ARCH

# ARCH D5.4

IoT Platform for Digital Twin

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# Executive Summary

This deliverable has been prepared for the European Commission-funded research project ARCH: Advancing Resilience of historic areas against Climate-related and other Hazards. It is the key output of task 5.4 "IoT Platform for real-time impact estimation based on Digital Twin" within work package 5 "Impact & Risk Assessment." The aim of Task 5.4 was the development and building of an Internet of Things (IoT) platform to gather relevant real-time data from heritage assets (temperature, humidity, crack width, vibration, etc.) for impact and risk assessment.

The D5.4 report, IoT Platform for Digital Twin, describes the architecture of the IoT Platform, how to deliver IoT sensing data to the management system, and the protocol and data format of captured data. Specifically, the work describes in this deliverable focuses on:

- the provision of the IoT Platform architecture for Digital Twin to collect data from sensors in real-time for monitoring the environmental status and transmits the data through LoRaWAN Gateway to the Data Monitoring System (DMS) and ARCH information systems (HArIS/THIS). The data could be used to predict potential risks using Artificial Intelligence (AI) or Big Data analysis and the Critical Infrastructure Protection risk analysis and foreCast Decision Support System (CIPCast DSS) to estimate impact and risk of hazard.
- the development of IoT sensor nodes for measuring such parameters as temperature & humidity, vibration, tilt, and cracks. They can be directly installed on the body of cultural assets almost without damage because they are small-sized and light.
- the development of an IoT communication Gateway that gathers data collected from sensor nodes and transmits it to DMS and the Threats and Hazard Information System (THIS). The transmission range of the sensor nodes to the Gateway is up to 5 km in open space.
- the implementation of an IoT monitoring system that shows the data collected from sensors on the web browser. By monitoring the data or graph displayed on the screen, the abnormal condition of cultural assets can be detected.
- the deployment of an IoT Platform to cultural heritage sites in South Korea called Gangwon-do province. The platform can measure the change of state in a total of 25 cultural assets, including 'Soyangjeong' located in 'Chuncheon' city.

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# Table of Abbreviations

| Abbreviation | Explanation |
|---|---|
| **3D** | Three Dimension |
| **4G/5G** | Fourth generation/Fifth generation of broadband cellular network technology |
| **AC** | Alternating Current |
| **AI** | Artificial Intelligence |
| **AMD** | (Company Name) Advanced Micro Devices |
| **AMP** | Amplifier |
| **API** | Application Programming Interface |
| **CAT** | Category |
| **CH** | Cultural Heritage |
| **CIPCast** | Critical Infrastructure Protection risk analysis and foreCast |
| **CPU** | Central Processing Unit |
| **DC** | Direct Current |
| **DGPIO** | Digital General-Purpose Input/output |
| **DHCP** | Dynamic Host Configuration Protocol |
| **DIV** | Division (HTML Tag) |
| **DMS** | Data Monitoring System |
| **DOM** | Document Object Model |
| **DSS** | Decision Support System |
| **GB** | Gigabyte |
| **GIS** | Geographic Information System |
| **GMT** | Greenwich Mean Time |
| **GPIO** | General Purpose Input & Out |
| **GTX** | (Brand Name) Video chipset of NVidia Corporation |
| **GUI** | Graphical User Interface |
| **HA** | Historical Area |

| Abbreviation | Explanation |
|---|---|
| **HArIS** | Historic Areas Information System |
| **HD** | High Definition |
| **HDD** | Hard Disk Drive |
| **HTTP** | Hypertext Transfer Protocol |
| **HTTPS** | Hypertext Transfer Protocol over Secure Socket Layer |
| **IC** | Integrated Circuit |
| **ID** | Identifier |
| **IE** | Internet Explorer |
| **IEC** | International Electrotechnical Commission |
| **IoT** | Internet of Thing |
| **IP** | Internet Protocol |
| **ISM** | Industrial, Scientific and Medical |
| **JSON** | JavaScript Object Notation |
| **KMA** | Korea Meteorological Administration |
| **LED** | Light Emitting Diode |
| **LoRaWAN** | Long Range Wide Area Network |
| **OS** | Operating System |
| **PCB** | Printed Circuit Board |
| **PHP** | Personal Home Page |
| **RAM** | Random Access Memory |
| **RDBMS** | Relational Data Base Management System |
| **REST** | REpresentational State Transfer |
| **RF** | Radio Frequency |
| **RH** | Relative Humidity |
| **SMPS** | Switching Mode Power Supply |
| **SSD** | Solid State Drive |
| **THIS** | Threats and Hazard Information System |

| Abbreviation | Explanation |
|---|---|
| **UI** | User Interface |
| **URL** | Uniform Resource Locator |
| **UTP** | Unshielded Twisted Pair cable |
| **VGA** | Video Graphics Array |

# 1. Introduction

ARCH is a European-funded research project that aims to enhance the resilience of areas of cultural heritage to climate change-related and other hazards. Tools and methodologies are developed with the pilot cities of Bratislava, Camerino, Hamburg, and Valencia, in a co-creative approach with local policy makers, practitioners, and community members. The results will be combined into a collaborative disaster risk management platform for local authorities and practitioners, the urban population, and international expert communities. A range of models and methods will be developed to support decision-making at appropriate stages of the management cycle. The results of the co-creation processes with the pilot cities will be disseminated to a broader circle of other European municipalities and practitioners and through European standardization.

As part of the project work, work package 5 examined how to develop and use Digital Twin models of heritage assets. Specifically, it developed an Internet of Things (IoT) sensor platform to gather live data from real-world heritage assets and link this data to 3D models to support visualizing impact estimates of risks or hazards for decision support.

This report (D5.4), reports on the development of the IoT platform, its prototypical deployment at South Korean heritage sites, and how the data from the platform is integrated with the information management systems developed as part of WP4.

## 1.1. Gender statement

This document has been developed taking into consideration the guidance on gender in research provided in the *Project Handbook* (D1.2)[1] as well as State-of-the-Art report number 5 of deliverable D7.1[2] on "*Gender aspects in conservation and regulation of historic areas, disaster risk management, emergency protocols, post-disaster response techniques, and techniques for building back better*".

## 1.2. Relation to other deliverables

This report (D5.4) is the accompanying document to the demonstrator for activity 5.4 'IoT Platform for real-time impact estimation based on Digital Twin' within Work Package 5 (WP5) 'Impact & Risk Assessment'. The objectives of WP5 are to provide methods and tools to assess, calculate, and visualise potential impacts to and risk of historic areas and to adapt the CIPCast decision support system for impact and risk estimation for historic assets. In the framework of WP5, hazard models for impact estimates and DSS are developed to support:

[1] D. Lückerath, "ARCH D1.2 *Project Handbook*," H2020 ARCH, GA no. 820999, 2019.
[2] V. Rebollo, T. Rangil-Escribano and E. Chapman, "*ARCH D7.1 State-of-the-Art report no. 5: Gender aspects in conservation and regulation of historic areas, disaster risk management, emergency protocols, post-disaster response techniques, and techniques for building back better*," H2020 ARCH, GA no. 820999, 2019.

- the HArIS (WP4) for archiving the properties of the heritage and the characteristics of the historic area as a whole interacting with the surrounding urban and natural systems;
- the Threats and Hazard Information System (THIS) to "combine" data from different sources to obtain measurable indicators to characterize the hazards that potentially affect the historical area and to collect historical and real-time data performed by climate services and/or through specific monitoring.

Accordingly, the contents of this document and the systems described therein are mainly linked to:

(1) environmental sensors of the IoT Platform for Digital Twin
(2) visualization of impact assessment with Digital Twin provided by WP5
(3) the needs arising from ARCH cities and the technical partners
(4) the consequent analyses performed by the other work packages

Therefore, D5.4 is directly related to the following deliverables:

- **D4.1** Sensing and Repositories
- **D4.2** Historic Area Information Management System (HArIS)
- **D4.3** Threats and Hazard Information Management System (THIS)
- **D5.1** Hazard models for impact assessment
- **D5.5** Digital Twin models for impact assessment
- **D7.4** Requirements description
- **D7.6** System design, realisation, and integration

The chart in **Figure 1** is a graphical representation of the interaction between D5.4 and the before mentioned deliverables with their related tasks.

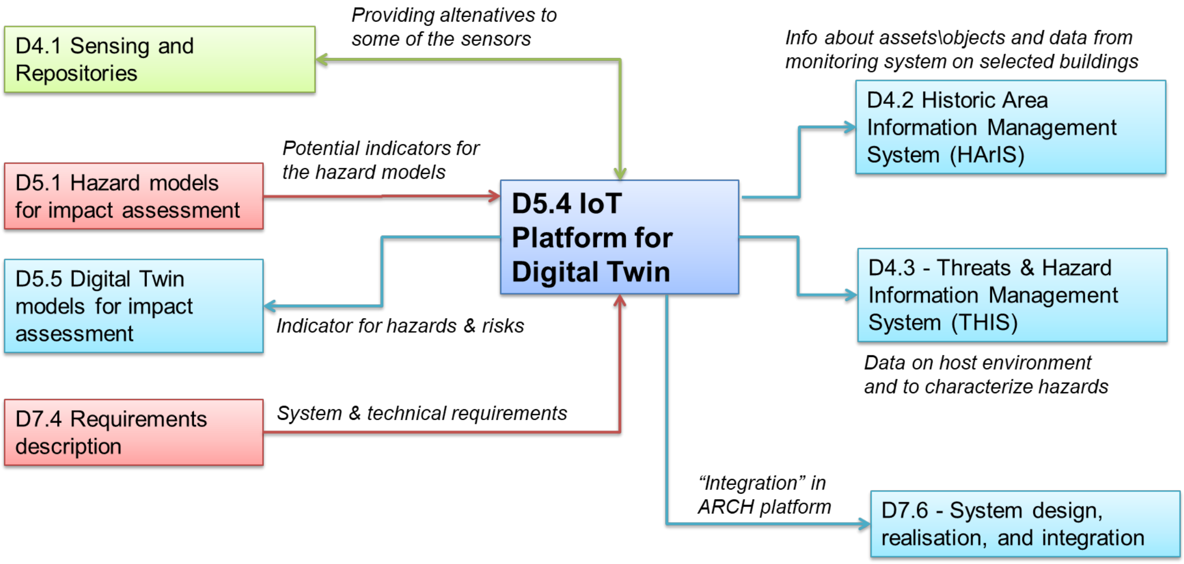


**Figure 1.** Representation of the main interactions between D5.4 and the other ARCH deliverables.

It is worth pointing out that the developments described in this document support dynamic information systems and can themselves undergo improvements, so they can be updated even after their delivery. Likewise, any new datasets and information collected by technological systems within the ARCH project will feed the information systems, even if they are obtained after the drafting of this document.

