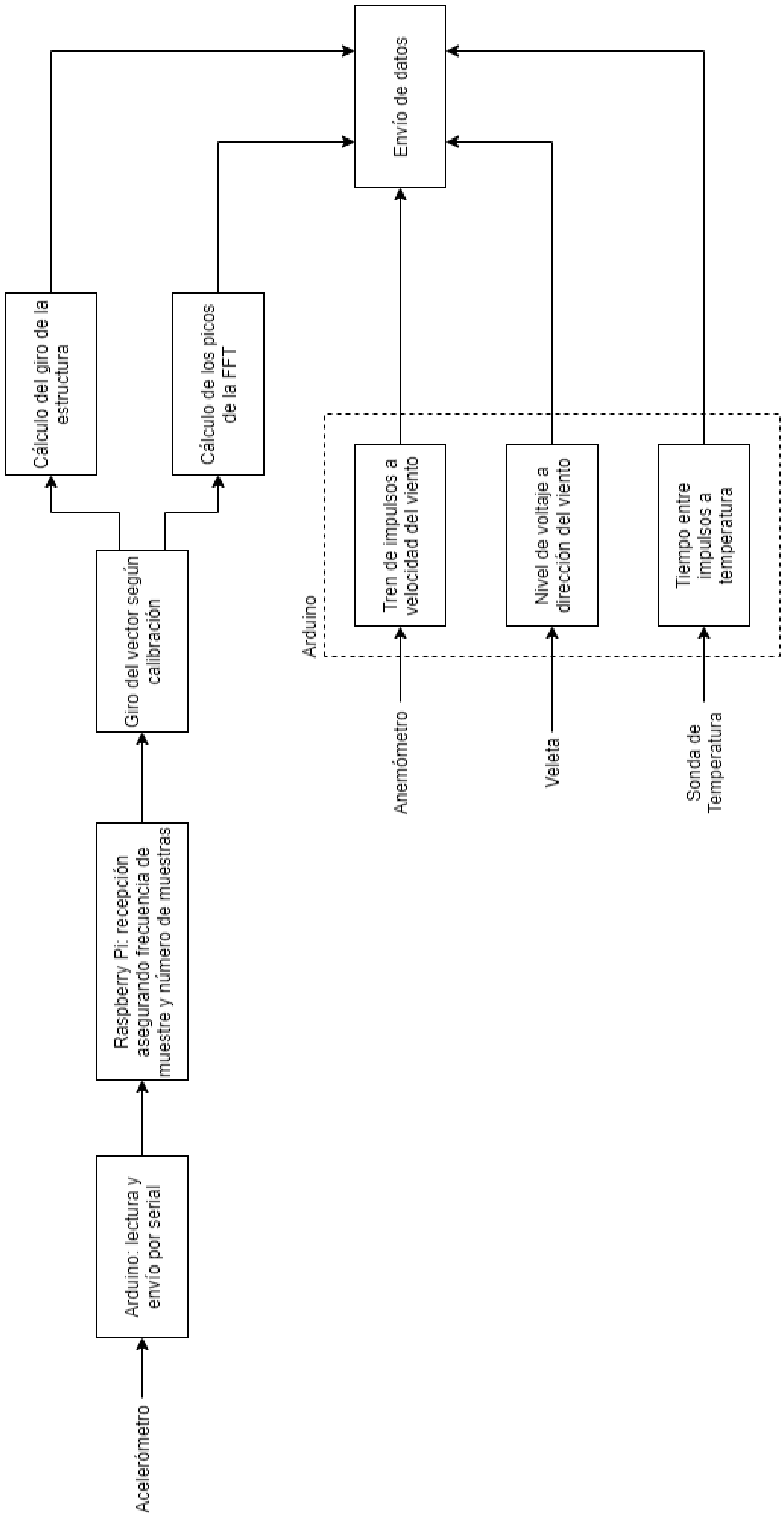
3 Captura de datos de clima

La captura de datos climatológicos es a la vez más sencilla y compleja. Los datos no requieren prácticamente posprocesado, a diferencia de los extensos algoritmos que requieren los datos de aceleración. La complejidad radica en el código encargado de convertir las señales de los sensores en cantidades fáciles de interpretar en el código del Arduino al que están conectados. Una vez los datos son recibidos por la Raspberry Pi, están ya listos para ser enviados junto con los datos de ángulos y aceleraciones.

El código de adquisición de datos de los sensores se divide, lógicamente, en tres partes:
Una dedicada al anemómetro, otra a la veleta y una última al sensor de temperatura.

Con respecto al anemómetro, se cuentan la cantidad de revoluciones en un intervalo de tiempo, ya que envía una señal que cada media vuelta cambia de verdadero a falso y viceversa. La relación entre las revoluciones por segundo y la velocidad en sistema internacional de unidades se puede calibrar experimentalmente. La veleta tiene valores de resistencia distintos para cada dirección posible, de manera que el algoritmo lee el voltaje en un puerto con un conversor analógico-digital del dispositivo *arduino* y asocia a cada valor discreto de voltaje una dirección. Finalmente, el sensor de temperatura se gestiona con la biblioteca *DallasTemperature.* Una vez recopilados los datos, se envían a la Raspberry Pi, y, como se ha mencionado antes, se envían junto con los datos de aceleración.

En la siguiente imagen puede verse esta operativa


Acelerómetro
Arduino: lectura y envío por serial
Raspberry Pi: recepción asegurando frecuencia de muestre y número de muestras
Giro del vector según calibración
Cálculo del giro de la estructura
Cálculo de los picos de la FFT
Envío de datos
Arduino
Tren de impulsos a velocidad del viento
Nivel de voltaje a dirección del viento
Tiempo entre impulsos a temperatura
Anemómetro
Veleta
Sonda de Temperatura

IO TOWER – Digitalización torres de comunicación y eléctricas

E4 Informe de arquitectura del sistema

Proyecto	IOTOWER	**Código de proyecto**	COMRDI15-1-0036
Entregable	E4	**Fecha**	Marzo 2021
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Contenido

1 Introducción

Este informe las características básicas de hardware de la plataforma IoT SmartTower, centrándose en las características que deben tener los diferentes sensores asociados a la misma. Dichas características básicas se determinarán en base a aquellas magnitudes que se considere oportuno medir, o sea: acelerancia, velocidad y dirección del viento. Se detallarán especialmente las características del espectro vibracional que se desea medir, pues es la parte más crítica del hardware.

La acelerancia, que viene a ser la aceleración de las vibraciones de la estructura normalizada en función de la excitación, es el dato más relevante de los que recogerá la plataforma. Esto se debe a que es en función de la acelerancia que se pretende detectar alteraciones en la estructura. Cualquier cambio en la masa, rigidez o amortiguación de la estructura se verá reflejado en la acelerancia y magnitudes derivadas. Para medir la acelerancia será necesario el uso de un acelerómetro.

Dado que la excitación que hará vibrar la estructura viene dada por el viento, cualquier dato disponible al respecto resulta relevante a la hora de evaluar la respuesta a la excitación de la estructura. Los datos meteorológicos son, a menudo, inexactos, de manera que sería importante conocer ambos: velocidad y dirección del viento. La temperatura es menos relevante, pero no deja de ser un dato importante a la hora de evaluar el estado de la estructura, teniendo en cuenta las considerables fluctuaciones entre las estaciones.

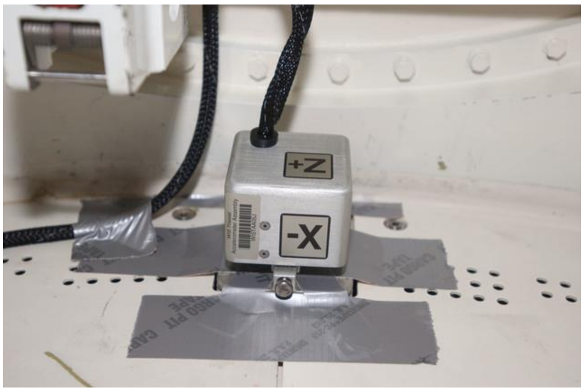
El establecimiento de estos requerimientos permitirá determinar qué características deben tener los diferentes sensores y como deben estar configurados. De esta forma el desarrollo del prototipo puede proceder con una cierta seguridad de que cumplirá con sus funciones.

2 Sensores

En esta sección se discutirán los diferentes sensores necesarios para la operación del prototipo: un acelerómetro, un anemómetro, una veleta y una sonda de temperatura. Por la naturaleza de este informe, más que características exactas, se describirán los requerimientos mínimos que se consideren oportunos. Para cada sensor se verá primero que todo qué características se esperan de cada medida y, luego, qué se requiere en un sensor del tipo adecuado para poder dar una medida dentro de los parámetros establecidos.

En general se debe decir que todos los sensores deberían ser capaces de operar a la intemperie y de transmitir sus medidas a algún dispositivo capaz de adquirir, almacenar y enviar datos. Con toda certeza se tratará de algún tipo de procesador electrónico, así que será *conditio sine qua non* que todos ellos puedan ser leídos desde, por lo menos, un conversor analógico-digital, una entrada digital o algún tipo de conexión de dispositivo a dispositivo, como serial o I2C.

2.1 Acelerómetro



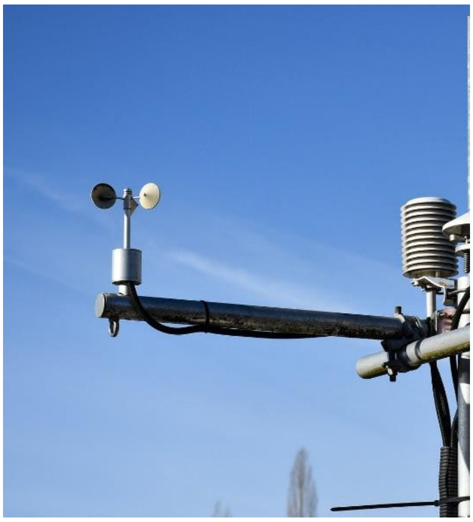
Acelerómetro

Con respecto al acelerómetro, la medida que condicionará las características del mismo es la forma del espectro vibracional que se quiere medir. Se ha observado que entre 0 Hz y 100 Hz se pueden observar los modos de interés. Del mismo modo, una resolución frecuencial de por lo menos 2 Hz garantiza que se pueda identificar con claridad dónde caen los picos y si se han movido. Dicho esto, una mayor resolución frecuencial resulta muy deseable.

Teniendo esto en cuenta, lo que se requiere del acelerómetro será que sea capaz de realizar una medición cada 5 ms durante, al menos, 0.5 s, aunque si fuese capaz de medir durante 2 s sería ideal, ya que permitiría una resolución frecuencial de 0.5 Hz. Asimismo, es conveniente que el acelerómetro sea capaz de medir en las tres direcciones del espacio, ya que la estructura puede presentar respuestas diferentes en direcciones diferentes.

En lo que a la magnitud se refiere, no es relevante observar valores de más de 2 $m \cdot s^{-2}$, mientras que por el lado de la resolución mínima sería muy importante leer al menos 0.01 $m \cdot s^{-2}$. Es importante que funcione en un rango de temperaturas de al menos -20ºC a 60ºC y que los datos de aceleración no se vean afectados significativamente por campos magnéticos cercanos.

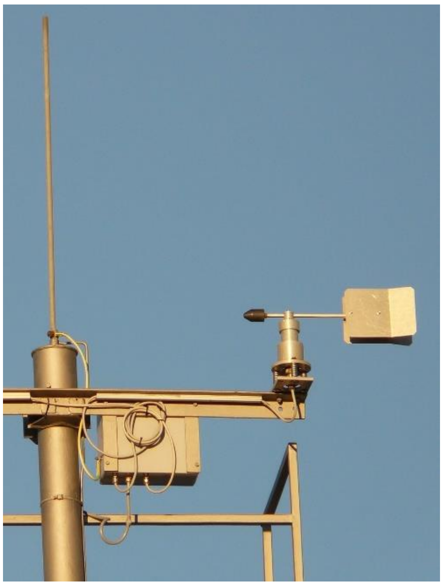
2.2 Anemómetro



Anemómetro

Los requerimientos del anemómetro no son unos requerimientos exigentes. Lo que se necesita saber es un valor aproximado de la velocidad del viento. Las velocidades de viento en la península ibérica suelen ser de entre 4 y 16 $km \cdot h^{-1}$, así que el anemómetro debería tener capacidad para medir velocidades de viento dentro de ese rango. Cabe decir que, a parte de las capacidades mecánicas del anemómetro en si, resulta muy relevante la electrónica con la que se adquirirán los datos. Si se asume que el funcionamiento del anemómetro es análogo al de un encoder angular, todo dependerá en definitiva de que la adquisición de datos pueda manejar trenes de impulsos con altas frecuencias, por lo que probablemente no presente mayor problema.

2.3 Veleta



Veleta electrónica

La dirección del viento es un dato de interés, sin duda, pero no es un dato que requiera mucha resolución. Interesa saber de qué dirección cardinal proviene el viento, así que ese sería un requerimiento mínimo para la veleta. Idealmente se podría dar información del la dirección exacta en grados, pero realmente la utilidad de semejante resolución es mínima, especialmente teniendo en cuenta que el precio de una veleta así se vería seriamente incrementado.

2.4 Sonda de temperature

Sonda de temperatura

La sonda de temperatura debería ser, ante todo, compacta. Debería estar calibrada para garantizar las mejores medidas entre 0ºC y 40ºC, y ser capaz de operar entre -20ºC y 60ºC. Realmente no hay ningún otro requerimiento para poder realizar las mediciones que se necesitan.

2.5 Adquisición de datos

Como se comentaba al principio de esta sección, la adquisición de datos no solo depende de los sensores en si mismos sino también de las características del adquisidor de datos. Sin tener en mano los datos de los sensores definitivos, pero es importante que quede reflejado que hay que dedicarle especial atención a como se realizará la adquisición de los datos y a seleccionar adecuadamente la electrónica que se encargará de ello.

3 Conclusiones

El dispositivo deberá ser capaz de medir velocidad y dirección del viento, temperatura, y vibración en la estructura en la que se instale. Para ello, deberá contar con un acelerómetro, un anemómetro, una veleta y un sensor de temperatura. Las características de los mismos vienen determinadas por las magnitudes que deben medirse: los rangos entre los que se mueven, la velocidad a la que deben ser adquiridas, etc. Todos ellos deben ser capaces de operar a la intemperie y de operar con una interfaz electrónica con el adquisidor de datos.

Las características básicas necesarias del acelerómetro son que debe ser capaz de medir aceleraciones de entre 0.01 $m \cdot s^{-2}$ y 2 $m \cdot s^{-2}$ cada 5 ms durante al menos 0.5 s, idealmente durante 2 s. La sonda de temperatura debe medir temperaturas entre -20ºC y 60ºC. La veleta debe dar información de, como mínimo, qué dirección cardinal viene el viento. El anemómetro debe ser capaz de medir velocidades de entre 4 $km \cdot h^{-1}$ y 16 $km \cdot h^{-1}$. Mientras cumplan con estas características, la operación del dispositivo será viable.

IO TOWER – Digitalización torres de comunicación y eléctricas

E5 Descripción de Detalles Técnicos, Funcionalidades y Capacidades de la Plataforma IoT Desarrollada

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Contenido

Introducción

Este informe tiene dos objetivos: detallar el hardware desarrollado en función de las necesidades descritas en el informe E4 y delinear las necesidas de la plataforma cloud que deberá gestionar los datos enviados por el dispositivo, que será desarrollada y explicada en el informe E6.

Por un lado, se explicitarán los componentes electrónicos tanto para la gestión de los diferentes sensores y su interfaz con un procesador central como ese procesador central en si mismo y su gestión de batería. También se explicará el hardware necesario para la gestión del envío de datos. Todo ello viene acompañado de una breve explicación de los programas necesarios para desarrollar las funciones expuestas y cómo se desarrollan.

Respecto a la plataforma de usuario donde se almacenarán y visualizarán los datos, se explicarán los requisitos tanto a un nivel técnico como de experiencia del usuario con el fin de facilitar que se puedan extraer conclusiones útiles de los datos capturados por la plataforma.

Hardware

Sensórica

En el informe E4 se detalla la necesidad de medir temperatura, aceleración, velocidad y dirección del viento. De acuerdo con las especificaciones de los diferentes sensores, se han utilizado los siguientes modelos para llevar a cabo las funciones del prototipo:

a) Acelerómetro HWT905 triaxial e inclinómetro de alta precisión. La función del acelerómetro es registrar el patrón de vibracioó de la estructura, así como determinar el ángulo de inclinación, tanto frontal como lateral, de la torre. Es un acelerómetro con especificaciones militares y con una carcasa IP67 que permite su uso en exteriores sin comprometer la electrónica del sensor.

Figura 1. HWT905

b) Termómetro DS18B20 que permite medir temperaturas en un rango desde -55ºC hasta 125ºC con una precisión de 0,5ºC. Esta encapsulado en un tubo de acero inoxidable resistente a la humedad.

Figura 2. DS18B20

c) Anemómetro SEN-08942 para medir tanto la velocidad del viento con una precisión de ±2km/h y la dirección del viento. Se ha construido un adaptador para poder instalar el anemómetro directamente a la caja para así reducir el tamaño del ensamblaje.

Figura 3. SEN-08942

Los sensores seleccionados cumplen todos con los requisitos previamente delimitados y están preparados para funcionar con hardware usado típicamente en prototipos de esta índole, además de contar con amplia documentación que facilita su implementación e interconexión.

Control

Para poder recibir los datos de los dispositivos, procesarlos, darles formato y enviarlos se requieren una serie de hardware adicional. Además de la gestión de los datos en si mismos también hay que tener en cuenta la alimentación y la gestión de la alimentación del dispositivo. Para ello se usan los siguientes componentes:

a) Placa base Raspberry Pi 4 para en control de la adquisición, el procesado y el envío de datos. Dispone una memoria de 2Gb de RAM. El modelo seleccionado optimiza el tiempo de adquisición y procesado reduciendo el consumo de batería.

Figura 4. Raspberry Pi 4

b) Convertidores analógico-digitales Arduino nano para acondicionar la señal de los sensores. Los arduinos nanos están conectados a la Raspberry mediante puertos USB.

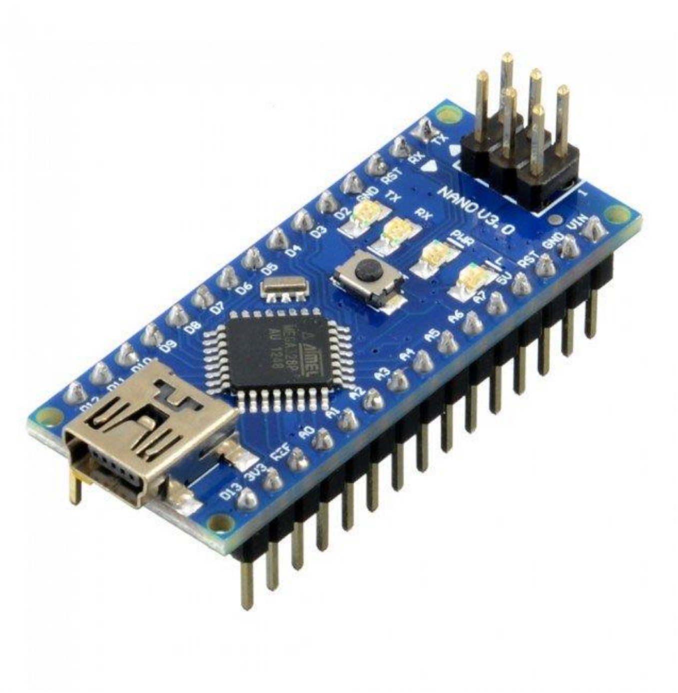


Figura 5. Arduino Nano

c) Módulo HAT PiJuice Pi-Supply para el control de energía de la Raspberry Pi. Este módulo se integra con el sistema operativo de la Raspberry y permite controlar la carga de batería, el encendido y apagado automático de la Raspberry así como la alimentación de los diversos sensores.

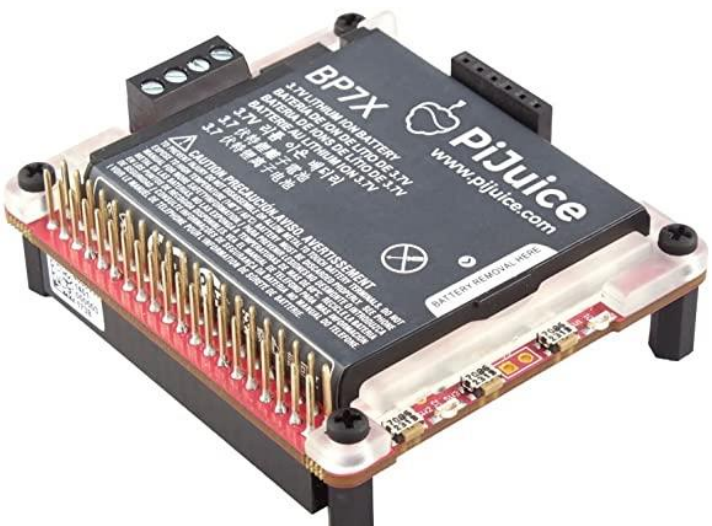


Figura 6. Hat PiJuice

d) Batería de litio de 12.000 mAh PIS-1129.

Figura 7. Batería PIS-1129

e) Panel solar de 1.6W para la recarga autónoma (EAN 823952646009).

Figura 8. Panel solar

f) Módulo de comunicación SIM7600E Waveshare para la transmisión de datos 2G/3G/4G/LTE. Este módulo esta controlado por la Raspberry Pi y el envío de datos se hace mediante el portal ThingsMobile que permite gestionar tarjetas SIM específicas para aplicaciones IoT como la desarrollada en este proyecto.

Figura 9. SIM7600E

En las figuras 10 y 11 se muestran los sensores y componentes hardware del prototipo fabricado una vez ensamblados y puestos en su caja IP67.

Figura 10. Detalle de los sensores.

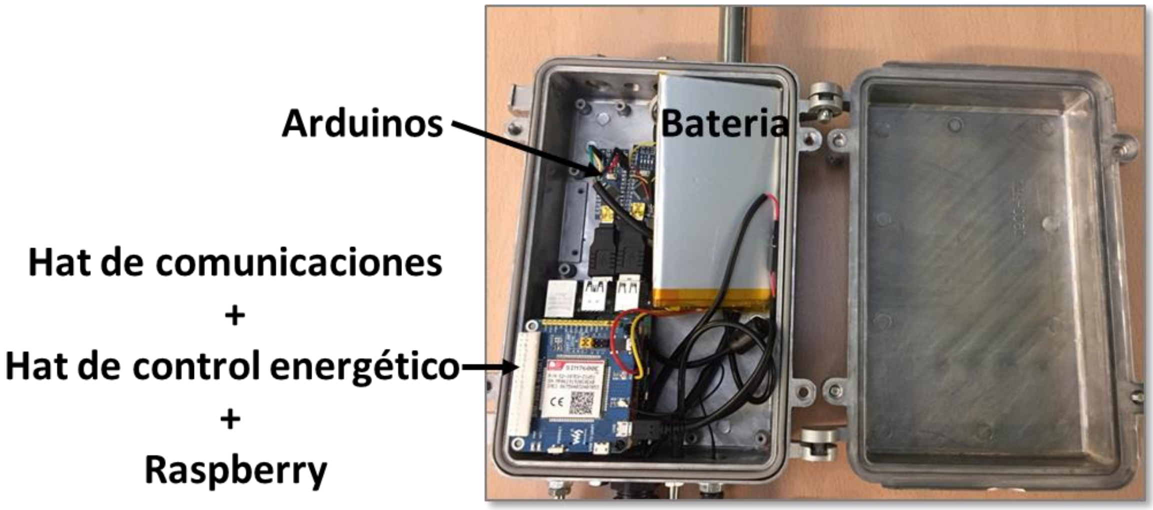


Figura 11. Detalle del hardware de control.

Software de control

El software e integrado en la placa Raspberry Pi está dividido en tres subprogramas: adquisición de datos de los sensores, procesado de datos y envío de los datos. Cuando el dispositivo se inicia se ejecuta cada uno de los códigos de forma consecutiva. Una vez confirmado el envío de los datos el dispositivo se desconecta automáticamente.

a) Adquisición de datos: el programa gestiona la conexión con los Arduino Nano, la toma de datos del acelerómetro, el termómetro y el anemómetro. Una vez se ha conectado con los dos arduinos, el programa almacena los datos de los diferentes sensores y asegura que los datos que está leyendo son consistentes. Si detecta algún fallo con los datos leídos, vuelve a reiniciar la conexión hasta que los datos son correctos.
b) Procesado de datos: el subprograma procesa los datos del acelerómetro para determinar los ángulos de inclinación frontal y lateral de la torre, así como los modos de vibración de la estructura. Además, también procesa los datos de temperatura, velocidad y dirección del viento. Una vez ha tratado y verificado los datos, el programa los almacena en archivos csv que se guardan en la Raspberry Pi.
c) Envío de datos: el subprograma inicia la conexión a internet, empaqueta los datos en formato json y los envía a la nube donde serán procesados por el servidor dedicado que se ha desarrollado. Una vez confirmado el envío de los datos, el subprograma se encarga de apagar la Raspberry. Los datos que se envían con este subprograma son los siguientes:
    i. Número de torre
    ii. Temperatura
    iii. Velocidad y dirección del viento
    iv. Estado de la batería
    v. Ángulo de inclinación
    vi. Frecuencias modales de la torre

Para realizar estas operaciones, se detalla a continuación que scripts se han creado en la Raspberry Pi:

‘system_shutdown.py’

Este script de Python apaga la Raspberry Pi y quita la alimentación a todos los periféricos a ella conectados. Es importante porque, de fallar cualquier parte del proceso de adquisición de datos de forma imprevista, este archivo se encarga de asegurarse de que la Raspberry Pi no se queda encendida y por lo tanto consuma la batería.

‘calibration.py’

Se encarga de alinear el sistema de referencia en el cual se expresa el vector aceleración en el espacio con la dirección de la gravedad, asegurando así que, si más adelante el vector gravedad no coincide con ese eje vertical una vez hecha la lectura, el ángulo que forma con este se corresponde con el ángulo de inclinación de la torre. Este archivo, una vez ejecutado, guarda la rotación que se debe hacer sobre el sistema en un archivo ‘angles1.npy’.

‘online.sh’

Este archivo lanza los comandos necesarios para iniciar la conexión a internet a través del hat 4G de la Raspberry Pi.

‘data_acquisition.py’

Este es el archivo más complejo de todos. Lo primero que hace es seleccionar los sensores por su dirección serial y medir velocidad y dirección del viento, temperatura, aceleración en el dominio temporal, y luego velocidad, dirección del viento y temperatura de nuevo, para tener así un buen valor medio. Si aún no se ha hecho la calibración, lanza ‘calibration.py’, y lo hace las dos primeras veces que mide si no existe un archivo ‘angles1.npy’ (este es el proceso de calibración, las dos primeras medidas deben descartarse). Después de aplicar la rotación pertinente a los ejes de referencia, calcula la inclinación de la torre, y descarta el valor de la gravedad para, después de hacer la transformada rápida de Fourier sobre la señal de aceleración en función del tiempo, hallar el primer y último pico de la respuesta vibracional de la torre.

Todos estos datos los guarda en una carpeta con el día y hora a la que mide, que se crea dentro de la carpeta ‘data’. Estos datos son enviados a través de protocolo HTTP. El programa hace diez intentos consecutivos de conexión a internet; si no consigue enviar los datos guarda el nombre de la carpeta que no ha conseguido enviar en un archivo ‘unsent.txt’, y volverá a intentar enviar los datos que contiene en el próximo periodo de adquisición. Si consigue enviar los datos, empaqueta la carpeta en un archivador zip y la borra, para ahorrar así espacio. Por último, se asegura que el próximo periodo está programado para ocho horas más tarde y apaga la Raspberry Pi, cortando la alimentación a todos sus periféricos.

Requisitos de la plataforma cloud

La plataforma que gestione los datos del dispositivo debe ser capaz de cumplir con tres requisitos: recibir los datos, almacenar los datos y representar los datos. La recepción de los datos esta condicionada por las capacidades del prototipo y de los programas escritos en el mismo, el almacenamiento de los datos debería estar ligado inexorablemente a como será su representación, y la representación debería ser cómoda para el usuario, representando el estado de la última medición, así como el histórico de datos.

La plataforma deberá, en primer lugar, recibir los datos a través de HTTP y redirigirlos de la manera más conveniente a entradas en una base de datos. Dicha base de datos debería tener tantos campos como datos envíe el dispositivo. La base de datos deberá de ser fácilmente legible por la plataforma de visualización.

La visualización de los datos deberá poder hacerse, preferiblemente, en entorno web. Deberá incorporar algún tipo de gestión de usuarios y la capacidad para representar datos tanto para ver el estado actual como un histórico de datos.

Conclusiones

El dispositivo es capaz de medir temperatura, velocidad y dirección del viento, y aceleración. Cumple con las especificaciones delineadas en el anterior informe y, después de haber sido ensamblado, funciona correctamente. Para su correcto funcionamiento, además de los sensores, necesita una serie de componentes extra para la gestión de la alimentación, la recepción y el envío de datos. Es en función del funcionamiento del dispositivo que se han especificado los requisitos de la plataforma cloud. Dicha plataforma, además de ser capaz de recibir los datos, también deberá almacenarlos y representarlos.