## 1.3. Structure of this report

The report is divided into six sections:

- Following this introduction, **Section 2** describes the Internet of Thing, IoT, platform architecture for Digital Twin composed of several sensor nodes, LoRaWAN Gateway, a server, and a monitoring system.
- **Section 3** describes the IoT monitoring system operating on the web browser. Data collected from several sensors are displayed with a graph on the dashboard.
- **Section 4** represents the integration of the IoT Platform and Web interface with the HArIS and THIS.
- **Section 5** gives a case study on the deployment of the IoT platform in South Korea. It was installed on the 'Soyangjeong' located in 'Chuncheon' city. Tilt displacement and the effect of the environment could be detected through the analysis of the graph.
- Bibliographic references (**Section 6**) are reported at the end of the document.
- **Annex A** reports on the sensors developed to collect an environmental status such as temperature & humidity or to measure crack & distance and install them to cultural heritages.
- **Annex B** focuses on the IoT communication Gateway and its operation and connection method. The internal components such as the power supply and motherboard are also illustrated.

# 2. IoT Platform Architecture for Digital Twin

## 2.1. Digital Twin for Cultural Heritage

Digital Twin couples the physical world and the physical systems with the same structures in the virtual world. It enables monitoring, simulating, visualizing information, validating services, and experiencing the relevant virtual space by using various sensing technologies provided by IoT and 5G. To make a Digital Twin of the heritage asset, it needs many technologies and resources such as a management history, real-time IoT sensor data, 3D model, hazard model, etc.

The 3D model, damage functions, hazard model, and fragility model from WP4 and WP5 can be used to realize Digital Twin for Cultural Heritage (CH). As a result, the Digital Twin of a heritage asset can be used to predict, manage, and respond to disasters before or after them (Figure 2).

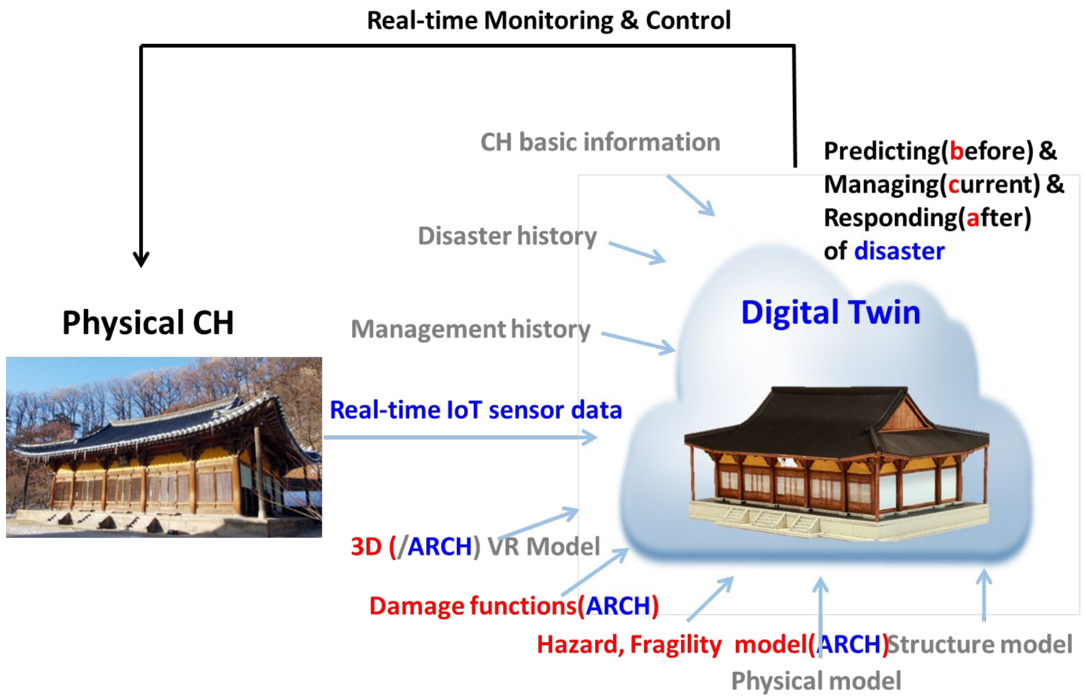


**Figure 2.** Concept of Digital Twin

Digital Twin can be integrated into the ARCH CIPCast DSS platform (T5.3) to visualize vulnerability and risk data on the 3D virtual space. And the data collected from the IoT Platform will be used in picturing the status of the cultural asset in task 5.5. How to visualize the data of the IoT Platform will be described in D5.5.

## 2.2. System Architecture

Figure 3 shows the diagram of system architecture that represents how data collected from sensors in the heritage sites are transmitted to LoRaWAN Gateway. Depending on the communication environment, it is recommended that the distance between the sensor and the Gateway be at least 1km apart.

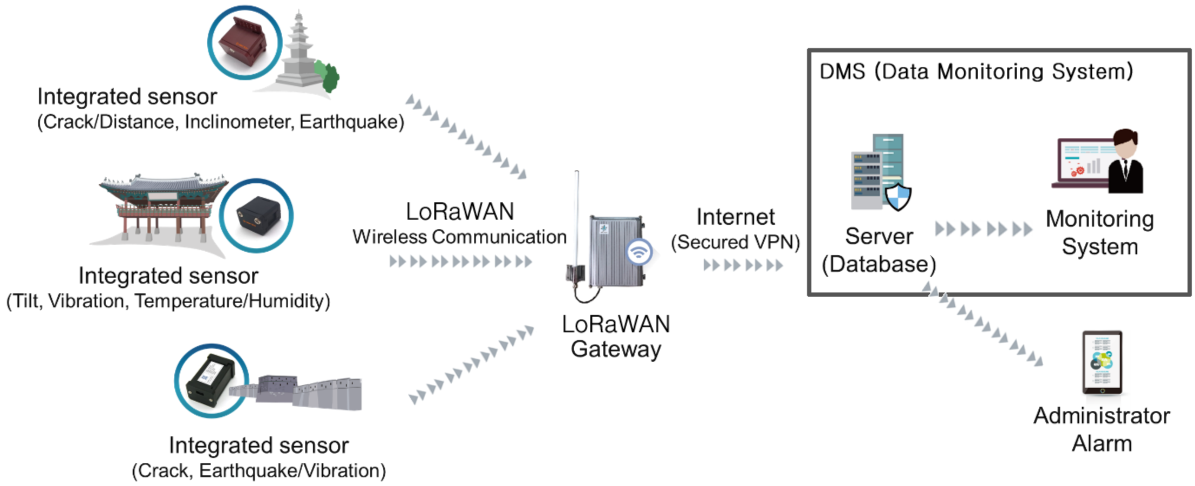


**Figure 3.** Diagram of system architecture

LoRaWAN Gateway can transmit data to a server over wired or wireless (4G/5G) Internet. A server stores the received data in the database, and then it can be used in data analysis or provided to the monitoring system. For example, a user can know the status of the sensor-installed heritage site through the monitoring system (Figure 3).

## 2.3. System components

### 2.3.1. Sensor Node

The sensor can be directly attached to the surface or component of each architectural or cultural property to collect state data and transmit it to a remote Gateway. It can communicate wirelessly. Since it uses a Lithium-ion primary battery, it has high-efficiency energy capacity and has high safety compared to the secondary batteries. The battery life is estimated at a minimum of 3 years and a maximum of 5 years.

When the battery reaches the end of its life, it should be replaced. Recharge or reuse is not supported. The battery life varies depending on the communication environment. The poorer the communication environment, the more battery is consumed. It is recommended to replace a battery every three years. Table 1 shows the developed IoT sensors.

**Table 1.** IoT sensors

| Name | Component(s) | Units |
|---|---|---|
| Temperature and humidity sensor | • Integrated measuring sensor | • Temperature: Celsius Degree<br>• Humidity: RH% |
| Tilt sensor (Inclinometer) | • Measurement sensor unit Communication module and battery part | • Inclination X, Y: Degree |
| Crack sensor (Distance sensor) | • Measuring magnet<br>• Measurement sensor unit<br>• Communication module and battery | • Distance between magnet and sensor: mm |

The IoT sensors are not the only sensors developed within the ARCH project. In order to collect environmental information over large geographical areas RFSAT acquires relevant information from 3rd-party open access cloud services, such as Netatmo Weathermap [3], OpenWeathermap [4], global natural disaster monitoring services and similar ones, for subsequent upload of processed data for each of the sites supported in ARCH to the THIS server deployed by INGV as describe in ARCH D4.1. In addition, RFSAT provides in-situ deployed sensors that can offer supplementary monitoring data and information in areas not covered by pre-existing sensor networks (Table 2) and/or when accurate measurements (using calibrated sensors) are required for very specific areas.