IOTOWER – Digitalización torres de comunicación y eléctricas

E6 Informe de la Arquitectura Completa del Sistema

Proyecto	IOTOWER	**Código de proyecto**	COMRDI15-1-0036
Entregable	E5	**Fecha**	Marzo 2021
Persona de contacto	Guillermo Reyes	**Organización:**	COMSA
E-Mail	guillermo.reyes@comsa.com	**Diseminación: Publica/Confidencial**	Confidencial

Contenido

Introducción

El objetivo de este informe es explicar cómo se ha desarrollado el software en la nube según lo especificado en el informe E5 y dar una idea de, una vez definido este aspecto del proyecto, cual es la arquitectura completa del prototipo, desde la adquisición de los datos hasta su visualización.

Dado que, después de este último desarrollo, el prototipo quedará listo para su instalación en una torre, otro objetivo de este documento es detallar que precauciones se deben tomar a la hora de instalar el prototipo, teniendo en cuenta los requerimientos de toda la infraestructura.

Software en la nube

Para la gestión de los datos en la nube se ha utilizado los servicios de Google Cloud Computing. Se ha alquilado un servidor con el sistema operativo Ubuntu y se ha programado para que realice las siguientes funciones:

a) Recibir los datos en formato json, separarlos el mensaje en los diferentes parámetros y enviarlos al campo correspondiente de la base de datos. Todo este procesa se ha programado mediante el módulo node-red instalado en el servidor virtual de Google Cloud Computing.

b) Todos los datos recibidos se almacenan en la base de datos InfluxDB que se ha instalado en el servidor virtual de Google Cloud.

La representación de los datos se realiza en la plataforma de visualización de datos Grafana Labs que se ha instalado en el servidor virtual. Ese módulo está conectado con la base de datos InfluxDB y muestra los diferentes valores en tiempo real, así como el histórico para poder identificar patrones de cambio. Se ha implementado en este módulo también un sistema de aviso por email que avisa cuando se detecta que alguno de los parámetros esta fuera de una zona de seguridad previamente definida. Esta interfaz permita la ampliación fácilmente de la plataforma ya que se podría duplicar cada una de las filas para el número de sistemas que fuese necesario de forma sencilla y rápida.

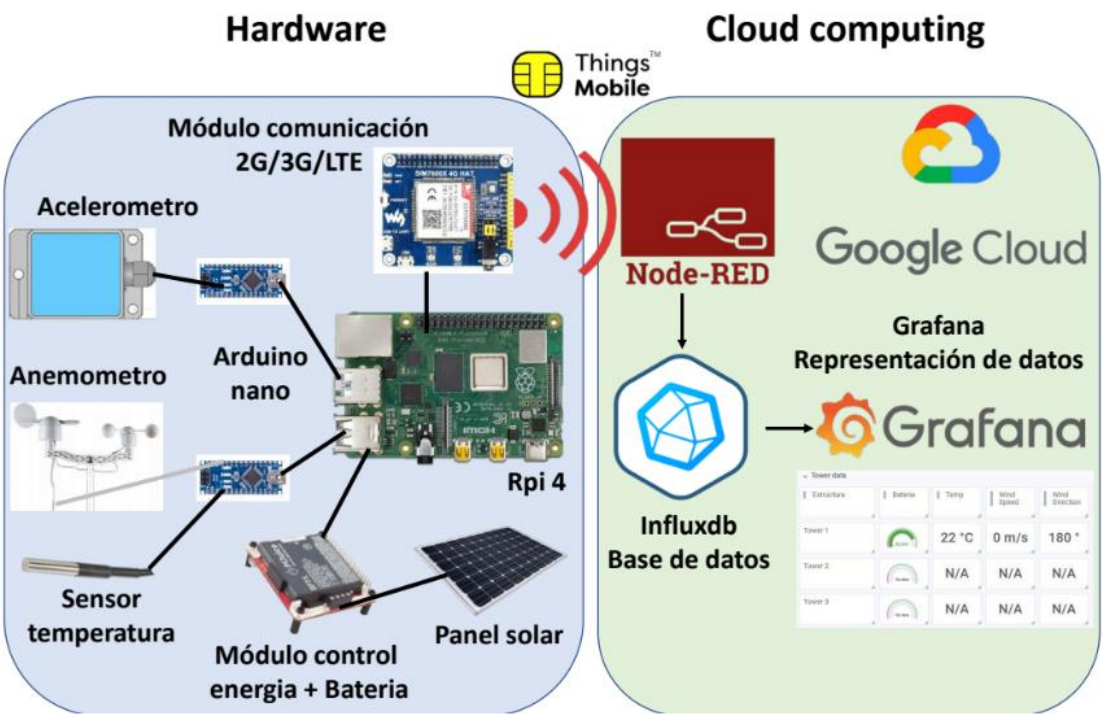


Figura 3. Esquema de la arquitectura hardware y software del prototipo.

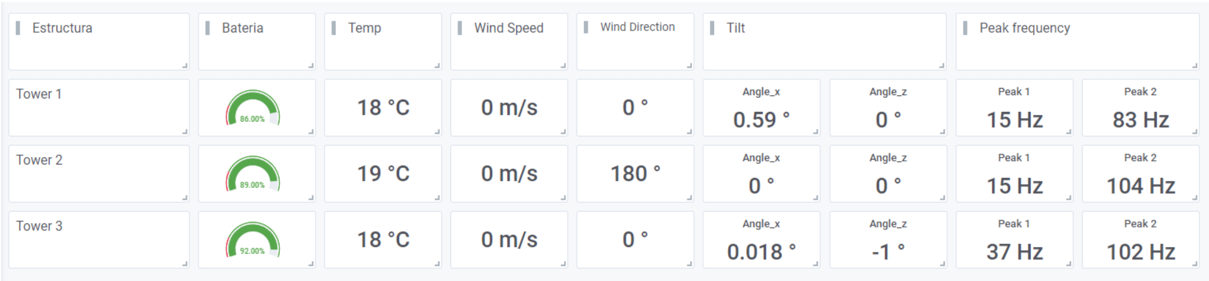


Figura 4. Interfaz de Grafana para la visualización de datos

Instrucciones de de instalación

Para el correcto funcionamiento del sistema es necesario conectar los cables de la batería. El sistema se entrega ensamblado, pero con los cables de la batería desconectados para evitar la descarga de batería mientras el aparato no se instala. Antes de instalar, es necesario conectar los cables de la batería, encender la raspberry pi y eliminar el archivo 'angles1.npy' que se encuentra en la carpeta 'SmartTower'. De esta forma cuando el sistema se encienda por primera vez una vez instalado hará la calibración de los ejes para poder identificar de forma correcta la inclinación del acelerómetro.

En la carpeta del usuario de la Raspberry Pi siempre debe haber una carpeta llamada 'SmartTower' que contendrá, a su vez, dos carpetas: 'logs' y 'data'. En cuanto a archivos, es imperativo para el correcto funcionamiento del dispositivo que existan los scripts de Python 'calibration.py', 'data_acquisition.py' y 'system_shutdown.py'. Además, se necesita el script de bash de Linux 'online.sh', y después de la calibración debe existir un archivo 'angles1.npy'. Por último, el archivo 'static.csv' guarda el identificador de la torre y también es imprescindible.

Es de capital importancia que el dispositivo esté instalado de forma tal que la placa solar mire hacia arriba y hacia el sur, para asegurar que siempre le da el sol cuando es posible. Si esto no es así, el dispositivo no tardará en quedarse sin batería.

Conclusiones

La arquitectura en la nube cumple con los requisitos especificados en el informe E5, siendo capaz de captar los datos enviados via protocolo HTTP en Node-RED, encauzarlos hacia una base de datos InfluxDB y visualizarlos en Grafana. Todo ello corre en un servidor de Google Cloud fácil y rápidamente accesible. Después de haber comprobado que el dispositivo, en efecto, funciona en conjunción con el software en la nube, se puede proceder a su instalación.

Para instalar el dispositivo se tienen que realizar una serie de conexiones de hardware, modificaciones de software y tomar precauciones de posicionamiento. Estas modificaciones están relacionadas, principalmente, con la calibración del dispositivo y con la alimentación del mismo. Con el trabajo ejecutado durante la realización de este informe el prototipo queda listo para su instalación.

IOTOWER – Digitalización torres de comunicación y eléctricas

E7 Informe de Instalación y Calibración del sistema

Proyecto	IOTOWER	**Código de proyecto**	COMRDI15-1-0036
Entregable	E7	**Fecha**	Marzo 2021
Persona de contacto	Guillermo Reyes	**Organización:**	COMSA
E-Mail	guillermo.reyes@comsa.com	**Diseminación: Publica/Confidencial**	Confidencial

Contenido

Introducción

Antecedentes

La empresa COMSA participa en un proyecto con el objetivo general de desarrollar un nuevo sistema basado en la plataforma IoT (Internet Internet) a partir de la distancia, y la estructura de una torre de telecomunicaciones a partir de su comportamiento de vibración Participar en tiempo real en tiempo real. evaluar.

El sistema debe ser capaz de detectar daños estructurales o presencia anormal, identificar el tipo y cuantificar la reducción. Para ello, se integra la red de sensores, que se colocan estratégicamente en la estructura de la torre, midiendo los parámetros deseados, y las señales inalámbricas periódicas o bajo demanda para el post-procesamiento Enviar a la nube. Este sistema debe proporcionar un intérprete único que puede ayudarle a determinar la futura infraestructura o la posible reparación.

Cuando se evalúa por la tarea anterior del proyecto, la viabilidad técnica de la metodología y la idoneidad de los daños de la torre de escala para detectar el daño a la torre de escala son la señal de aceleración, el espectro de frecuencia del sensor, Y desarrollamos la condensación de la información de la información fácil de correlación espectral. Valor escalar interpretable. El indicador actúa como un binario y advierte de los daños en la estructura. El sistema debe funcionar de forma autónoma y en tiempo real y proporcionar indicadores de daños según sea necesario.

En las primeras fases del proyecto se diseñaron y construyeron prototipos de hardware y plataformas de software para la detección remota de sensores. En la fase actual del proyecto, las pruebas de verificación del sistema requieren que el prototipo fabricado se instale en la torre real. Por lo tanto, es necesario documentar técnicamente la instalación y calibración del prototipo y el análisis de los resultados.

Objetivos, metodología y avasto

Los objetivos de este informe son:

- Un informe técnico sobre la instalación y verificación de los prototipos de hardware desarrollados en torres reales para probar el sistema.
- El análisis de los resultados de la campaña de pruebas durante el ensayo piloto.

El dispositivo de hardware fue instalado en dos postes reales de servicios públicos por COMSA y otro subcontratista. Se determinó la posición óptima del sensor para registrar el espectro de vibraciones. Además, la torre debía estar en una zona expuesta al viento suficiente para garantizar una excitación adecuada.

Ubicación de la instalación

La primera propuesta del proyecto fue instalar los dispositivos de hardware para las pruebas piloto en una torre de telecomunicaciones, que es una estructura metálica autónoma o de tipo malla, como una torre eléctrica. El objetivo era limitar las posibles complicaciones de la instalación del dispositivo en un entorno con riesgo de electrocución. Sin embargo, Endesa ha aceptado apoyar el proyecto piloto donando dos postes de electricidad y un instalador profesional en el marco de un subcontrato de Cobra.

El poste en cuestión se corresponde con el poste de alta tensión cercano a Villafranca del Penedés, al sur de la localidad de Ramla (Figura 1), especialmente los nº 21 y 22 (Fig. 2) (coordenadas geográficas 41º 19`01,2" N1º 41'53,5" E). La torre pertenece a la línea de 110 kV entre Tarragona y San Boydel Roblegat y consiste en un eje de doble circuito a través de la subestación Tarragona-Altafra-Villano por Lagertor-Garraf-Lamura-San Perederives-San Boydel Roblegat. Así es. Estas subestaciones suministran energía a las comarcas del Garraf, el Alto, el Baix Penedès y parte de las comarcas de Tarragona. Los equipos de la Torre 21 se instalaron el 20 de enero de 2021 y los de la Torre 22 el 10 de febrero de 2021.

Figura 1. Localización de la torre donde se ha instalado el prototipo.

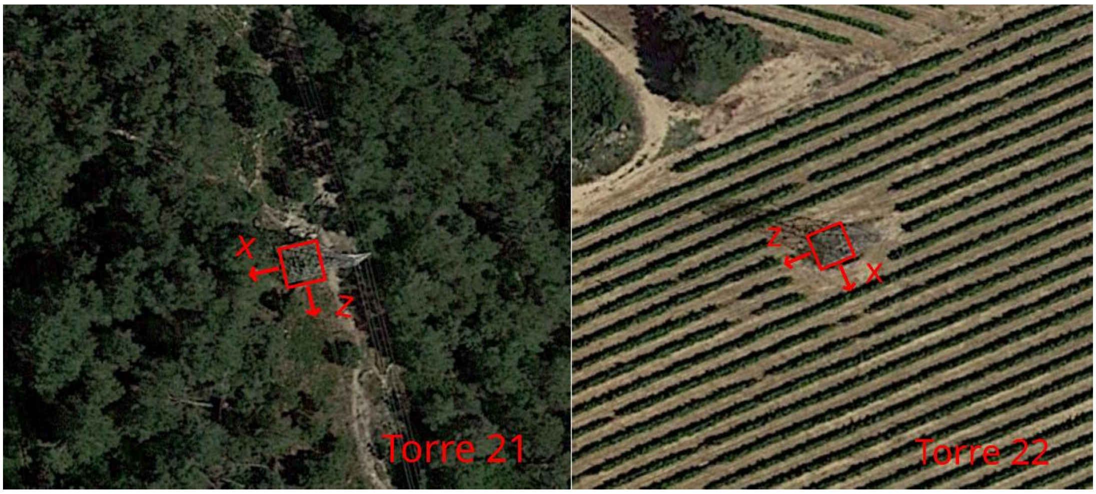


Figura 2. Detalle de la ubicación de las torres.

Ensayos de Verificación

Para comprobar sensores de temperatura, velocidad y dirección del viento, validar acelerómetros e inclinómetros y determinar el rendimiento de la batería y la capacidad de carga después de desarrollar y fabricar un dispositivo de hardware y antes de instalarlo en el campo. Se ha realizado una prueba de validación. panel solar. Además, se determinaron los pesos de los paquetes de datos enviados y se estimó el consumo de energía y datos.

Los sensores de temperatura, velocidad y dirección del viento han sido validados en condiciones de laboratorio utilizando un termómetro certificado o un anemómetro Velleman DEM900 (SN: 2016024561). El acelerómetro y el inclinómetro se validaron en un instrumento experimental Burel & Kjaer que consta de dos acelerómetros piezoeléctricos de un solo eje 4518003 (SN: 62644 y 62645) y un sistema de adquisición de datos HBM.

Las pruebas preliminares al aire libre se realizaron durante cinco días consecutivos en la terraza del Edificio IQS School of Management. Esta prueba se utilizó para determinar el consumo de batería en función del número de lecturas y la cantidad de datos consumidos para enviar las lecturas a la plataforma de computación en la nube. Esta información se muestra en la siguiente tabla (Tabla 1). El consumo estimado de batería por lectura es del 2 % y el tamaño de los datos es de 0,2 Mb/lectura.

Adquisiciones de datos	Duraciones de la carga de la batería	Consumo de datos previsto
Cada 1 h	96 horas	3 €/Semana
Cada 4 h	60 días	0,8 €/Semana
Cada 8 h	1 años	0,4 €/Semana
Cada 12 h	3 años	0,3 €/Semana
Cada 24 h	No disponible	0,18 €/Semana
Cada 48 h	No disponible	0,1 €/Semana
Cada 72 h	No disponible	0,07 €/Semana

Tabla 1. Consumo energético y de datos de cada sistema.

Validación del sistema

Tras la instalación del equipo se procedió a la comprobación del correcto funcionamiento del sistema de adquisición y envío, y al ajuste de parámetros antes de iniciar la captura de datos.

El prototipo está diseñado para la captura de las siguientes magnitudes (Tabla 2):

Medida	Unidades	Precisión
Nivel de batería	%	±0.01
Temperatura	ºC	±1
Dirección del viento	Graus	±5
Inclinación en x	Graus	±0.01
Inclinación en z	Graus	±0.01
1er modo del espectro	Hz	±0.01
2º modo del espectro	Hz	±0.01

Tabla 2. Magnitudes y precisiones de los datos registrados del prototipo.

Las variables registradas se transfieren desde el dispositivo liberado al servidor para el almacenamiento y visualización de datos. Los datos se envían al servidor de Google a través de 4G utilizando el protocolo HTTP en un formato similar a un paquete JSON. Una instancia de nodeRED almacena todos los datos en la base de datos que ejecuta InfluxDB (consulte la Figura 3). El visor de Grafana lee la base de datos y se puede acceder a ella desde un sitio web privado. La interfaz de Grafana permite a los usuarios ver y descargar los datos que envía el dispositivo. Los datos se pueden exportar como un archivo CSV en cualquier gráfico que muestre los datos.

Figura 3. Arquitectura de software del prototipo instalado en la cruz superior de la torre.

Después de verificar que los datos se transmitieran y mostraran correctamente, analizamos la señal de vibración del acelerómetro. En la Figura 4, cada espectro de frecuencia de la señal del acelerómetro de 3 ejes se representa en el eje ortogonal. El eje x corresponde a la vibración del plano horizontal de la torre, el eje y corresponde a la superficie lateral y el eje z corresponde al plano frontal. En la señal correspondiente al plano coronal se observan dos picos significativos debidos a los dos modos de vibración, mientras que en las otras dos direcciones el ruido de la señal enmascara la identificación fiable del modo de las condiciones de excitación del viento que se dieron el día de la instalación.

Estas curvas de aceleración confirman la idoneidad de la posición del sensor y la correcta excitación de la torre a las condiciones de viento encontradas el día de la instalación. De acuerdo con los resultados de las pruebas de validación y validación, se considera que el prototipo cumple con las necesidades y requisitos del sistema diseñado. Las señales de aceleración, temperatura, velocidad, dirección del viento y nivel de batería se obtienen y envían correctamente para su visualización remota.

Análisis de resultados de la prueba piloto

Esta sección muestra los resultados experimentales del piloto. Aquí, presentamos los datos de acuerdo con varias estrategias estadísticas y presentamos la hipótesis propuesta utilizando técnicas estadísticas. Los datos se muestran de tres maneras. En primer lugar, se examinan las correlaciones que existen entre los datos, primero en términos de distribución y luego en términos de evolución en el tiempo.

El análisis preliminar de los datos en el diagrama de caja de la Figura 5 muestra que los ángulos de ambas torres varían más o menos. Hay pocos da-tos atípicos y los bigotes se están alargando hacia valores más pequeños, a excepción de las lecturas de la torre 21 xangle. En cuanto a la temperatura (ver figura 5), los valores registra-dos para ambas torres son similares pero no iguales, y se puede ver que la torre 22 registra una temperatura más baja. Finalmente, el viento no fue fuerte en ninguna de las torres, pero la torre 21 registró vientos más rápidos.

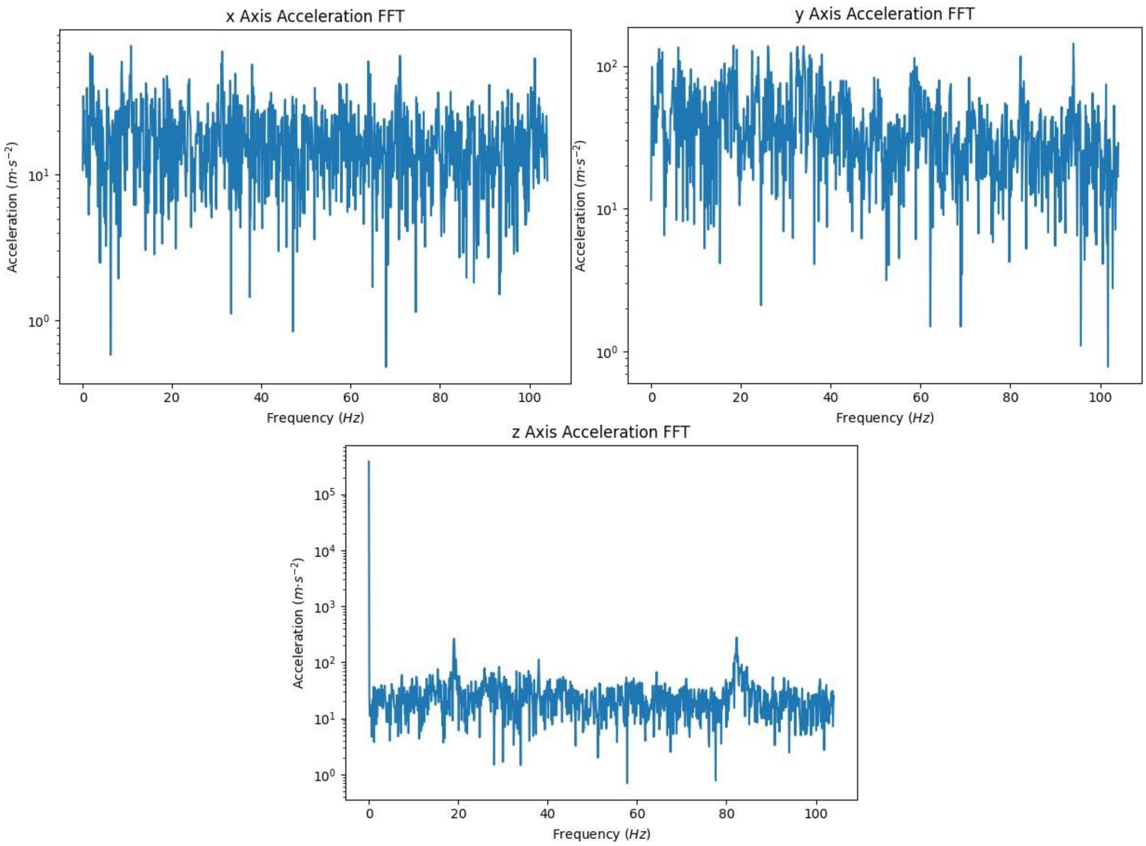


Figura 4. Espectros frecuenciales de aceleración en cada uno de los ejes ortogonales.

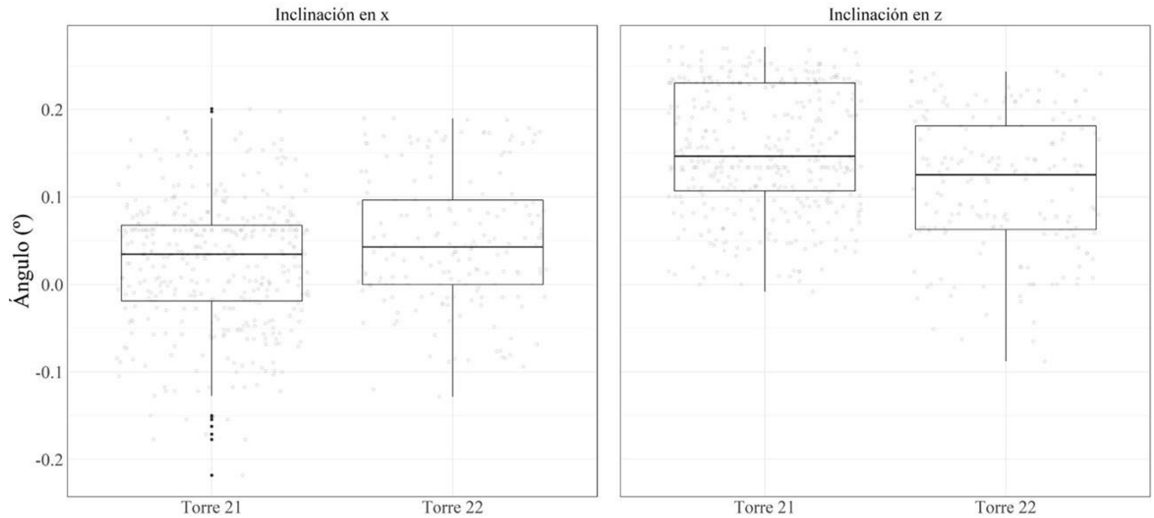


Figura 5. Diagramas de caja de los datos de inclinación de las torres.

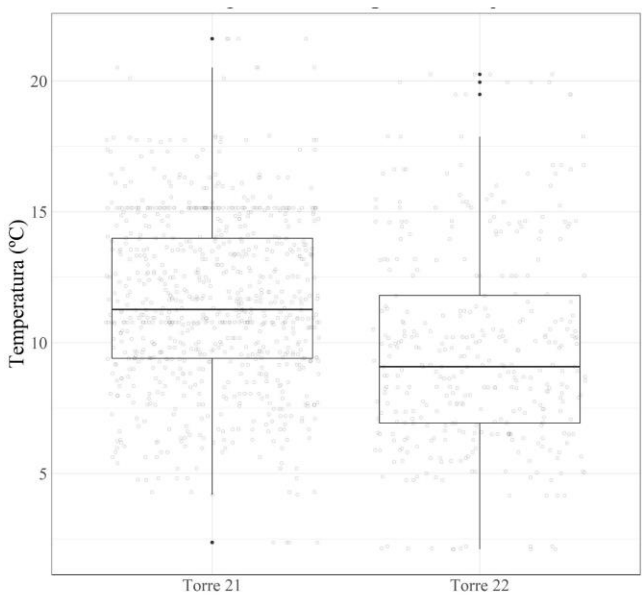


Figura 6. Diagramas de caja de los datos de temperatura ambiental.

En la Fig. 7 se representa el nivel de batería de los dispositivos instalados a lo largo del tiempo en el que se desarrolló la prueba piloto. La diferencia que puede verse entre la torre 21 y la torre 22 está en la frecuencia de medida. La 21 mide cada 8 horas, mientras que la 22 mide cada 6 horas. En la práctica, esto se traduce en que la torre 21 demuestra tener una vida casi infinita, nunca bajando del 90% de carga, mientras que la alimentación solar del dispositivo de la torre 22 no es capaz de aportar más energía de la que termina consumiendo el dispositivo. Sin embargo, puede concluirse que el factor orientación y exposición del panel solar es más relevante que el factor frecuencia de medida.

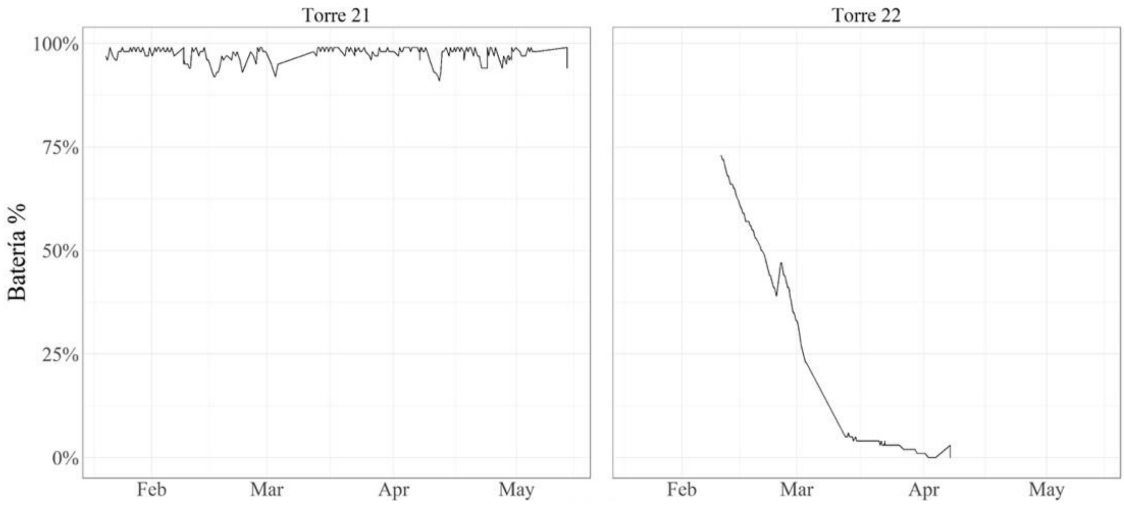


Figura 7. Nivel de carga de batería de los prototipos a lo largo del tiempo.

En la Fig. 8 se ha representado la evolución de la temperatura ambiental en cada una de las torres durante la prueba piloto. La tendencia al alza de las temperaturas observada es similar en ambas torres y es coherente con la época del año en la que se desarrolló la prueba (enero-mayo).