Sensor nodes purposely developed by RFSAT in collaboration with Analog Devices in Ireland and based on the MVP gas sensor board offer added value in providing more sensing elements (temperature, humidity, pressure, and four more custom sensors out of a list of over 70 different options) compared to similar nodes such as Libelium Plug & Sense [5] offering six custom sensors. Sensors built by RFSAT can operate both in a fixed position (mounted at a specific location) for constant monitoring of important environmental parameters as described in the ARCH D4.1 and for mobile applications when measurements can be made periodically while traversing over predefined routes e.g. suitable for mounting on bikes, motorbikes, public transport/utility vehicles and so attractive for cities.

Table 2 compares the provided sensors from ARCH D4.1 and ARCH D5.4 (the IoT sensors). We can complement the sensors & approaches from RFSAT and INGV, although these sensors were developed for the IoT platform for real-time impact estimation based on Digital Twin and visualization of impact assessment with Digital Twin. So, we can provide alternatives to some of the sensors to give users more choice and test out a more extensive 'set' of sensors.

[3] NetAtmo Weathermap: https://weathermap.netatmo.com/
[4] OpenWeathermap: https://openweathermap.org/
[5] Libelium Plug & Sense: https://www.libelium.com/iot-products/plug-sense/

**Table 2.** Comparison of Sensor Node

| Sensors | ARCH D4.1 | ARCH D5.4 |
|---|---|---|
| Temperature sensor | Provided<br>• Analog devises MVP (RFSAT)<br>• RASPI-Zero + Turta uHAT (RFSAT)<br>• M5Stack + Grove-based nodes (RFSAT) | Provided<br>• STM32L0 based integrated sensor node<br>• Sensirion environment sensor (ETRI) |
| Humidity sensor | Provided<br>• Analog devises MVP (RFSAT)<br>• RASPI-Zero + Turta uHAT (RFSAT)<br>• M5Stack + Grove-based nodes (RFSAT) | Provided<br>• STM32L0 based integrated sensor node (ETRI)<br>• Sensirion environment sensor (ETRI) |
| Tilt (Inclinometer) sensor | Not Provided | Provided<br>• STM32L0 based integrated sensor node<br>• SCA103T 2-Axis Inclinometer with SPI connection (ETRI) |
| Crack (Distance) sensor | Not Provided | Provided<br>• STM32L0 based integrated sensor node<br>• Magnetic detection using Bosch BMX055 sensor (ETRI)<br>• Magnetometer value to distance (mm) conversion (ETRI) |
| Crack size: length, width, and depth (subject to 3D model available) | Provided<br>• Machine Learning detection using aerial images from UAVs (RFSAT)<br>• FBX model analysis for depth estimation from high-res 3D models (RFSAT) | Not Provided |
| Pressure sensor | Provided<br>• Analog devises MVP (RFSAT)<br>• RASPI-Turta uHAT (RFSAT)<br>• M5Stack + Grove-based nodes (RFSAT) | Not Provided |
| Air quality and pollution | Custom parameters:<br>• Analog devises MVP (RFSAT) supports 4 out of 70 to choose from compatible with 2-lead, 3- | Not Provided |

| Sensors | ARCH D4.1 | ARCH D5.4 |
|---|---|---|
| | lead, and 4-lead electrochemical gas sensors | |
| Air quality and pollution | Custom parameters (various):<br>• M5Stack based (RFSAT) compatible with Grove-based sensors | Not Provided |

### 2.3.2. Gateway

The Gateway operates as an intermediary that forwards the data received from the sensors to the server. Therefore, it is generally installed within 1km away from cultural assets. The Gateway must always be connected to the internet, and the power supply must be stable. Table 3 shows the hardware characteristics of Gateway.

**Table 3.** Gateway Components

| Name | Specification |
|---|---|
| Material | Aluminium die casting |
| Size | Width: 225mm<br>Height: 300mm<br>Depth: 86mm |
| Operation temperature | (-)15 ~ (+)40$^{o}$C |
| Wireless communication | LoRaWAN AP2<br>KR920 Bandwidth Configuration |

### 2.3.3. Monitoring System

The monitoring system can provide data from the Gateway or the server in real-time. It can also provide historical tracking. Specifically, the interface of the monitoring system was developed based on Geographic Information System (GIS) and aimed to display additional information and the current safety status of cultural properties installed in each historical region. Table 4 shows the technical components of the monitoring system.

**Table 4.** Monitoring System Components

| Name | Specification |
|---|---|
| Server | CentOS 7.3 x64 |
| Client | Web browser, Chromium-based |
| Protocol | HTTP or HTTPS |
| Authentication | Cookie (Nonsecure) |

# 3. IoT Monitoring System

## 3.1. System requirements

### 3.1.1. Minimum requirements

Table 5 shows the minimum system requirements of the IoT monitoring system for the dedicated computer required to run it.

**Table 5.** Minimum requirements of the IoT Monitoring System

| Name of component | Specification | Remarks |
|---|---|---|
| CPU | Dual-core Intel Pentium 1.6GHz | |
| RAM | 4GB | |
| HDD | Available space of 2GB or more | |
| VGA | 3D accelerator graphic card (Intel HD Graphics) | |
| OS | Windows 7 | |
| Internet Connection | Ethernet over 100Mbps | Wired Internet is required |
| Web Browser | Google Chrome | Chromium tested |

### 3.1.2. Recommended requirements

Table 6 describes the recommended system requirements of the IoT monitoring system for the dedicated compute required to run it.

**Table 6.** Recommended requirements for the IoT Monitoring System

| Name of component | Specification | Remarks |
|---|---|---|
| CPU | Quad-core Intel i5 3.0GHz | |
| RAM | 8GB | |
| HDD | Available space of 2GB or more | SSD disk recommended |
| VGA | NVidia GeForce GTX960 or equivalent AMD VGA | 2GB Video memory or more |
| OS | Windows 10 | |
| Internet Connection | Ethernet over 100Mbps | Wired Internet is required |
| Web Browser | Google Chrome | Chromium tested |

## 3.2. Access and Authentication

### 3.2.1. Supported web browsers

The Monitor System can operate on various web browsers such as Chrome, Edge, and Safari (Table 7). Some functions may not work on Internet Explorer (IE). For example, the screen layout can be broken, so the use of IE is not recommended

**Table 7.** Supported web browsers

| Icon | Name | Description |
|---|---|---|
| | Google Chrome | All major versions are supported. |
| | Microsoft Edge" | Supports both the legacy Edge and the new Edge. |
| | Apple Safari | All major versions are supported. (Also available on Mac OS) |
| | Mozilla Firefox | All versions are supported, but we have not verified some older versions. (Versions released before 2020) |

### 3.2.2. Log in to the Monitoring System

To log in to the monitoring system, a user should input its Internet Protocol (IP) address on the address bar. Then, after successfully accessing the server, a user can add the Uniform Resource Locator (URL) into Favourites for fast access and then put its shortcut icon on Desktop through drag & drop.

For example, after typing the address http://49.254.151.254/archetri/, it is required to confirm the login window and then do the authentication process (Figure 4).

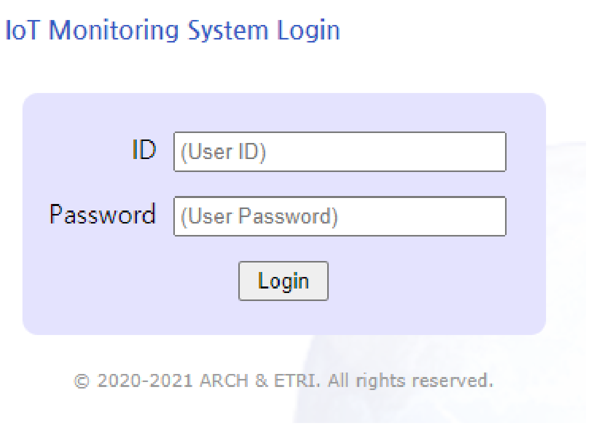


**Figure 4.** Login window

The default ID and password are '*admin'* and '*1234',* respectively. It should be modified after the development service period, so it needs to consult about the account information for the system manager. All that we described below assume that the login is successful.

## 3.3. Main Screen

Figure 5 shows the main screen of the monitoring system. The functional elements of the main screen are divided mainly into three sections; (A) Displacement indicator, (B) Select and search of the location to be monitored, and (C) Data view for the sensors.

Section (A) shows the status of the entire sensors managed by the DMS. Section (C) represents the data collected from sensors in real-time for the selected location on (B).