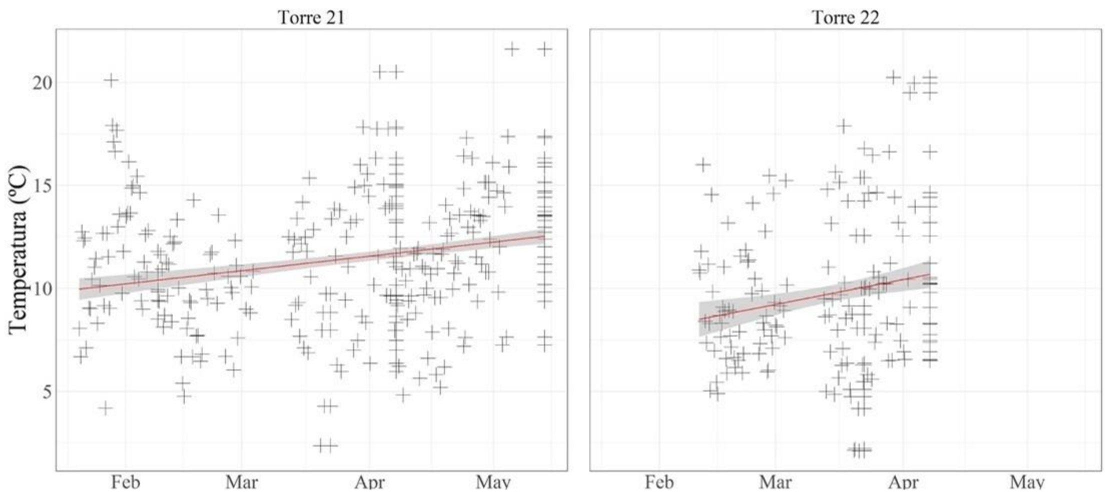


Figura 8. Evolución de la temperatura durante la prueba piloto.

En la Fig. 9 se puede observar cómo los ángulos de inclinación de ambas torres han demostrado una tendencia a aumentar con el tiempo. En futuros estudios sería necesario determinar si la transición de una estación cálida a una fría tiene el mismo impacto, pero al revés, o si, por el contrario, esta tendencia se mantiene en el tiempo a pesar de un cambio en la tendencia de la temperatura. Más adelante, en la correlación entre ángulo y temperatura, se discutirán estas posibilidades más exhaustivamente. Los ángulos de inclinación en este informe hacen referencia a giros dextrógiros en torno a los ejes señalizados en las fotografías de la Fig. 2.

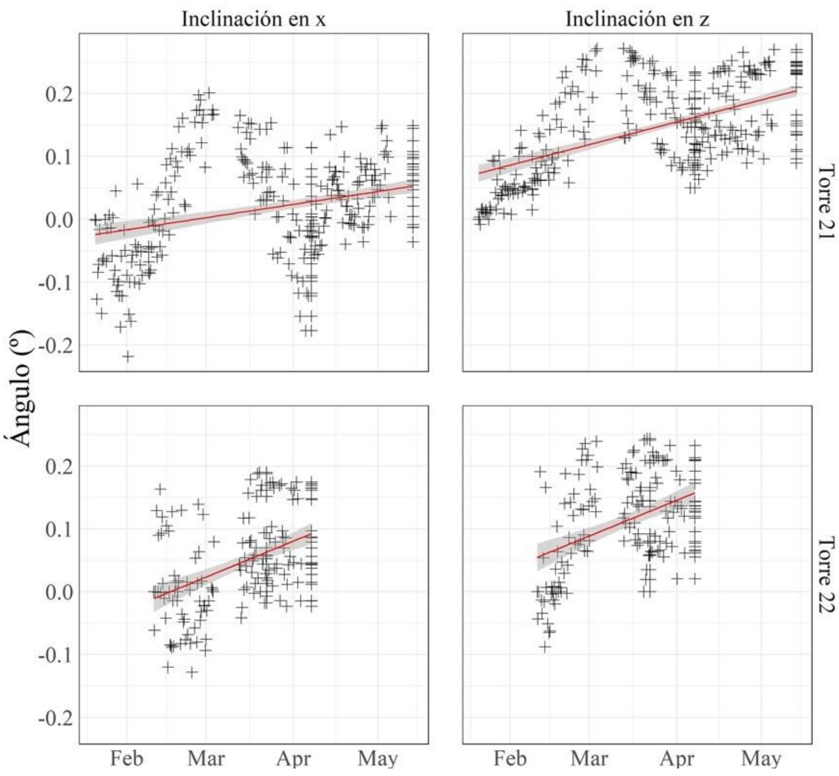


Figura 9. Evolución de la inclinación de las torres en las dos direcciones durante la prueba piloto.

En la Fig. 10 se ha representado la velocidad del viento a lo largo de la duración de la prueba piloto. De acuerdo con los resultados obtenidos, no se observan variaciones significativas en la intensidad del viento. En la Torre 21, ubicada en la zona boscosa, las velocidades son ligeramente superiores. Sin embargo, al tratarse de resultadas medias, éstos se ven afectados por los puntos anómalos identificados durante las primeras semanas en la Torre 21.

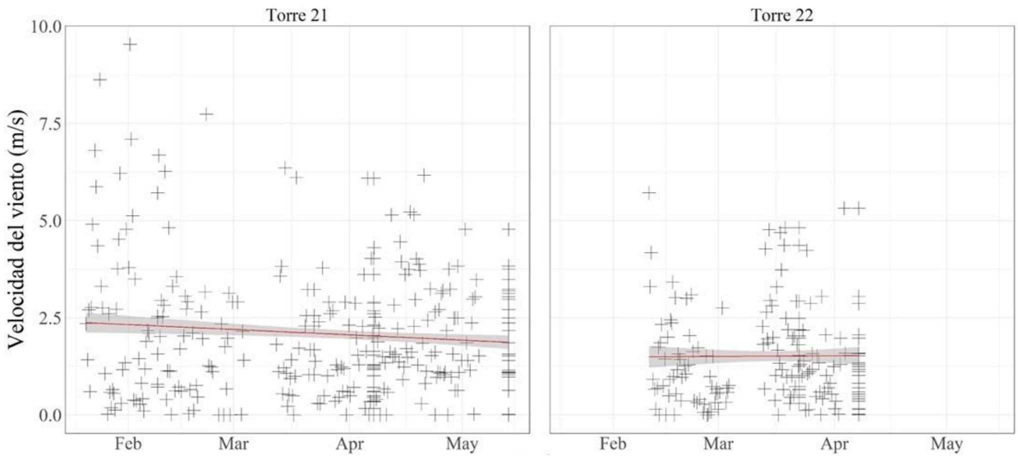


Figura 10. Evolución de la velocidad del viento durante la prueba piloto.

A continuación, se muestran 3 correlaciones entre los elementos climáticos específicos y la rotación de las torres: temperatura y velocidad del viento para cada torre y cada trayectoria de rotación.

La correlación más clara entre las ubicadas en la Fig. once es la de temperatura y perspectiva de inclinación. Con respecto a la pendiente z en la torre 21 y la pendiente x en la torre 22, la moda no siempre es muy distinguida y la correlación no está clara. En la pendiente x de la torre 21 y la pendiente z de la torre 22, se encuentra una correlación más evidente, de forma fuerte pero contraria: reduciéndose en la torre 21 y creciendo en la 22. Un examen más designado con un profesional dentro del campo Debería arrojar luz sobre las posibles razones de esta correlación.

Si se hubiera correlacionado a la vez la temperatura y la perspectiva, se puede afirmar que cuando se considera que las temperaturas llegan a ser más calientes a lo largo del tiempo estudiado, la realidad de que la perspectiva de rotación de las torres aumentará con el paso de los años es lógica y podría ser anticipó que después de que las temperaturas volvieran a bajar, los ángulos de las torres podrían hacer lo mismo. Sin embargo, se encuentra que la correlación no siempre es directa, sino que en algunos casos es incluso fuertemente inversa. Con esos registros, la especulación máxima alcanzable es que las torres están girando, y que no es probable que volver a una estación fría haga que los ángulos vuelvan al promedio en sus valores de calibración. Para afirmar esta especulación es muy importante tener registros en diferentes cambios de estación.

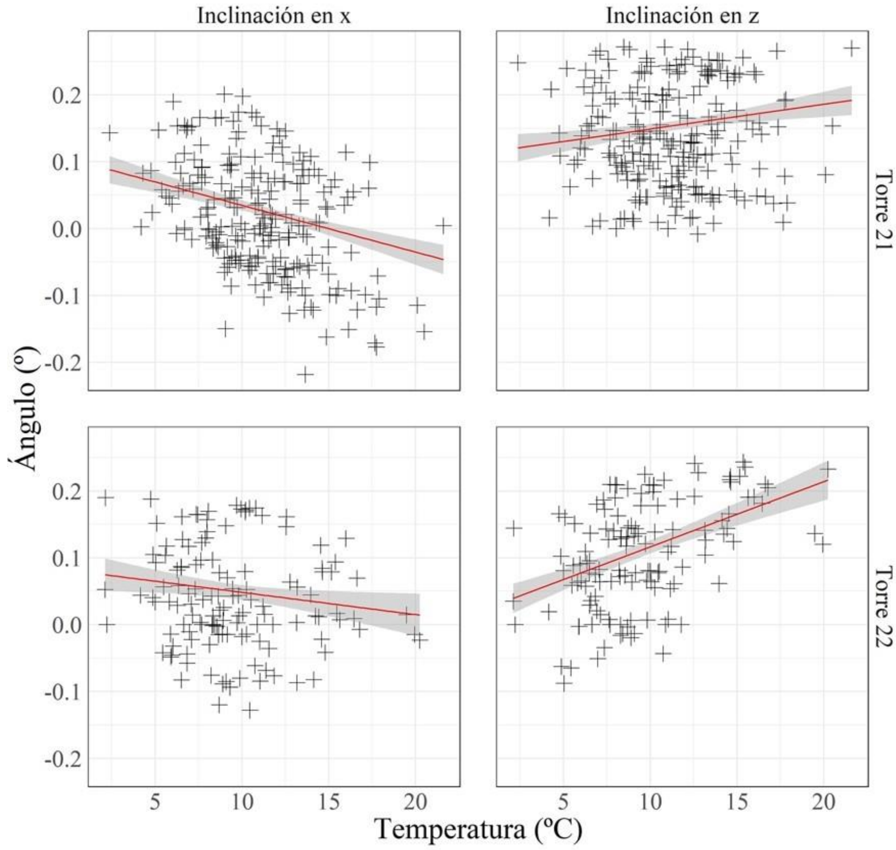


Figura 11. Correlación entre temperatura y ángulos de inclinación de las torres.

La figura 12 muestra la relación entre la velocidad del viento y la temperatura de ambas torres. Si no existe una correlación clara entre las variables, o si la correlación es similar a la temperatura, entonces si la correlación observada con las otras variables se debe a la velocidad del viento y la temperatura, o viceversa. Este resultado es apropiado porque es difícil de juzgar.

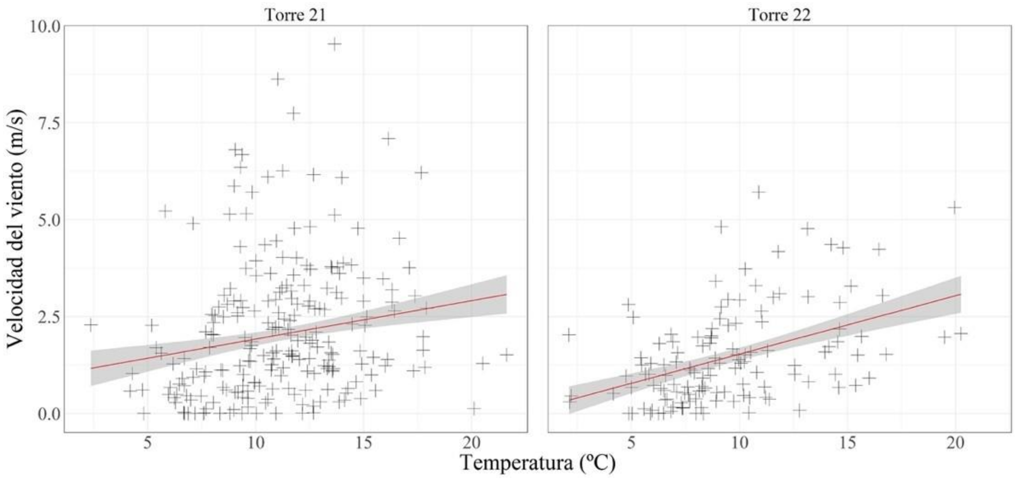


Figura 12. Correlación entre la temperatura y la velocidad del viento.

Al analizar la correlación de la velocidad angular del viento en la Figura 13, podemos concluir que las tendencias observadas de ninguna manera se deben a los efectos de la temperatura. Se observan vientos fuertes a altas temperaturas, pero como era de esperar, los vientos fuertes parecen tener un efecto adverso en el ángulo de rotación de la torre, independientemente de la temperatura. Se calculan las tendencias para las temperaturas por encima y por debajo del promedio y se observa que las tendencias son las mismas en ambos casos.

Dada la variabilidad en los resultados presentados, el grado de correlación debe determinarse estadísticamente. Para ello se utilizaron correlaciones de Pearson en cada comparación entre variables. La tabla 3 muestra los valores de cada diferencia significativa. El único valor por encima del nivel de significación de 0,05 es la relación entre la inclinación y la velocidad del viento en la Torre 22 en el eje z. Sin embargo, estadísticamente, las otras correlaciones que se muestran aquí no son insignificantes.

Torre	Eix de rotació	p-valor (temperatura)	p-valor (velocitat del vent)
21	*x*	1.6E-10	1.8E-06
	z	5.2E-04	4.8E-08
22	*x*	2.2E-02	3.3E-04
	z	3.4E-12	3.2E-01

Tabla 3. Significancia de las correlaciones analizadas.

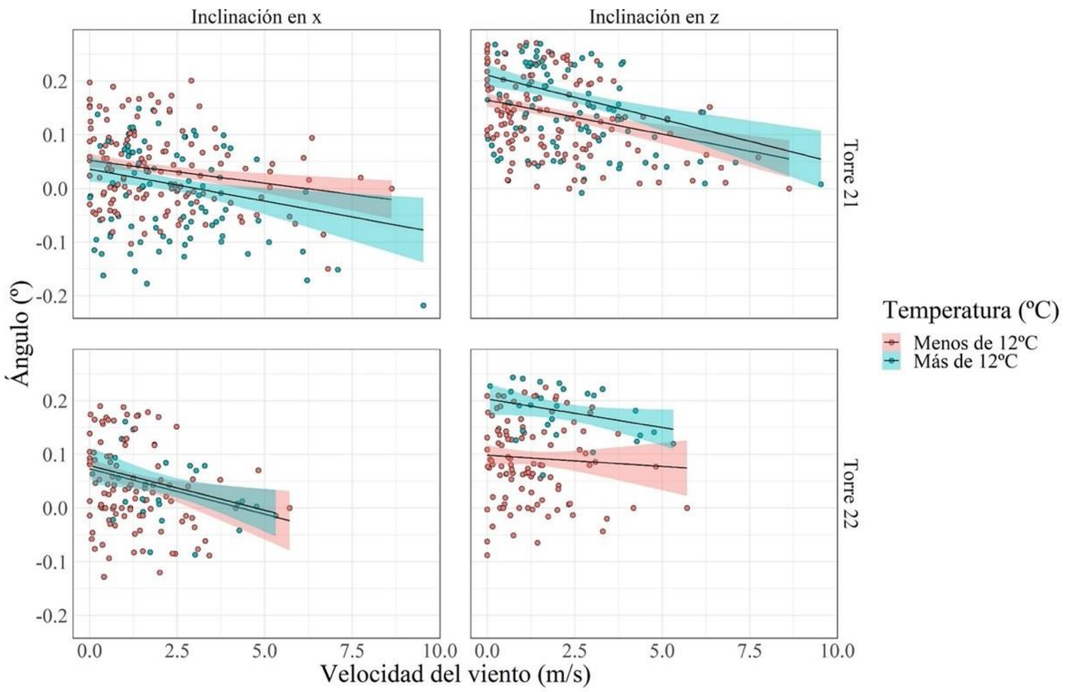


Figura 13. Correlación entre velocidad del viento y el ángulo de inclinación en cada torre, separado por nivel de temperatura.