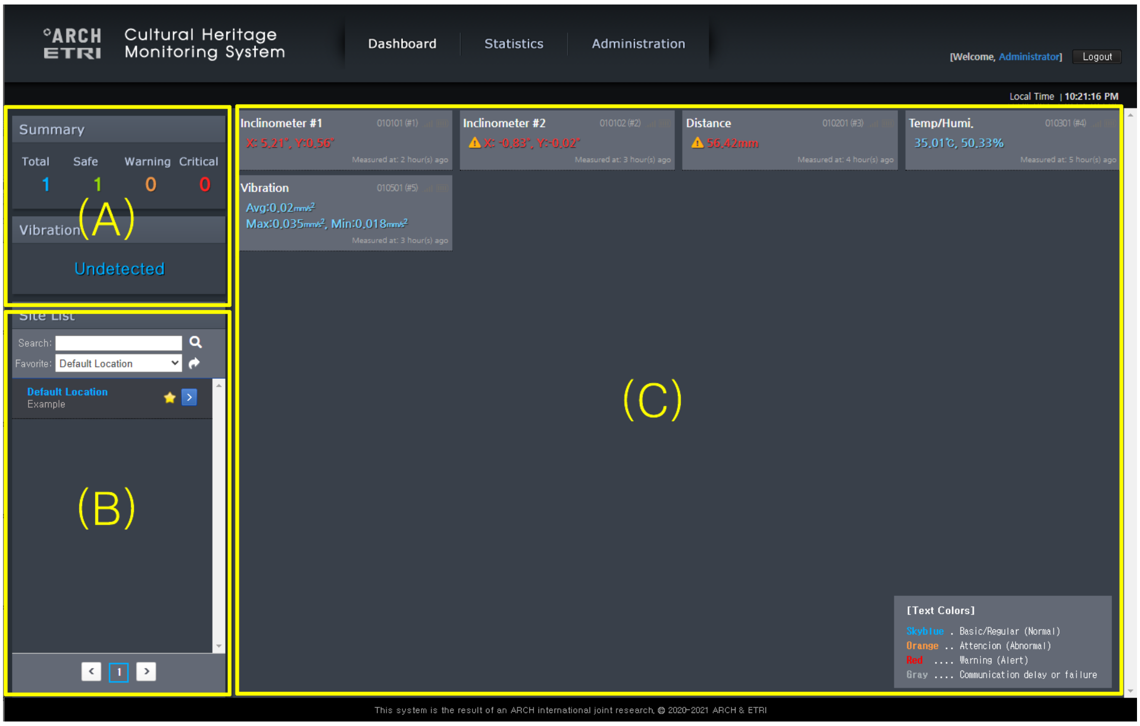


**Figure 5.** Screenshot of the main screen

### 3.3.1. Displacement indicator

Figure 6 shows the total sensors and their status.

- Total: The total number of sensors
- Safe: The number of sensors without problems (attention & warning)
- Warning: The number of sensors whose data exceeds 'normality' but fails to reach 'attention.'
- Critical: The number of sensors whose data exceeds 'attention.'


**Figure 6.** Displacement indicator

### 3.3.2. Select and search of the location to be monitored

Figure 7 describes searching a location to be monitored. A user can search it using a name or select one displayed in the list of detailed sensor information or the latest data values shown in the right column.

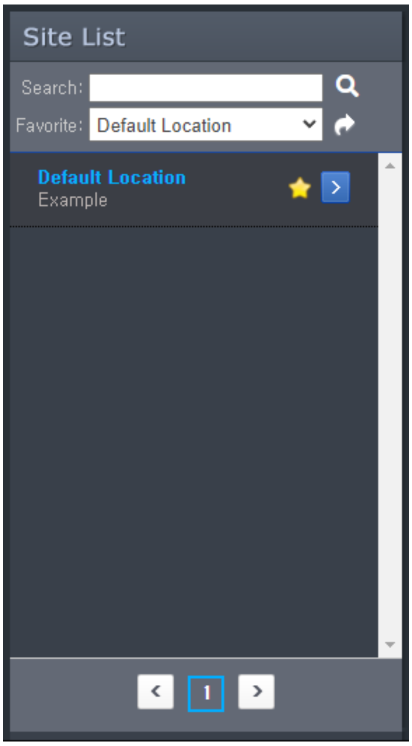


**Figure 7.** Searching a location

- Site List: A list of locations of cultural heritage under management is shown. The example shows only one default location.
- Search: It is possible to search for a location using a cultural heritage name. It also supports the ability to designate points of interest using the 'Add to Favorites' button with yellow star icon and navigate through the drop-down list at the top.

### 3.3.3. Latest data monitoring of sensor

While the IoT sensor generates large volumes of streaming data [1], only the latest data is provided. As shown in Figure 8, sensors installed on the cultural heritage and the latest collected data are displayed on the screen for the selected location of the cultural heritage.

In the first line, a sensor name, a system address, a communication status, and a battery status are displayed. Next, the measured data of sensors and a collection time are displayed on the second line. When a user clicks an item, another window appears to access the data statistics.

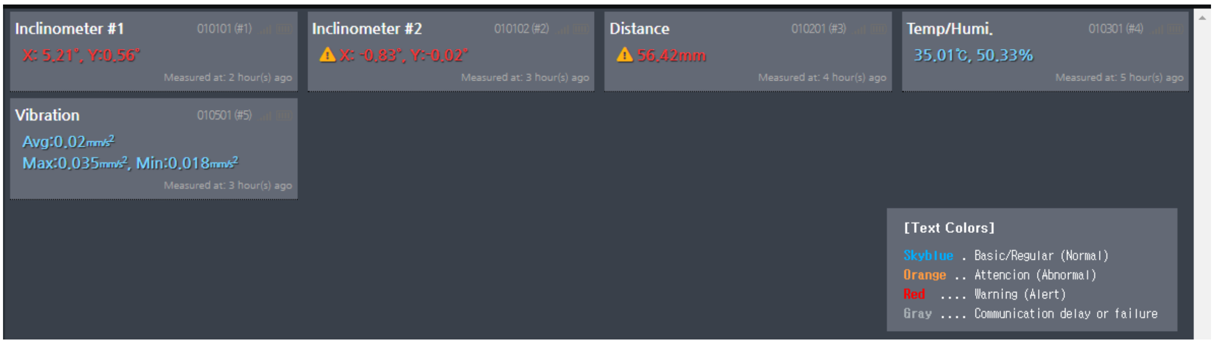


**Figure 8**. Latest data monitoring of sensor

A legend for the text colour used by the system is located in the lower right corner of the screen. The colour of the texts of items are categorized into sky blue (basic & regular), grey (communication failure or delay), orange (attention) and red (warning).

### 3.3.4. System address, battery level, and communication status

An installed sensor has a form of a square icon. The latest data are presented (Figure 9). The colours of the sensor item are categorized into sky blue (basic & regular), grey (communication failure or delay), orange (attention), and red (warning).

In the first line, a sensor name, a system address (e.g., 010101 #1), a communication status (icon of antenna bar), and a battery status (icon of battery shape with separated four cells) are displayed. Next, the measured data of sensors and a collection time are presented on the second and third lines.


**Figure 9.** An example of a sensor item (inclinometer)

A system address means a unique sensor address registered in the IoT Platform of cultural heritage, accompanying a virtual Index number starting with '#'. A communication status is displayed with the icon of the antenna. The whiter the bar, the better its situation. The status of communication depends on the condition of the wireless communication or obstacles around the site where the sensor is mounted rather than the sensor's performance.

The percentage (%) of the voltage with the mV unit indicates a battery capacity level; the whiter bar, the more battery. If there is only one battery level left, it is time to replace it. Data collection time represents the actual time it takes to collect it from a sensor. Therefore, it is possible to display it with a second, minute, hour, or day unit.

If there is no communication for more than 3 hours, the icon of communication status and the remaining battery level turn grey. After 24 hours of data collection, all texts on the sensor item turn grey.

## 3.4. Data Monitoring

### 3.4.1. Inclination data

All numerical values of the inclinometer are presented with inclinations X and Y with the unit of millimetres (mm) (Figure 10). The reference values displayed are based on average inclinations. It is possible to find maximum and minimum inclination values by using the function of Statistics Search as described in the section of '3.5 Search for Statistics by Location'.


**Figure 10.** Inclinometer sensor data

It is also possible to measure an inclination by up to 30 degrees with the '+' or '–' direction. In the case of the '+' direction, the sign '+' is not presented. But X has '+' in the right direction, and Y has '+' in the upper order when the front side is put down.

### 3.4.2. Crack & distance data

The distance from the initial measurement point is measured in the unit of mm and can have a positive or negative sign ('+' or '-'). In the case of positive, there is no symbol in front of the value. When a problem occurs, the distance value turns into red colour. The measurement interval can be 5 to 30 minutes, depending on the sensor's setting. Figure 11 shows an example of displaying the data measured with a crack & distance sensor.


**Figure 11.** Crack & distance sensor data

### 3.4.3. Vibration & earthquake data

The unit of a vibration value is $mm/s^2$. The average and maximum values for measurement are displayed on the screen (Figure 12). Like crack & distance sensor, when a problem occurs, the value turns red.


**Figure 12.** Vibration & earthquake sensor data

The sensor works when an earthquake occurs. The interval of the collection is 15 to 30 minutes by default and can be one hour maximally.

### 3.4.4. Temperature & humidity data

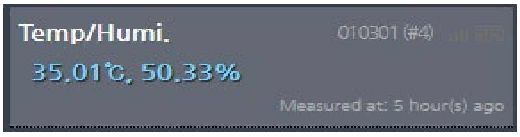


**Figure 13.** Temperature & humidity sensor data

The data from the temperature & humidity sensor are displayed on the screen (Figure 13). The measurement range of a temperature sensor is -40 to +95 degrees Celsius, and a relative humidity sensor is 0 to 99%. The interval of the collection is 15 to 30 minutes by default and can be one hour maximally.

## 3.5. Search for Statistics by Location

### 3.5.1. Statistics search

It is possible to search for the location of cultural properties and statistical data created by a sensor. There are two types of statistics available; location or sensor-specific statistics.