Por otro lado, la dirección del viento es otro factor a tener en cuenta. La Figura 14 muestra la agrupación y distribución direccional por franja de intensidad del viento. El gráfico muestra que los vientos del oeste son generalmente más fuertes que los vientos del este y que la mayoría de los anticiclones atípicos son vientos del oeste.

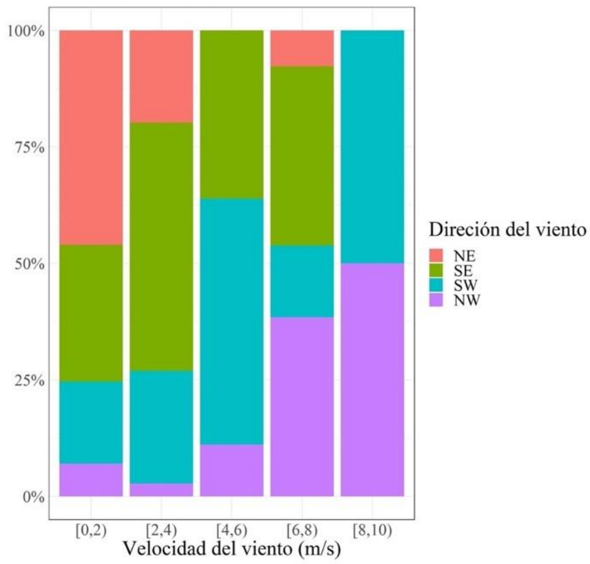


Figura 14. Distribución de la dirección del viento a diferentes niveles de velocidad.

Finalmente, se realizó un análisis de correlación global que incluye variables para el ángulo de inclinación de cada torre, la dirección del viento y la velocidad del viento y los resultados del gráfico se muestran en la Figura 15. Los resultados muestran una tendencia negativa más pronunciada en el viento del oeste que en el viento del este, pero la tendencia a reducir el ángulo parece ser independiente de la dirección en la que viene el viento.

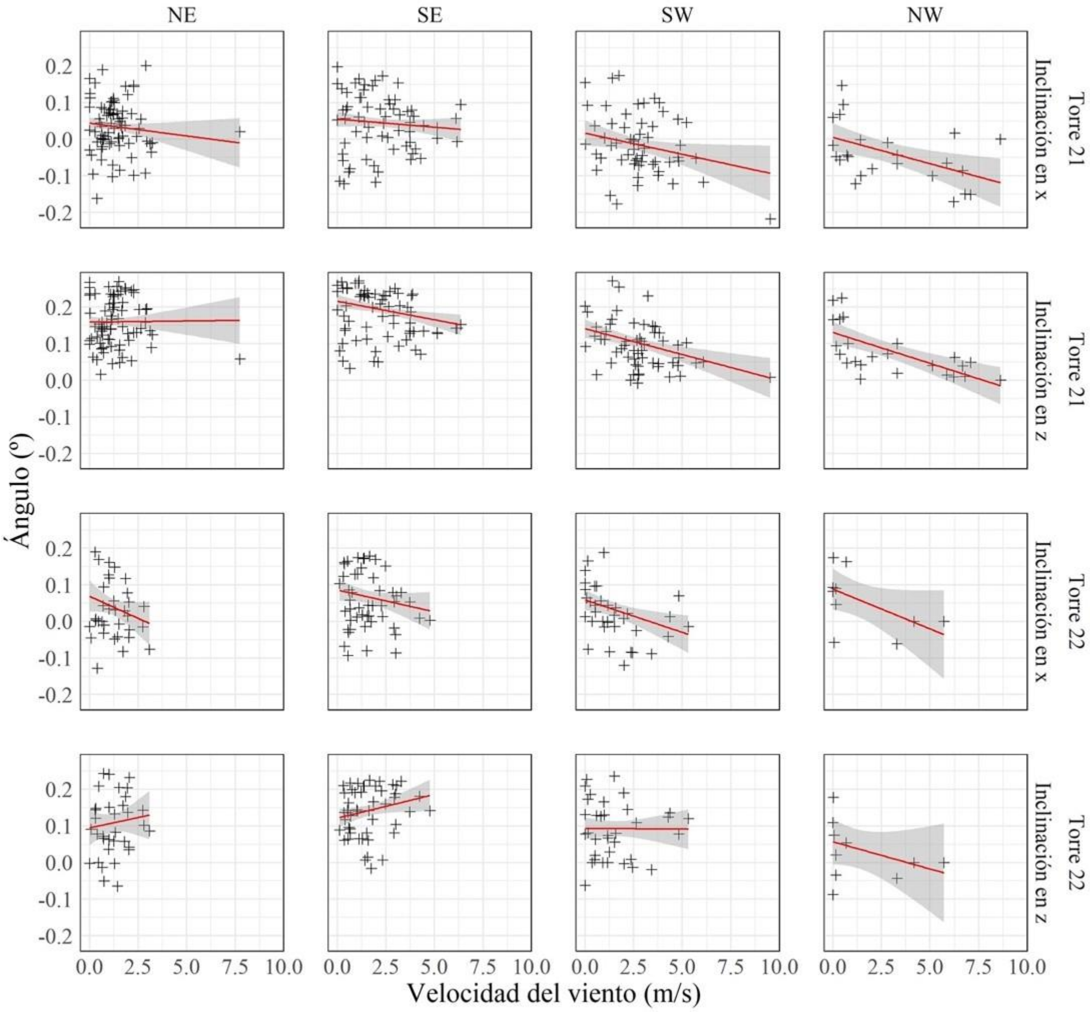


Figura 15. Correlación entre la inclinación de las torres, la dirección y velocidad del viento por cada torre.

Conclusiones

Las siguientes conclusiones se extraen de la evidencia presentada y explicada en las secciones anteriores de este informe.

- El prototipo se instaló correctamente en el pilón, que representa el entorno de trabajo real.
- Se encontró que la orientación del panel solar y el factor de exposición eran más relevantes que el factor de medición de frecuencia. Este factor tiene un efecto decisivo sobre el estado de carga de la batería y, por tanto, sobre la capacidad del sistema.
- Esta prueba no pudo cambiar ni dañar la estructura del poste de luz utilizado, pero el sistema mostró la efectividad de detectar cambios angulares consistentes lo suficientemente pequeños como para advertir sobre un posible deterioro estructural. Yo hice.
- El ángulo de inclinación de la torre se ve afectado por la velocidad del viento y la temperatura local. Se identifican todos estos factores sin obstrucciones que pueden afectar la tendencia de la torre.
- El prototipo se considera como requisitos del sistema diseñado y requisitos basados en los resultados de la verificación y los resultados obtenidos en el intento de verificación. Las señales de aceleración, temperatura, velocidad, dirección del viento y estado de la batería se registran correctamente y se envían a la pantalla remota.

IO TOWER – Digitalización torres de comunicación y eléctricas

E8 Gestión y coordinación del proyecto

Proyecto	IOTOWER	**Código de proyecto**	COMRDI15-1-0036
Entregable	E4	**Fecha**	Marzo 2021
Persona de contacto	Guillermo Reyes	**Organización:**	COMSA
E-Mail	guillermo.reyes@comsa.com	**Diseminación: Publica/Confidencial**	Confidencial

Contenido

1 Introducción

Este documento detalla las provisiones de gestión y coordinación del proyecto. La idea de este documento es explicar como se han gestionado las diferentes comunicaciones e interacciones entre las distintas instituciones que se han visto involucradas en el desarrollo del proyecto. Dichas partes, IQS y COMSA, se han comunicado principalmente a distancia, pero ha habido visitas a las instalaciones en las que se han realizado los desarrollos técnicos pertinentes.

La naturaleza de la comunicación entre ambas parte ha sido eminentemente técnica, sobre todo en temas relacionados con las fases iniciales del proyecto, tanto en materia de planificación como en materia de colaboración de cara a determinar las necesidades de los desarrollos tecnológicos imperativos para la consecución del proyecto.

2 Métodos de comunicación

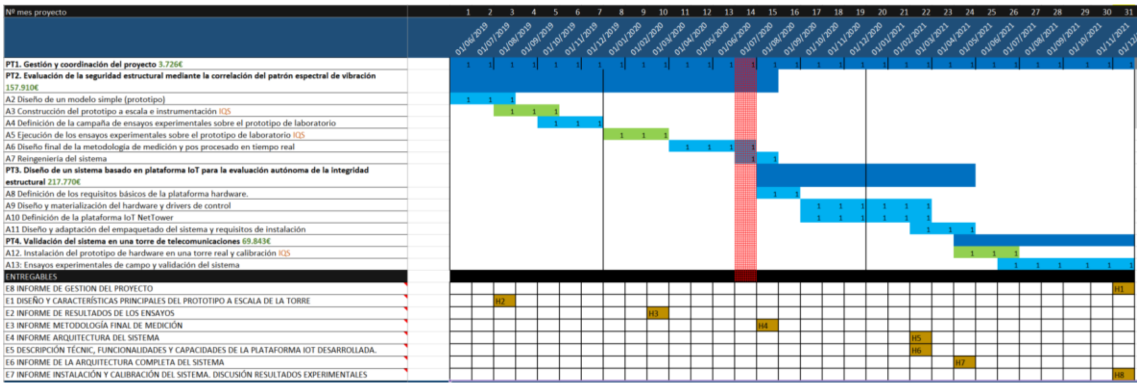
A lo largo del desarrollo del proyecto se usaron varias herramientas para la comunicación entre las partes, que se detallan en la siguiente tabla:

Herramientas	Propósitos y comentarios	Condiciones adicionales
E-mail	Preferentemente para discusiones que no devengan foros, para los entregables y para comunicación bilateral entre las partes.	Se debe evitar su proliferación.
Mensajería	Movimiento de equipos.	
Teléfono	Reuniones técnicas y de coordinación.	
Reunión telemática	Reuniones técnicas y de coordinación.	Se requiere envío previo de la documentación relativa a la reunión.

3 Visitas presenciales

A lo largo del proyecto se realizaron dos reuniones presenciales donde todas las partes pudieron intercambiar información de interés y se pudieron demostrar los principios de funcionamiento y los prototipos en pruebas de laboratorio en vivo y en directo.

Durante la primera reunión el personal de COMSA pudo observar todo el equipo de laboratorio con el que se desarrollarían los experimentos. La reunión también posibilitó que ambos equipos técnicos se conociesen y pudiesen poner de manifiesto una hoja de ruta.



La hoja de ruta se cumplió escrupulosamente.

La segunda visita presencial permitió ver como se habían desarrollado los experimentos que permitieron llevar a cabo las pruebas de laboratorio, así como ver los prototipos en funcionamiento. Además, se pudieron detallar los parámetros de la prueba operacional de los prototipos.