Data from all sensors mounted on cultural properties can be retrieved by means of setting the start and end date for the location-specific statistics, by which raw data is not provided. By using another method, data of the selected sensor can be inquired for sensor-specific statistics, by which raw data can be provided.

The statistics by location can be used to find the absolute displacement singularity that cultural heritage faces due to risks such as earthquakes or heavy rain at a particular date or time [2]. The statistics by the sensor can be used to find the short-term or long-term change trend of a specific sensor and search for its raw data.

### 3.5.2. Statistics calculation by the sensor

When a user clicks a button of the sensor item in the real-time data screen, its statistics interface appears. Then, by default, raw data is not displayed. But one-day (24 hours) data are shown totally, and the entire legend of the data is displayed (Figure 14).

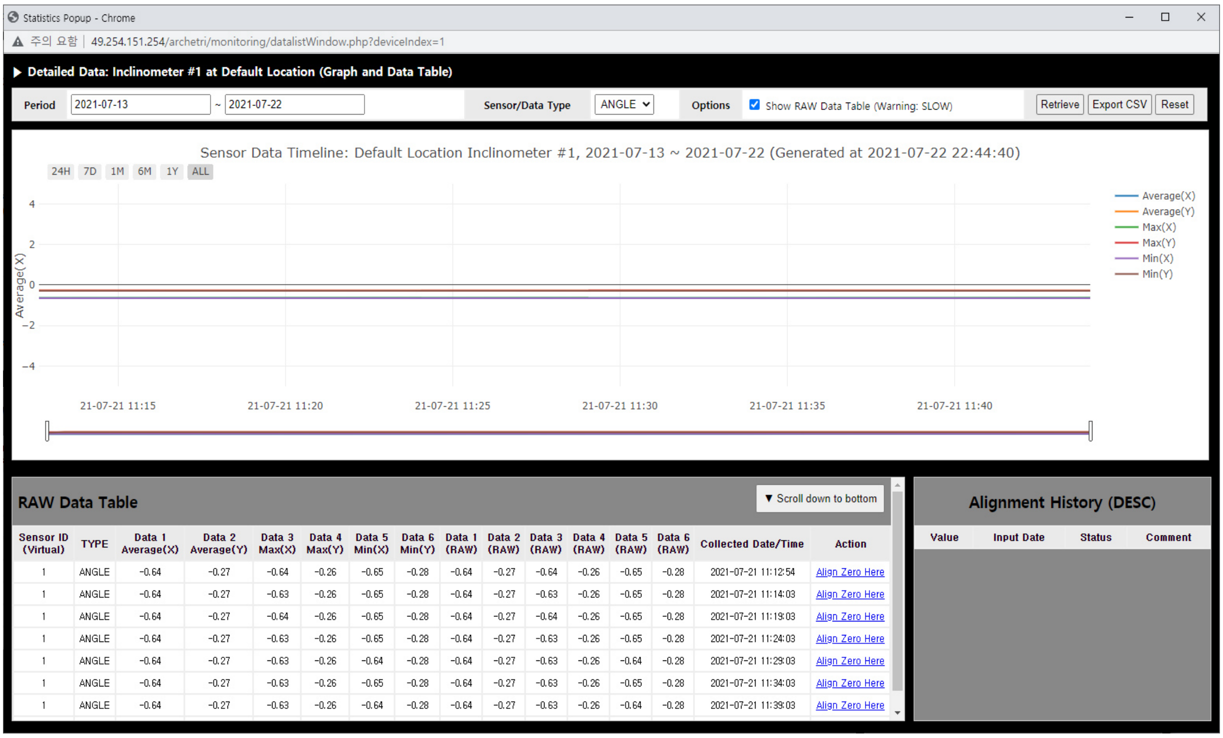


**Figure 14.** Popup window of the statistics calculation by the sensor

To change a statistics period, a user should select dates in the date interface and click the button on the right side as shown in Figure 15. If the system capacity is sufficient, it is possible to search for data up to one year.

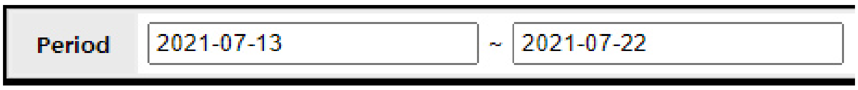


**Figure 15.** Change in a statistics period

To see raw data (Figure 17), a user should check the 'Show RAW Data Table' checkbox as shown in Figure 16 and click the 'Retrieve' button on the right side of the interface.


**Figure 16.** "Show RAW Data Table" checkbox

**RAW Data Table** ▼ Scroll down to bottom

| Sensor ID (Virtual) | TYPE | Data 1 Average(X) | Data 2 Average(Y) | Data 3 Max(X) | Data 4 Max(Y) | Data 5 Min(X) | Data 6 Min(Y) | Data 1 (RAW) | Data 2 (RAW) | Data 3 (RAW) | Data 4 (RAW) | Data 5 (RAW) | Data 6 (RAW) | Collected Date/Time | Action |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ANGLE | -0.64 | -0.27 | -0.64 | -0.26 | -0.65 | -0.28 | -0.64 | -0.27 | -0.64 | -0.26 | -0.65 | -0.28 | 2021-07-21 11:12:54 | Align Zero Here |
| 1 | ANGLE | -0.64 | -0.27 | -0.63 | -0.26 | -0.65 | -0.28 | -0.64 | -0.27 | -0.63 | -0.26 | -0.65 | -0.28 | 2021-07-21 11:14:03 | Align Zero Here |
| 1 | ANGLE | -0.64 | -0.27 | -0.64 | -0.26 | -0.65 | -0.28 | -0.64 | -0.27 | -0.64 | -0.26 | -0.65 | -0.28 | 2021-07-21 11:19:03 | Align Zero Here |
| 1 | ANGLE | -0.64 | -0.27 | -0.63 | -0.26 | -0.65 | -0.28 | -0.64 | -0.27 | -0.63 | -0.26 | -0.65 | -0.28 | 2021-07-21 11:24:03 | Align Zero Here |
| 1 | ANGLE | -0.64 | -0.27 | -0.63 | -0.26 | -0.64 | -0.28 | -0.64 | -0.27 | -0.63 | -0.26 | -0.64 | -0.28 | 2021-07-21 11:29:03 | Align Zero Here |
| 1 | ANGLE | -0.64 | -0.27 | -0.63 | -0.26 | -0.65 | -0.28 | -0.64 | -0.27 | -0.63 | -0.26 | -0.65 | -0.28 | 2021-07-21 11:34:03 | Align Zero Here |
| 1 | ANGLE | -0.64 | -0.27 | -0.63 | -0.26 | -0.64 | -0.28 | -0.64 | -0.27 | -0.63 | -0.26 | -0.64 | -0.28 | 2021-07-21 11:39:03 | Align Zero Here |

**Figure 17.** A table of RAW Data

Each sensor has a history of alignment settings made by a manager. It is necessary to adjust to the zero point. In the case of the inclinometer, the zero point is (0,0) for X-axis and Y-axis at the time of initial sensor installation, maintenance such as sensor replacement or relocation, or connection with previous data (Figure 18). These raw data can be used as a reference for data search.

**Alignment History**

| Value | Input Date | Status | Comment |
|---|---|---|---|
| -2.07, 8.67, , , , , , | 19-07-22 16:10 | ACTIVE | |
| 0.1, 7.79, , , , , , | 19-06-19 11:50 | INACTIVE | |
| 0.37, 6.44, , , , , , | 19-02-13 18:58 | INACTIVE | |

**Figure 18.** Alignment history

### 3.5.3. A shift of data search point

The navigation bar is provided as a user-friendly function. By moving the navigation bar to the left or right with the mouse, it is possible to lengthen or shorten a search period for graph data (Figure 19). It is also possible to shift a point of time in the range of the search period.

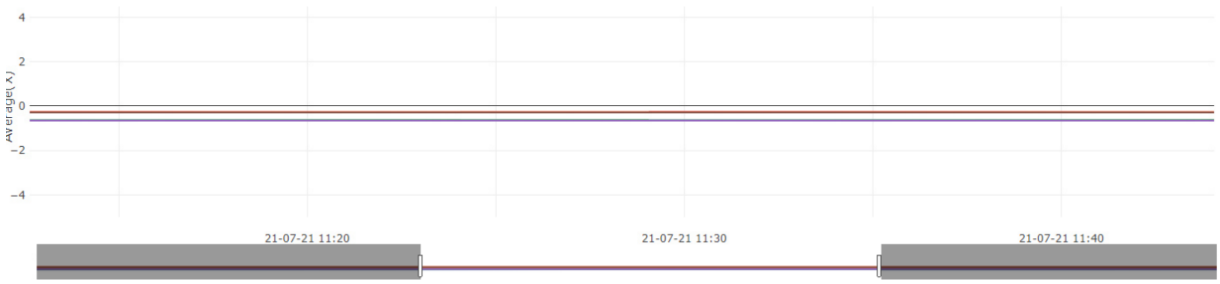


**Figure 19.** The shift of data search point with the use of navigation bar

### 3.5.4. Show & hide graph by clicking legend

It is possible to show only the X-axis or Y-axis of an inclinometer by clicking the legend option. And when a legend on the top right of a graph is clicked once with a mouse, it becomes hidden. And it appears again when we click it once more.

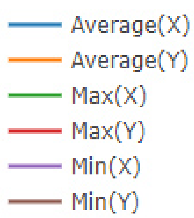


**Figure 20.** Graph legend (in case of inclinometer)

### 3.5.5. Statistics by location

As described in the previous section, it is possible to show simultaneously statistics graphs for all the sensors installed in each location (Figure 21).