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163,37.5,68.7,10.2,10.2,0.20864457621,0.02,0.168740681257,48.4288806915,0.472727272727,0.02,2021-04-01 08:03:17.590167
164,225.0,68.7,10.26,10.2,0.0553657440245,0.02,-0.0141781778897,48.4563391209,1.51666666667,0.02,2021-04-01 15:23:00.360659
165,165.0,68.7,10.22,10.2,0.208568231511,0.02,0.171542852632,48.4082727432,1.33939393939,0.02,2021-04-01 22:42:43.131151
166,210.0,68.7,8.31,10.2,0.128301413926,0.02,0.0967362416421,43.4495818615,0.590909090909,0.02,2021-04-02 06:02:25.901643
167,195.0,68.7,6.49,10.2,0.0773192846306,0.02,0.0868163320999,48.4092888832,0.00984848484848,0.02,2021-04-02 13:22:08.672135
168,157.5,68.7,16.625,10.2,0.210106752408,0.02,0.0695830746515,48.4119715691,3.04318181818,0.02,2021-04-02 20:41:51.442626
169,165.0,68.7,11.21,10.2,0.117026669557,0.02,0.0274752315604,48.4186880589,0.413636363636,0.02,2021-04-03 04:01:34.213118
170,90.0,68.7,6.51,10.2,0.0953814907993,0.02,0.0855039847749,48.4435350895,0.590909090909,0.02,2021-04-03 11:21:16.983610
171,75.0,68.7,20.2483333333,10.2,0.232414773028,0.02,-0.0234117962806,48.4223997593,2.05833333333,0.02,2021-04-03 18:40:59.754102
172,120.0,68.7,14.43,10.2,0.143903830204,0.02,0.0115120742022,43.4442477226,1.01439393939,0.02,2021-04-04 02:00:42.524594
173,30.0,68.7,8.26,10.2,0.0717133020807,0.01,0.0428247046483,48.400894165,0.699242424242,0.02,2021-04-04 09:20:25.295086
174,232.5,68.7,13.19,10.2,0.126440510144,0.01,0.0560438402475,48.4525597095,0.817424242424,0.02,2021-04-04 16:40:08.065578
175,135.0,68.7,7.46,10.2,0.143082978457,0.01,0.164392130746,48.4048323631,0.531818181818,0.02,2021-04-04 23:59:50.836069
176,165.0,68.7,12.55,10.2,0.191834318499,0.01,0.146337094815,48.4610025883,1.24090909091,0.01,2021-04-05 07:19:33.606561
177,300.0,68.7,6.93,10.2,0.0206232679085,0.01,0.0463161327189,48.4126822948,0.157575757576,0.01,2021-04-05 14:39:16.377053
178,127.5,68.7,6.55,10.2,0.136538352469,0.01,0.161332279279,48.4172701836,0.354545454545,0.01,2021-04-05 21:58:59.147545
179,262.5,68.7,10.43,10.2,0.177939143009,0.0,0.174202488242,43.4469299316,0.019696969697,0.01,2021-04-06 05:18:41.918037
180,22.5,68.7,9.07166666667,10.2,0.132275171481,0.0,0.147877513551,48.3777089119,1.3,0.01,2021-04-06 12:38:24.688529
181,75.0,68.7,19.4883333333,10.2,0.136421231744,0.0,0.0146289264621,48.4672288895,1.9696969697,0.01,2021-04-06 19:58:07.459020
182,210.0,68.7,19.95,10.2,0.120044866076,0.0,-0.0146238210583,48.4477338791,5.31818181818,0.01,2021-04-07 03:17:50.229512
183,135.0,68.7,13.96,10.2,0.0612392209252,0.0,0.0443228381516,48.4593477249,1.58560606061,0.0,2021-04-07 10:37:33.000004

```
import time
import numpy as np
import re
import matplotlib.pyplot as plt
import time
import serial
import os
import scipy.signal as signal
import datetime
from scipy.optimize import minimize
from scipy.spatial.transform import Rotation as R

working_dir = '/home/pi/SmartTower/'

def rotation(angles, acc_vector, vertical_axis):
    angles = np.asarray([angles[0], 0, angles[1]])
    r = R.from_euler('zyx', angles, degrees = True) #Define rotation
    ideal_value = np.zeros(3) #Define an ideal outcome vector after the
application of rotation
    ideal_value[vertical_axis] = -1 #Set the vertical axis value to gravity,
while keeping the rest of axes with 0 value
    acc_vector = abs(r.apply(acc_vector) - ideal_value) #Apply rotation and
substract ideal outcome
    return np.linalg.norm(acc_vector) #Return the norm. The norm of the desired
vector should be 0
try:
    try:
        ser_weather = serial.Serial('/dev/ttyUSB1', 9600) #Serial connection to
weather Arduino
        ser_acc1 = serial.Serial('/dev/ttyUSB0', 115200) #Serial connection to
accelerometer Arduino
        value = ser_weather.readline().decode('utf-8') #Get the serial value and
decode it to string
    except:
        ser_weather = serial.Serial('/dev/ttyUSB0', 9600) #Serial connection to
weather Arduino
        ser_acc1 = serial.Serial('/dev/ttyUSB1', 115200) #Serial connection to
accelerometer Arduino
except:
    try:
        ser_weather = serial.Serial('/dev/ttyUSB6', 9600) #Serial connection to
weather Arduino
        ser_acc1 = serial.Serial('/dev/ttyUSB5', 115200) #Serial connection to
accelerometer Arduino
        value = ser_weather.readline().decode('utf-8') #Get the serial value and
decode it to string
    except:
        ser_weather = serial.Serial('/dev/ttyUSB5', 9600) #Serial connection to
weather Arduino
        ser_acc1 = serial.Serial('/dev/ttyUSB6', 115200) #Serial connection to
accelerometer Arduino

i = 0
vertical_axis = 1 #Axis which points down
```

```
sample_number = 1000 #Amount of samples to be obained (time_window =
sample_number*delta_t)
time_vector = []
acc_vector1 = []
# acc_vector2 = []
# acc_vector3 = []

t = time.time() #Get refference time

while i<sample_number+10:
    value1 = ser_acc1.readline().decode('ISO-8859-1') #Acquire data from Arduino
in serial
#     value2 = ser_acc2.readline().decode('ISO-8859-1') #Acquire data from
Arduino in serial
#     value3 = ser_acc3.readline().decode('ISO-8859-1') #Acquire data from
Arduino in serial
    if i == 0:
        elapsed_init = time.time() - t #Get true initial time vs refference
    elapsed = time.time() - t #Get current time vs refference
    if elapsed > (elapsed_init + i*5/1000): #Get only values propperly formatted
every (1/desired_sampling_rate)
        elapsed = time.time() - t #Get current time vs refference
        time_vector.append(elapsed) #Store current time
        acc_vector1.append(value1) #Store the acceleration value
#         acc_vector2.append(value2) #Store the acceleration value
#         acc_vector3.append(value3) #Store the acceleration value
        i = i+1

#Format the time vector properly for stacking with acc if needed and with the
propper length, discarding initial 10 values
time_vector = np.array(time_vector).reshape((-1,1))
time_vector=time_vector-time_vector[10]
time_vector=time_vector[10:,:]
average_delta_t = np.average(np.array([time_vector[i]-time_vector[i-1] for i in
range(1,len(time_vector))])) #Get average (1/sampling_rate)

acc_vector1 = acc_vector1[10:] #Discard 10 initial values
acc_vector1 = np.array([np.nan_to_num(np.array(re.findall(r"[-+]?\d*\.\d+|\d+",
i), dtype='<U5').astype(np.float)) for i in acc_vector1]) #Convert acceleration
vector to float by finding all floats in every acc entry with re, forcing it to
strings with 5 or less characters type, and converting it to float, for every
acc entry
# acc_vector2 = acc_vector2[10:] #Discard 10 initial values
# acc_vector2 =
np.array([np.nan_to_num(np.array(re.findall(r"[-+]?\d*\.\d+|\d+", i),
dtype='<U5').astype(np.float)) for i in acc_vector2]) #Convert acceleration
vector to float by finding all floats in every acc entry with re, forcing it to
strings with 5 or less characters type, and converting it to float, for every
acc entry
# acc_vector3 = acc_vector3[10:] #Discard 10 initial values
# acc_vector3 =
np.array([np.nan_to_num(np.array(re.findall(r"[-+]?\d*\.\d+|\d+", i),
dtype='<U5').astype(np.float)) for i in acc_vector3]) #Convert acceleration
vector to float by finding all floats in every acc entry with re, forcing it to
```

```
strings with 5 or less characters type, and converting it to float, for every
acc entry

#Discard all null acceleration values, substituting them for the next value, or
the previous value if the last one is null
for i in range(len(acc_vector1)):
        if
((np.abs(acc_vector1[i,0])+np.abs(acc_vector1[i,1])+np.abs(acc_vector1[i,2]))<0.
25):
            if i<(len(acc_vector1)-1):
                acc_vector1[i,:]=acc_vector1[i+1,:]
            else:
                acc_vector1[i,:]=acc_vector1[i-1,:]
# #Discard all null acceleration values, substituting them for the next value,
or the previous value if the last one is null
# for i in range(len(acc_vector2)):
#         if
((np.abs(acc_vector2[i,0])+np.abs(acc_vector2[i,1])+np.abs(acc_vector2[i,2]))<0.
25):
#             if i<(len(acc_vector2)-1):
#                 acc_vector2[i,:]=acc_vector2[i+1,:]
#             else:
#                 acc_vector2[i,:]=acc_vector2[i-1,:]
# #Discard all null acceleration values, substituting them for the next value,
or the previous value if the last one is null
# for i in range(len(acc_vector3)):
#         if
((np.abs(acc_vector3[i,0])+np.abs(acc_vector3[i,1])+np.abs(acc_vector3[i,2]))<0.
25):
#             if i<(len(acc_vector3)-1):
#                 acc_vector3[i,:]=acc_vector3[i+1,:]
#            else:
#                 acc_vector3[i,:]=acc_vector3[i-1,:]
acc_vector1 = np.mean(acc_vector1, axis=0) #Get the mean of the acceleration on
each axis
angles1 = minimize(rotation, [0, 0], args = (acc_vector1, vertical_axis))
#Obtain the angles that makes the value of the acceleration the closest to
having the gravity value entirely in the vertical axis
angles1 = np.asarray([angles1.x[0], 0, angles1.x[1]])
np.save(working_dir + 'angles1.npy', angles1) #Save the angle values in an npy
file for later use
# acc_vector2 = np.mean(acc_vector2, axis=0) #Get the mean of the acceleration
on each axis
# angles2 = minimize(rotation, [0, 0, 0], args = (acc_vector2, vertical_axis))
#Obtain the angles that makes the value of the acceleration the closest to
having the gravity value entirely in the vertical axis
# np.save('angles2.npy', angles2.x) #Save the angle values in an npy file for
later use
# acc_vector3 = np.mean(acc_vector3, axis=0) #Get the mean of the acceleration
on each axis
# angles3 = minimize(rotation, [0, 0, 0], args = (acc_vector3, vertical_axis))
#Obtain the angles that makes the value of the acceleration the closest to
having the gravity value entirely in the vertical axis
# np.save('angles3.npy', angles3.x) #Save the angle values in an npy file for
```