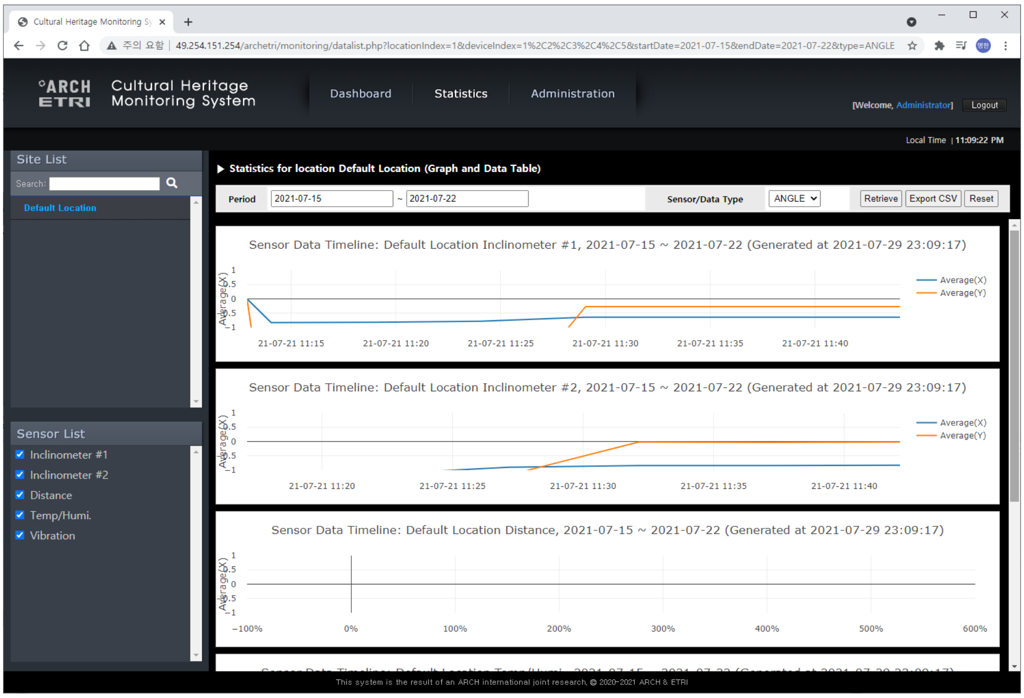


**Figure 21.** Statistics calculation by location

A user can search for data by typing start, and end dates equally for all the sensors installed in a cultural heritage site. There are no raw data. A user can use the statistics by the location to find the absolute displacement singularity that cultural heritage faces due to risks such as earthquakes and heavy rain on a particular date or time.

The maximum search period is restricted to one month. But it is possible to extend it by increasing system performance. Its interface is displayed when a user clicks the [Statistics/Report] button on the top of the main menu in Main Screen. A default value is 24 hours, and the first one in the list of cultural heritage sites is automatically selected.

## 3.6. Protocol and packets

To provide data collected from the IoT Platform to other systems, we provide an open Application Programming Interface (API) that is implemented with Representational State Transfer (REST) API. The data format is based on JavaScript Object Notation (JSON). The JSON data from LoRaWAN application has many fields. The data for DMS is contained in the attribute with the name of the 'data' field. They consist of strings, and their structure is shown in Figure 22.

```
(Inclinometer)

E1 [4byte] [2byte] [2byte] [2byte] [2byte] [2byte] [2byte] [2byte] [2byte]
    time   battery  temp.   x-avg   y-avg   x-max   y-max   x-min   y-min


(Crack/Distance)

E2 [4byte] [2byte] [2byte] [2byte] [2byte] [2byte]
    time   battery  temp.    avg     max     min

(Temperature/Humidity)

E3 [4byte] [2byte] [2byte] [2byte]
    time   battery temp.    humi.

(Vibration)

E5 [4byte] [2byte] [2byte]     [2byte]
    time   battery  m/s^2 max  m/s^2 avg
```

**Figure 22.** Structure of data field in the JSON data

All sensors contain one byte of sensor type indicator, four bytes of timestamp information, and two bytes of battery capacity. They are followed by a sensor value with multiple fields. The sensor value has a different structure for each sensor. In the case of the inclination sensor, it has seven data fields totally. That is, the temperature value containing the essential environmental information and the average & maximum & minimum values are divided into the X-axis and Y-axis, respectively.

In the case of a crack & distance sensor, the first two bytes after battery field are the temperature value in Celsius degree, which is the basic environmental information. This value is used to compensate for changes in the magnetic strength with temperature. The next following six bytes represent the average & maximum & minimum value of two bytes in the unit of mm, respectively.

In the case of the temperature & humidity sensor, the temperature and humidity values are transmitted at the time of measurement. Likewise, the maximum and average values in the unit of $m/s^2$ are sent for vibration sensors within the measurement interval.

# 4. Integration with HArIS and THIS

## 4.1. Data integration

The Historical Areas Information System (HArIS) and the Threats and Hazards Information System (THIS) are two information systems provided by the ARCH project: the first is developed to capture the characteristics of the historical areas; whereas, the second one is oriented to the collection of information and data to quantify indicators related to the hazards affecting the same areas. The two information systems have the same concept and are integrated between them. However, the IoT Platform for Digital Twin has a similar concept but operates individually. But we can integrate the data from the IoT Platform into HArIS through the Open APIs provided by the IoT Platform.

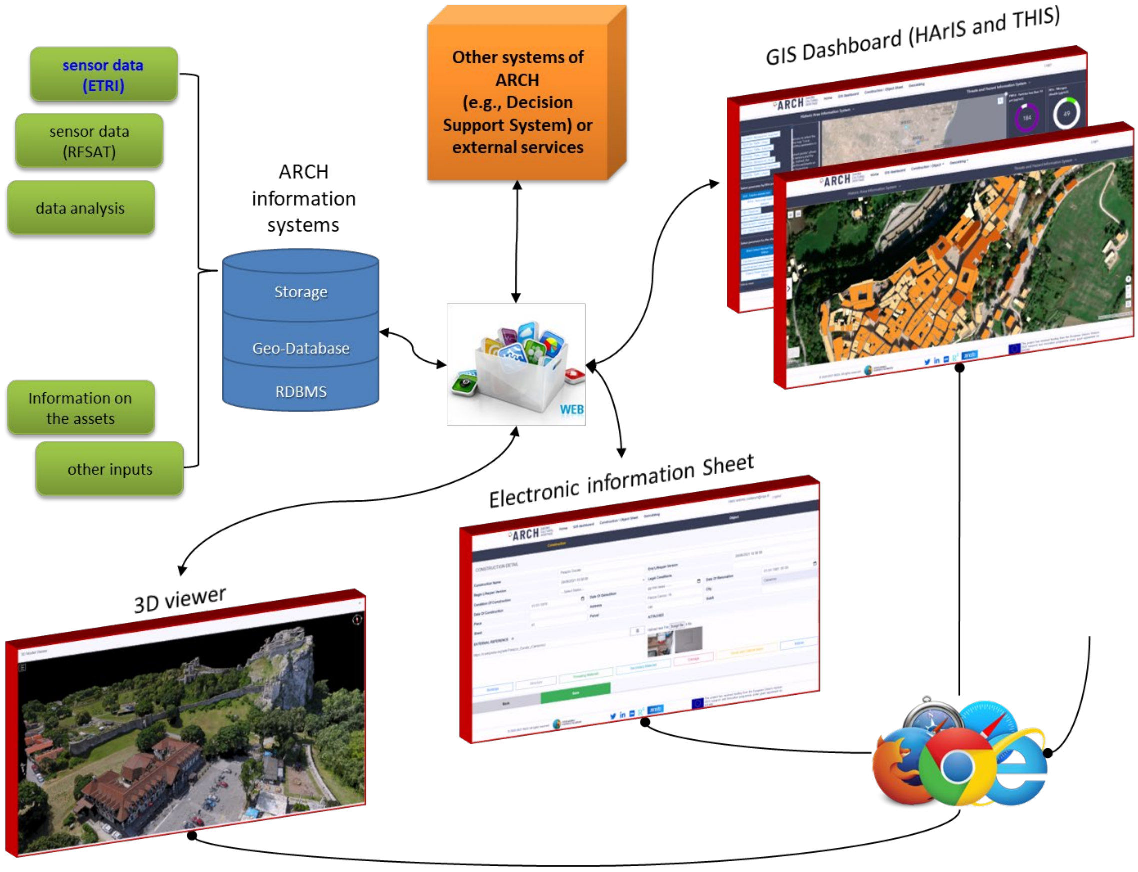


**Figure 23.** Functional schema of the ARCH information systems: data sources (green boxes), relational databases, repositories and management services (blue cylinders), data consumers (yellow cube), tools to access data via the web (red panels).

As shown in Figure 23, the ARCH information systems (HArIS/THIS) can be fed by the IoT Platform by several different data sources:

- sensors developed by ETRI for Digital Twin
- sensors developed by RFSAT for recording physical parameters;
- data analyses to produce processed information;
- external services to include data already available in other systems.

And the data will be integrated into the Relational DataBase Management System (RDBMS) of the ARCH information systems. Therefore, the information is accessible through the THIS web tools theoretically as well as the DMS of the IoT Platform.

## 4.2. Open APIs of the IoT Platform

As described in section 3.6, the IoT Platform provides the open REST API to support integrating the sensor data. They are transmitted over HTTP through the ChirpStack Application Server's Integration feature. It consists of JSON format (Table 8) that can be implemented by referring to '3.6. Protocol and packets' and Figure 22.