later use

```
import time
import numpy as np
import re
import serial
import os
import scipy.signal as signal
import datetime
from scipy.spatial.transform import Rotation as R
import warnings
import pijuice
import RPi.GPIO as GPIO
from scipy.optimize import minimize
import shutil
import socket
import subprocess
import pickle
import sklearn

uptime = time.time()

warnings.filterwarnings("ignore")

#PiJuice WakeUpEnable script
while not os.path.exists('/dev/i2c-1'):
    time.sleep(0.1)

pj = pijuice.PiJuice(1, 0x14)

pj.rtcAlarm.SetWakeupEnabled(True)
#End of PiJuice WakeUpEnable script

battery_start = pj.status.GetChargeLevel()['data']/100

def internet(host="8.8.8.8", port=53, timeout=3):
  """
  Host: 8.8.8.8 (google-public-dns-a.google.com)
  OpenPort: 53/tcp
  Service: domain (DNS/TCP)
  """
  try:
    socket.setdefaulttimeout(timeout)
    socket.socket(socket.AF_INET, socket.SOCK_STREAM).connect((host, port))
    return True
  except socket.error as ex:
    print(ex)
    return False

def rotation(angles, acc_vector, vertical_axis):
    angles = np.asarray([angles[0], 0, angles[1]])
    r = R.from_euler('zyx', angles, degrees = True) #Define rotation
    ideal_value = np.zeros(3) #Define an ideal outcome vector after the 
application of rotation
    ideal_value[vertical_axis] = -1 #Set the vertical axis value to gravity, 
while keeping the rest of axes with 0 value
```

```
    acc_vector = abs(r.apply(acc_vector) - ideal_value) #Apply rotation and
substract ideal outcome
    return np.linalg.norm(acc_vector) #Return the norm. The norm of the desired
vector should be 0

working_dir = '/home/pi/SmartTower/'
data_dir = working_dir + 'data/' #Directory where data will be stored
current_dir_name = '{date:%Y-%m-%d_%H-%M}'.format(date=datetime.datetime.now())
current_dir = data_dir + current_dir_name
if not os.path.exists(current_dir):
    os.makedirs(current_dir)

shutil.copyfile(working_dir + 'static.csv', current_dir + '/static.csv')

#This function gets the coefficients for the construction of a lowpass filter of
cutoff frequency "cutoff", sampling
#frequency "fs" and order "order".
def butter_lowpass(cutoff, fs, order=5):
    nyq = 0.5 * fs
    normal_cutoff = cutoff / nyq
    b, a = signal.butter(order, normal_cutoff, btype='low', analog=False)
    return b, a

#This function applies the filter built with the previous function to the data
vector "data".
def butter_lowpass_filter(data, cutoff, fs, order=5):
    b, a = butter_lowpass(cutoff, fs, order=order)
    y = signal.lfilter(b, a, data)
    return y

try:
    try:
        ser_weather = serial.Serial('/dev/ttyUSB1', 9600) #Serial connection to
weather Arduino
        ser_acc1 = serial.Serial('/dev/ttyUSB0', 115200) #Serial connection to
accelerometer Arduino
        value = ser_weather.readline().decode('utf-8') #Get the serial value and
decode it to string
    except:
        ser_weather = serial.Serial('/dev/ttyUSB0', 9600) #Serial connection to
weather Arduino
        ser_acc1 = serial.Serial('/dev/ttyUSB1', 115200) #Serial connection to
accelerometer Arduino
    value = ser_weather.readline().decode('utf-8') #Get the serial value and
decode it to string
except:
    try:
        ser_weather = serial.Serial('/dev/ttyUSB6', 9600) #Serial connection to
weather Arduino
        ser_acc1 = serial.Serial('/dev/ttyUSB5', 115200) #Serial connection to
accelerometer Arduino
        value = ser_weather.readline().decode('utf-8') #Get the serial value and
decode it to string
    except:
```

```
        ser_weather = serial.Serial('/dev/ttyUSB5', 9600) #Serial connection to
weather Arduino
        ser_acc1 = serial.Serial('/dev/ttyUSB6', 115200) #Serial connection to
accelerometer Arduino

#ser_acc2 = serial.Serial('/dev/ttyUSB2', 115200) #Serial connection to
accelerometer Arduino
#ser_acc3 = serial.Serial('/dev/ttyUSB2', 115200) #Serial connection to
accelerometer Arduino

i = 0 #Reset counter
size = 3 #Amount of wind speed, direction and temperature data points before the
vibrations measurement
time_hist=[] #define the vector where the weather info will be stored

while i<size + 1:
    try:
        value = ser_weather.readline().decode('utf-8') #Get the serial value and
decode it to string
        time_hist.append(value) #Store the value in the time_hist vector
    except:
        i = i-1
    i = i+1
time_hist = time_hist[1:] #Discard the first value

g = 9.80665 #Value of gravity on Earth
vertical_axis = 1 #Axis which points down x:0 y:1 z:2
sample_number = 2000 #Amount of samples to be obained (time_window =
sample_number*delta_t)
average_delta_t = 1

# print(5)
# time.sleep(1)
# print(4)
# time.sleep(1)
# print(3)
# time.sleep(1)
# print(2)
# time.sleep(1)
# print(1)
# time.sleep(1)
# print('Go!')

while average_delta_t>=0.005001:
    i = 0
    acc_vector1 = []
#    acc_vector2 = []
#    acc_vector3 = []
    time_vector = []
    t = time.time() #Get refference time

    while i<sample_number+10:
        value1 = ser_acc1.readline().decode('ISO-8859-1') #Acquire data from
Arduino in serial
```

```
#        value2 = ser_acc2.readline().decode('ISO-8859-1') #Acquire data from
Arduino in serial
#        value3 = ser_acc3.readline().decode('ISO-8859-1') #Acquire data from
Arduino in serial
        if i == 0:
            elapsed_init = time.time() - t #Get true initial time vs refference
        elapsed = time.time() - t #Get current time vs refference
        if elapsed > (elapsed_init + i*4.8/1000): #Get only values propperly
formatted every (1/desired_sampling_rate)
            elapsed = time.time() - t #Get current time vs refference
            time_vector.append(elapsed) #Store current time
            acc_vector1.append(value1) #Store the acceleration value
#            acc_vector2.append(value2) #Store the acceleration value
#            acc_vector3.append(value3) #Store the acceleration value
            i = i+1

    #Format the time vector properly for stacking with acc if needed and with
the propper length, discarding initial 10 values
    time_vector = np.array(time_vector).reshape((-1, 1))
    time_vector = time_vector - time_vector[10]
    time_vector = time_vector[10:,:]
    acc_vector_monitor = acc_vector1
    average_delta_t = np.average(np.array([time_vector[i] - time_vector[i-1] for
i in range(1, len(time_vector))])) #Get average (1/sampling_rate)
# print('read')

i = 0 #Reset counter
while i<size:
    value = ser_weather.readline().decode('utf-8') #Get the serial value and
decode it to string
    time_hist.append(value) #Store the value in the time_hist vector
    i = i+1

time_hist = np.array([i.split('\\')[0].split(';') for i in time_hist]) #Reformat
the "time_hist" vector to have all values separated
windspeed =  np.average(time_hist[:,0].astype('float')) #Get average wind speed
direction = time_hist[:,1] #Get direction values
direction_dictionary = {'N': 0, 'NE': 45, 'E': 90, 'SE': 135, 'S': 180, 'SW':
225, 'W': 270, 'NW': 315} #Dictionary for direction to degree conversion
direction = np.average(np.array([direction_dictionary[i] for i in direction]))
#Convert direction to degrees
temp =  np.average(time_hist[:,2].astype('float')) #Get temperature

acc_vector1 = acc_vector1[10:] #Discard 10 initial values
acc_vector1 = np.array([np.nan_to_num(np.array(re.findall(r"[-+]?\d*\.\d+|\d+",
i), dtype='<U5').astype(np.float)) for i in acc_vector1]) #Convert acceleration
vector to float by finding all floats in every acc entry with re, forcing it to
strings with 5 or less characters type, and converting it to float, for every
acc entry
acc_vector1 = acc_vector1*g #Convert acceleration values to m*s^-2
#acc_vector2 = acc_vector2[10:] #Discard 10 initial values
#acc_vector2 = np.array([np.nan_to_num(np.array(re.findall(r"[-+]?\d*\.\d+|\d+",
i), dtype='<U5').astype(np.float)) for i in acc_vector2]) #Convert acceleration
vector to float by finding all floats in every acc entry with re, forcing it to
```

```
strings with 5 or less characters type, and converting it to float, for every
acc entry
#acc_vector2 = acc_vector2*g #Convert acceleration values to m*s^-2
#acc_vector3 = acc_vector3[10:] #Discard 10 initial values
#acc_vector3 = np.array([np.nan_to_num(np.array(re.findall(r"[-+]?\d*\.\d+|\d+",
i), dtype='<U5').astype(np.float)) for i in acc_vector3]) #Convert acceleration
vector to float by finding all floats in every acc entry with re, forcing it to
strings with 5 or less characters type, and converting it to float, for every
acc entry
#acc_vector3 = acc_vector3*g #Convert acceleration values to m*s^-2

try:
    rotation_angles1 = np.load(working_dir + 'angles1.npy') #Import calibration
rotation angles
except:
    try:
        rotation_angles1 = np.load(working_dir + 'angles2.npy') #Import
calibration rotation angles
        os.system('python3 ' + working_dir + 'calibration.py')
        os.remove(working_dir + 'angles2.npy')
        rotation_angles1 = np.load(working_dir + 'angles1.npy') #Import
calibration rotation angles
    except:
        os.system('python3 ' + working_dir + 'calibration.py')
        os.rename(working_dir + 'angles1.npy', working_dir + 'angles2.npy')
        rotation_angles1 = np.load(working_dir + 'angles2.npy') #Import
calibration rotation angles

#rotation_angles2 = np.load(working_dir + 'angles2.npy') #Import calibration
rotation angles
#rotation_angles3 = np.load('angles3.npy') #Import calibration rotation angles
r1 = R.from_euler('zyx', rotation_angles1, degrees = True) #Define the rotation
#r2 = R.from_euler('zyx', rotation_angles2, degrees = True) #Define the rotation
#r3 = R.from_euler('zyx', rotation_angles3, degrees = True) #Define the rotation

for i in range(len(acc_vector1)):
    acc_vector1[i,:] = r1.apply(acc_vector1[i,:]) #Apply the rotation to all
acceleration values
#for i in range(len(acc_vector2)):
#    acc_vector2[i,:] = r2.apply(acc_vector2[i,:]) #Apply the rotation to all
acceleration values
#for i in range(len(acc_vector3)):
#    acc_vector3[i,:] = r3.apply(acc_vector3[i,:]) #Apply the rotation to all
acceleration values

#Discard all null acceleration values, substituting them for the next value, or
the previous value if the last one is null
for i in range(len(acc_vector1)):
        if
((np.abs(acc_vector1[i,0])+np.abs(acc_vector1[i,1])+np.abs(acc_vector1[i,2]))<0.
25):
            if i<(len(acc_vector1)-1):
                acc_vector1[i,:]=acc_vector1[i+1,:]
            else:
```

```
                acc_vector1[i,:]=acc_vector1[i-1,:]
##Discard all null acceleration values, substituting them for the next value, or
the previous value if the last one is null
#for i in range(len(acc_vector2)):
#        if
((np.abs(acc_vector2[i,0])+np.abs(acc_vector2[i,1])+np.abs(acc_vector2[i,2]))<0.
25):
#            if i<(len(acc_vector2)-1):
#                acc_vector2[i,:]=acc_vector2[i+1,:]
#            else:
#                acc_vector2[i,:]=acc_vector2[i-1,:]
##Discard all null acceleration values, substituting them for the next value, or
the previous value if the last one is null
#for i in range(len(acc_vector3)):
#        if
((np.abs(acc_vector3[i,0])+np.abs(acc_vector3[i,1])+np.abs(acc_vector3[i,2]))<0.
25):
#            if i<(len(acc_vector3)-1):
#                acc_vector3[i,:]=acc_vector3[i+1,:]
#            else:
#                acc_vector3[i,:]=acc_vector3[i-1,:]

#Get angle of inclination of the tower by seeing how it has to rotate it's
refference to align with gravity (euler angles intrinsic)
acc_vector_current = np.mean(acc_vector1, axis=0) #Get the mean of the
acceleration on each axis
angles_current = minimize(rotation, [0, 0], args = (acc_vector_current,
vertical_axis)) #Obtain the angles that makes the value of the acceleration the
closest to having the gravity value entirely in the vertical axis
angle_x = angles_current.x[1]
angle_z = angles_current.x[0]
angles_current = np.asarray([angle_z, 0, angle_x])
r2 = R.from_euler('zyx', angles_current, degrees = True) #Define the rotation

for i in range(len(acc_vector1)):
    acc_vector1[i,:] = r2.apply(acc_vector1[i,:]) #Apply the rotation to all
acceleration values

acc_vector1[:,vertical_axis] = acc_vector1[:,vertical_axis]-g #Clean vertical
axis to only vibration induced acceleration
#acc_vector2[:,vertical_axis] = acc_vector2[:,vertical_axis]-g #Clean vertical
axis to only vibration induced acceleration
#acc_vector3[:,vertical_axis] = acc_vector3[:,vertical_axis]-g #Clean vertical
axis to only vibration induced acceleration

#Generate the time respone vector
#time_response = np.hstack((time_vector,acc_vector1,acc_vector2,acc_vector3))
#time_response = np.hstack((time_vector,acc_vector1,acc_vector2))
time_response = np.hstack((time_vector,acc_vector1))

#Save the time series vector
np.savetxt(current_dir + '/' + 'time_response.csv', time_response,
delimiter=',')
```

```
#Compute vector of frequencies
freq = np.fft.fftfreq(acc_vector1.shape[0], d = average_delta_t)
freq = freq[0:int(np.round(len(freq)/2))]

#Compute FFT for every axis
fft_x1 = np.fft.fft(acc_vector1[:,0])
fft_y1 = np.fft.fft(acc_vector1[:,1])
fft_z1 = np.fft.fft(acc_vector1[:,2])
#Discard negative frequencies half
fft_x1 = fft_x1[0:int(np.round(len(fft_x1)/2))]
fft_y1 = fft_y1[0:int(np.round(len(fft_y1)/2))]
fft_z1 = fft_z1[0:int(np.round(len(fft_z1)/2))]
#Set value of first point to a reasonable value
fft_x1[0] = fft_x1[1]
fft_y1[0] = fft_y1[1]
fft_z1[0] = fft_z1[1]

fft = {0:fft_x1, 1:fft_y1, 2:fft_z1}

peaks = []

for i in range(3):
    peaks.append(freq[signal.find_peaks(np.abs(fft[i]),
height=np.average(np.abs(fft[i]))*1.5, distance=500)[0]])

battery_end = pj.status.GetChargeLevel()['data']/100
uptime = time.time()-uptime

#np.savetxt(current_dir + '/' + 'data.csv', np.array([windspeed, direction,
temp, angle, longitude, latitude, battery_start, battery_end,
uptime]).conj().transpose(), delimiter=',') #Store all that data to csv file

windspeed = windspeed * (3.9/6.6)

data = np.array([windspeed, direction, temp, angle_x, angle_z, battery_start,
battery_end, uptime]).conj().transpose()
np.savetxt(current_dir + '/' + 'data.csv', data, delimiter=',') #Store all that
data to csv file

shutil.make_archive(data_dir + '/' + current_dir_name, 'zip', current_dir)

f = open(working_dir + 'unsent.txt', 'a+')
f.write(data_dir + current_dir_name + '\n')
f.close()

log = []

import smtplib
from email.mime.text import MIMEText
from email.mime.multipart import MIMEMultipart
from email.mime.base import MIMEBase
from email import encoders
import os.path
import requests
```

```
with open(working_dir + 'unsent.txt', 'r') as f:
    lines = f.readlines()

for line in lines:
    email = 'labseat@gmail.com'
    password = 'LabSeat2020'
    send_to_email = 'labseat@gmail.com'
    subject = line.split('/')[-1]
    message = subject
    file_location = line.split('\n')[0]

    msg = MIMEMultipart()
    msg['From'] = email
    msg['To'] = send_to_email
    msg['Subject'] = subject

    msg.attach(MIMEText(message, 'plain'))

    # Setup the attachment
    filename = os.path.basename(file_location + '.zip')
    attachment = open(file_location + '.zip', "rb")
    part = MIMEBase('application', 'octet-stream')
    part.set_payload(attachment.read())
    encoders.encode_base64(part)
    part.add_header('Content-Disposition', "attachment; filename= %s" %
filename)

    # Attach the attachment to the MIMEMultipart object
    msg.attach(part)

    with open(working_dir + 'unsent.txt', 'r') as f:
                lines_count = f.readlines()
    unsent_length = len(lines_count)

    i = 0
    while i < 10:
        j = 0
        try:
            while (not(internet()) and j < 10):
                log.append(internet())
                p = subprocess.Popen([working_dir + 'online.sh'])
                try:
                    p.wait(10)
                except subprocess.TimeoutExpired:
                    p.kill
                j = j + 1
        except Exception as e3:
            log.append(e3)
        try:
            with open(working_dir + 'unsent.txt', 'r') as f:
                lines_count = f.readlines()
            new_unsent_length = len(lines_count)
            if unsent_length == new_unsent_length:
```

```
                try:
                    server = smtplib.SMTP('smtp.gmail.com', 587, timeout=10)
                    server.starttls()
                    server.login(email, password)
#                     server.connect()
#                     print('possible error1')
                    text = msg.as_string()
    #                 server.sendmail(email, "marco.aperez@smarttower.tech", 
text)
    #                 server.sendmail(email, "guillermoreyesc@iqs.edu", text)
    #                 server.sendmail(email, "joan.fernandez@iqs.edu", text)
                    server.sendmail(email, "labseat@gmail.com", text)
#                     print('possible error2')
                except Exception as e1:
                    log.append(e1)
                data = np.genfromtxt(file_location + '/data.csv', delimiter=',')
#                 for i in range(data):
#                 payload = {'tower' : 1, 'longitude' : 1.15645856525, 
'latitude' : 4.52525541589, 'windspeed' : data[0], 'direction' : data [1], 
'temp' : data[2], 'angle_x' : data[3], 'angle_z' : data[4], 'battery_start' : 
data[5], 'battery_end' : data[6], 'uptime' : data[7],
#                            'peak1x' : peaks[0], 'peak2x' : peaks[1], 'peak3x' 
: peaks[2], 'peak4x' : peaks[3], 'peak5x' : peaks[4],
#                            'peak1y' : peaks[5], 'peak2y' : peaks[6], 'peak3y' 
: peaks[7], 'peak4y' : peaks[8], 'peak5y' : peaks[9],
#                            'peak1x' : peaks[10], 'peak2z' : peaks[11], 
'peak3z' : peaks[12], 'peak4z' : peaks[13], 'peak5z' : peaks[14]}
                static = np.genfromtxt (working_dir + 'static.csv', 
delimiter=",")
                try:
                    payload = {'tower' : static[0], 'longitude' : static[1], 
'latitude' : static[2], 'windspeed' : data[0], 'direction' : data [1], 'temp' : 
data[2], 'angle_x' : data[3], 'angle_z' : data[4], 'battery_start' : data[5], 
'battery_end' : data[6], 'uptime' : data[7], 'peak1' : peaks[0][0], 'peak2' : 
peaks[0][1]}
                except:
                    payload = {'tower' : static[0], 'longitude' : static[1], 
'latitude' : static[2], 'windspeed' : data[0], 'direction' : data [1], 'temp' : 
data[2], 'angle_x' : data[3], 'angle_z' : data[4], 'battery_start' : data[5], 
'battery_end' : data[6], 'uptime' : data[7], 'peak1' : 0, 'peak2' : 0}

                try:
                    log.append('try')
                    post = requests.post('http://35.187.62.162:1880/towers', 
data=payload, auth=('admin', 'Sm4rtt0w3r'), timeout=1)
#                     post = requests.post('http://35.187.62.162:1880/towers', 
data=payload, timeout=1)
#                     post = requests.post('http://35.242.140.41:1880/test1', 
data=payload, timeout=1)
                except requests.Timeout:
                    time.sleep(0)
                    log.append('sent')
#                 server.quit()
                shutil.rmtree(file_location + '/')
```

```
#                 os.remove(file_location + '.zip')
                i = 10
                with open(working_dir + 'unsent.txt', 'r') as f:
                    lines_rewrite = f.readlines()
                with open(working_dir + 'unsent.txt', 'w') as f:
                    for line_rewrite in lines_rewrite:
#                         print(line_rewrite)
                        if line_rewrite.strip('\n') != file_location:
                            f.write(line_rewrite)
            else:
                i = 10
        except Exception as e2:
            log.append(e2)
            i = i + 1

with open(working_dir + 'log/' + subject.strip('\n') + '.txt', 'w+') as f:
    for item in log:
        f.write("%s/n" % item)

pj.rtcAlarm.SetAlarm({'second': 0, 'minute': 0, 'hour': '0;8;16', 'day':
'EVERY_DAY'})

pj.power.SetPowerOff(20)

os.system('sudo shutdown -h now')
```

```
import time
import os
import subprocess
from pijuice import PiJuice

time.sleep(60*5)

pj=PiJuice(1,0x14)
pj.power.SetPowerOff(25)

os.system('sudo shutdown -h now')
```

```
import time
import os
import subprocess
from pijuice import PiJuice

pj=PiJuice(1,0x14)
pj.power.SetPowerOff(10)

os.system('sudo shutdown -h now')
```