Received data from sensors are handled in the '/rest/uplink.php' of the webserver. Data migration to RDBMS or other systems can be carried out by modifying the corresponding Personal Home Page (PHP) scripts. Table 8 shows an example of JSON format processed by the PHP script.

**Table 8.** Information for JSON data fields

| Name | Parameter |
|---|---|
| deviceName | Name of the device (sensor node) |
| devEUI | Hex ID of device (e.g.: 03700A0A01010101) |
| data | data collected from sensors |
| rxInfo {array} | Radio information of the device (e.g., signal strength, data rate and signal to noise ratio, connected Gateway information, etc.) |

## 4.3. Web interface integration

To integrate the Web interface, we have dynamically loaded data into the Division element with the name of 'DIV' within the system and implemented content within a frame using a DOM element such as an iframe. It can occur as a cross-domain-related error in modern web browsers. The DMS User Interface (UI) has a pre-setting function that allows entirely cross-domain access. When a problem occurs, it should be used for real-time data expression with limited information using REST API. Table 9 shows the information for implementing iframes.

**Table 9.** Information for implementing iframes

| Name | Parameter |
|---|---|
| URL | http://address of webserver/archetri/monitoring/ext_arch.php |
| Protocol | HTTP or HTTPS |
| Cross-domain policy | Allow from all |
| Limited functions | Full stats, admin mode access |

The sensor data can be accessed through the DMS Web interface or THIS web interface as shown in Figure 24, where the DMS Web interface can be integrated into the THIS Web interface. It can be implemented with 'iframe' in the corresponding code of the web page by changing the address of the iframe through the DOM Inspector.

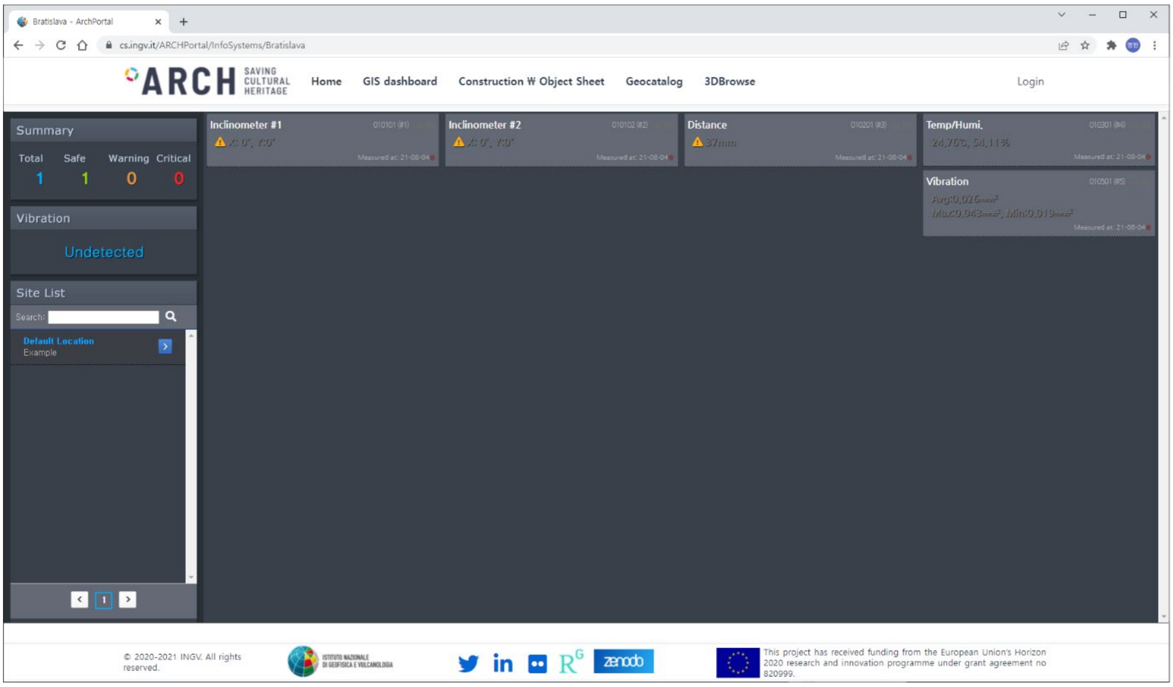


**Figure 24.** Web interface integration

# 5. Deployment to a cultural heritage site

## 5.1. Application examples in Gangwon-do province

The sensor node, Gateway, and monitoring system that can measure the change of state were deployed at 25 sites of cultural assets, including 'Soyangjeong' located in 'Chuncheon' city in order to collect and analyse sensor data. Figure 25 shows an example of installing sensors in the 'Soyangjeong' cultural property.

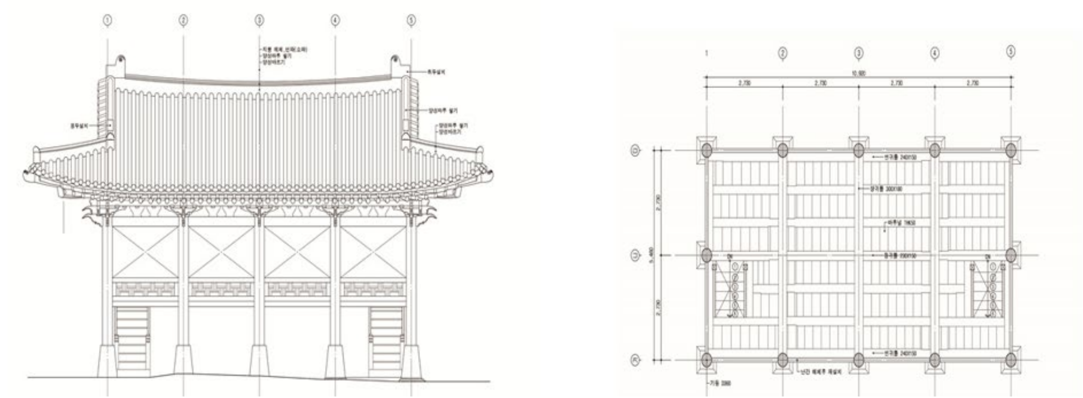

**Figure 25. '**Soyangjeong' cultural property

We have mounted an inclinometer at a pillar of a wooden cultural property to measure the degree of inclination of the building. Four units were installed at least to receive the X-axis and Y-axis data, respectively. In the case of stone cultural properties, the degree of inclination was measured by attaching them to the base floor for stone pagoda cultural properties.

In the case of temperature & humidity sensors, one per cultural property was installed and used to measure the correlation of the degree of displacement of cultural property according to the temperature change. We installed one vibration sensor per cultural property to monitor the amount of vibration caused by earthquakes as well as surrounding vehicle traffic and other natural or anthropogenic factors.

In principle, one Gateway should be installed per each cultural asset independently. However, we also installed two Gateways for some cultural assets due to a poor network connection environment. Specifically, it was determined by referring to the success rate of data reception and various performance indicators of wireless communication after installing the sensor node.

Table 10 indicates the form and quantity of sensors installed in the 'Soyangjeong' cultural heritage.

**Table 10.** Type and quantity of sensors

| Symbol | Type Name | Specification | Quantity |
|---|---|---|---|
| | TYPE A | Inclinometer | 12 |
| | TYPE B | Temperature and humidity | 1 |
| | TYPE C | Crack/Distance | 0 |
| | TYPE D | Vibration | 0 |

In Table 10, TYPE A represents slope, TYPE B for temperature, TYPE C for cracking, and TYPE D for a vibration sensor. The arrows of Type A indicate the vertical X-axis and Y-axis of inclination. Figure 26 shows the actual installation location of each sensor on the 'Soyangjeong' cultural property.


**Figure 26.** Installation location of each sensor on the Soyangjeong cultural property

Through this, we installed a total of 12 'TYPE A' (tilt sensor) and 1 'TYPE B' (temperature sensor) in the relevant cultural property, and we can see the position of each inclination sensor is the same as the position of the column.

## 5.2. Interpretation of results

When we investigated the results for each cultural property based on the measurement data of the sensors installed on each cultural property, it seemed that all cultural properties tended to change and recover to their original state repeatedly depending on the surrounding environment and weather environment. Therefore, continuous data collection and analysis should be followed for more detailed analysis in the future [3].

### 5.2.1. Tilt displacement

Figure 27 shows the progress of the building's tilt displacement after it has occurred with respect to an initial benchmark.

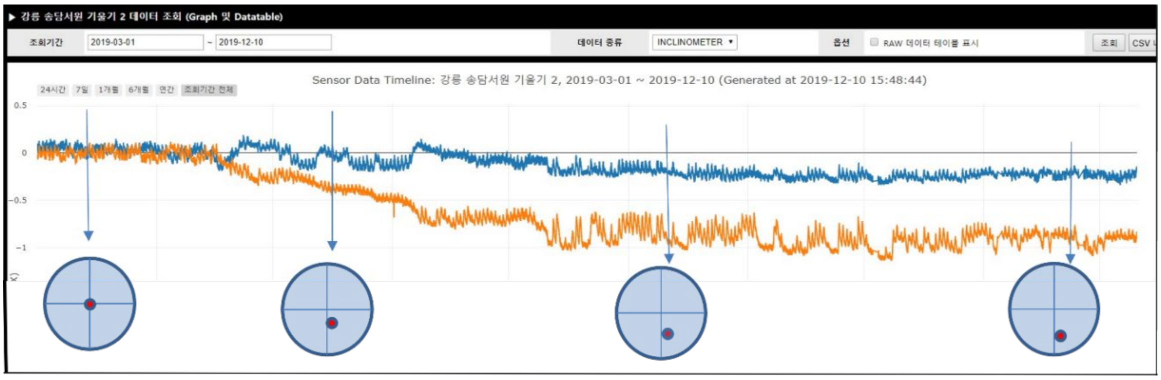


**Figure 27.** Data graph

Figure 28 shows the shape of the increased displacement gradually becoming stable and trying to return to the origin. It indicates that it is difficult to judge the safety condition and inclination only by monitoring the amount of inclination displacement in the short term. Therefore, we concluded that it was necessary one-year period at least to determine the degree of displacement.

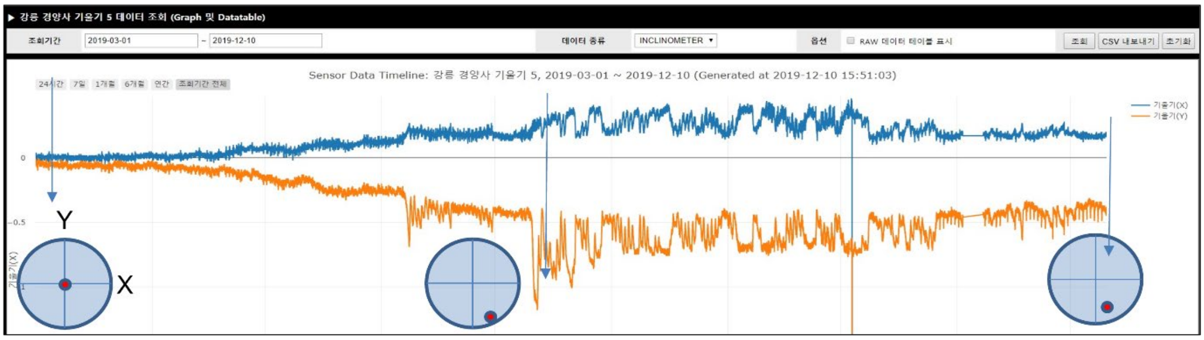


**Figure 28.** Restored data graph

Figure 29 shows similar observations resulting from other measurements of distant columns on the same cultural property. The amount of displacement of cultural properties may appear only at one point or at two or more points. It can be analysed as more reliable data on the amount of displacement can appear simultaneously at two or more points.

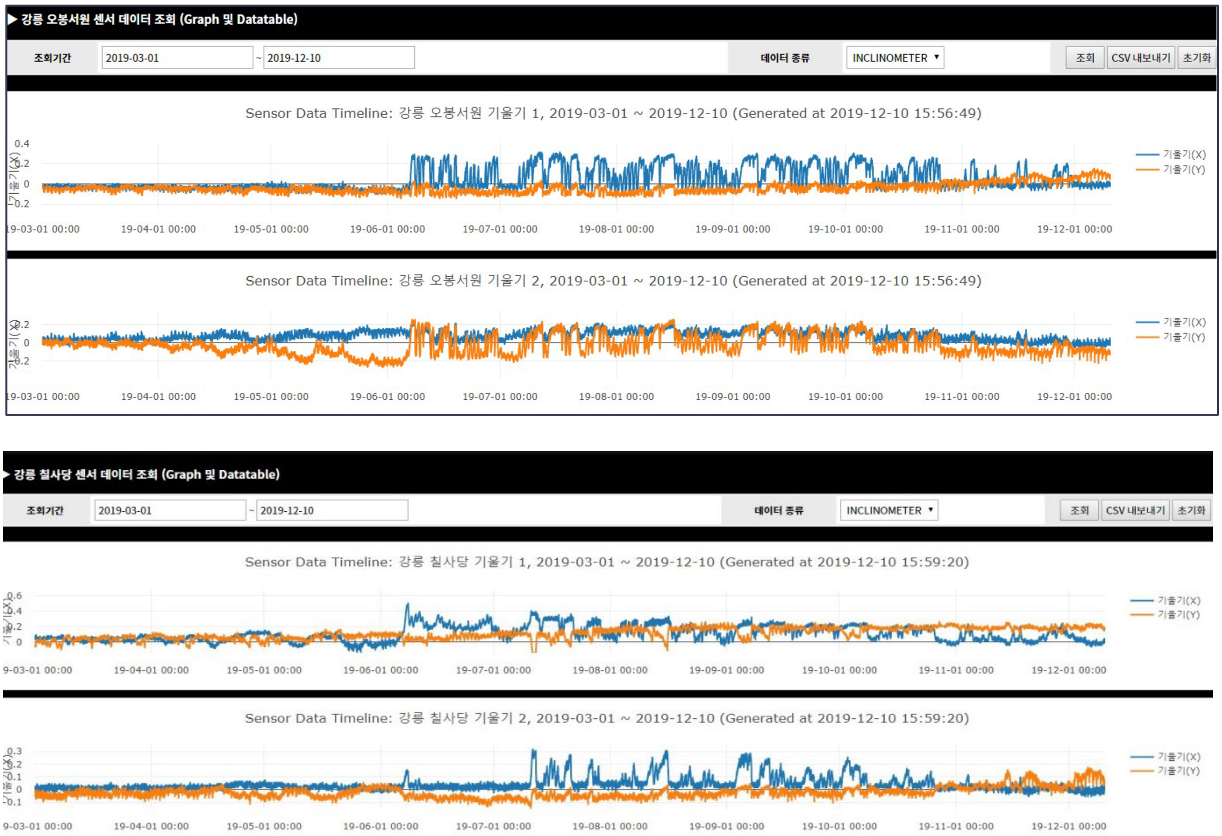


**Figure 29.** Tilt displacement

### 5.2.2. Effect of the environment

We performed a correlation analysis between the measurement data of cultural properties and the standard data measured from the Korea Meteorological Administration (KMA) together with the installed humidity sensor. As a result, we found that the displacement state of cultural assets was changed according to the weather environment.

In particular, in the case of wooden cultural properties, the materials' characteristics are greatly affected by humidity. We understood that the amount of displacement is observed due to contraction and expansion.

### 5.2.3. Displacement aspect of stone pagoda

We have found that stone cultural properties called stone pagodas have also undergone seasonal displacement. In particular, shrinkage and expansion occurred according to seasonal temperature changes. We need further research concerning this in the future.

### 5.2.4. Effects of natural disasters

Figure 30 shows the effects of natural disasters. As a result of long-term observation, we concluded that it was restored to its original state, although the instantaneous change of the X and Y axes was significant from the screen's centre. The earthquake occurred at a depth of 32 km under the sea and 136 km distance away from the cultural asset. Then, the scale was

M4.3. But the earthquake did not cause any damage to cultural properties. So, additional research is necessary to determine accurately whether an earthquake has occurred.

We confirmed the instantaneous occurrence of displacement due to natural disasters such as earthquakes during the installation and monitoring period. But it was just a momentary shaking, and we knew that we could effectively confirm the safety and damage status of the entire cultural property by checking the amount of displacement before and after the occurrence.


**Figure 30.** Effect of natural disasters

## 5.3. Future improvements and expected effects

In terms of history management, it was possible to expect continuous improvement in the safety management of cultural assets by securing the connection between the cultural heritage management history and data.

In addition, we found the correlation with the displacement of cultural assets through analysis of data, including meteorological factors such as wind direction, wind speed, temperature, humidity, and rainfall, including earthquakes and typhoons. Therefore, we expect that it will be possible to predict the displacement of cultural assets for safety management through Big data analysis in the future.

# 6. Bibliography


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[2] J. G. Choi, M. H. Yu, and Y. C. Yoon. "A study on the installation and operation of cultural property monitoring system based on low power IoT sensors." Journal of the Society of Cultural Heritage Disaster Prevention 3.2 (2018): 101-105.

[3] Choi, Jong-un, Misuk Kim, and Young-chul Yoon. "A Study on the Intelligent Platform for Cultural Property Management." (2021): 13-20.

[4] Choi, Jong-un, Myung-han Yu, and Young-chul Yoon. "Visualization of the Tilt Amount for Cultural Property Monitoring System." (2020): 143-149.

# Annex A. Installation and Maintenance of IoT Sensors.

## A.1. Installation requirements

Table 11 presents the environmental requirements for operating the IoT sensor nodes.

**Table 11**. Sensor node requirements

| Context of Use | Requirement(s) | Notes |
|---|---|---|
| Urban area | Distance from Gateway at least within 1 km | The closer, the better |
| Suburb area | Distance from Gateway at least within 2 km | The closer, the better |
| Full open area/ Line-of-Sight conditions | Distance from Gateway at least within 5 km | The closer, the better |
| Attachable cultural property | Architectural, cultural property with a flat surface and a hard surface that can be perforated | Beware of damage to the perforated area |
| Outdoor and indoor environment | Temperature range: -20~+45°C<br>Humidity range: 0~99%RH | Avoid direct sunlight |

## A.2. How to install

### A.2.1 Sensor node installation

As previously mentioned, we can install the sensor node by attaching it directly to a surface of cultural assets. Depending on the site situation, we can do it flexibly in the form of adhesives (epoxy-based), metal bands, or even direct drilling and installation. A common point to note is that we should install it to minimize damage to cultural properties and install it firmly and quickly so that it does not move.

Figure 31 shows how to install sensor nodes on the cultural assets. Since the sensor node can operate wirelessly with a battery, we can install it in various locations. Moreover, we can install it in a way that it does not spoil the aesthetics of the cultural assets for tourists.

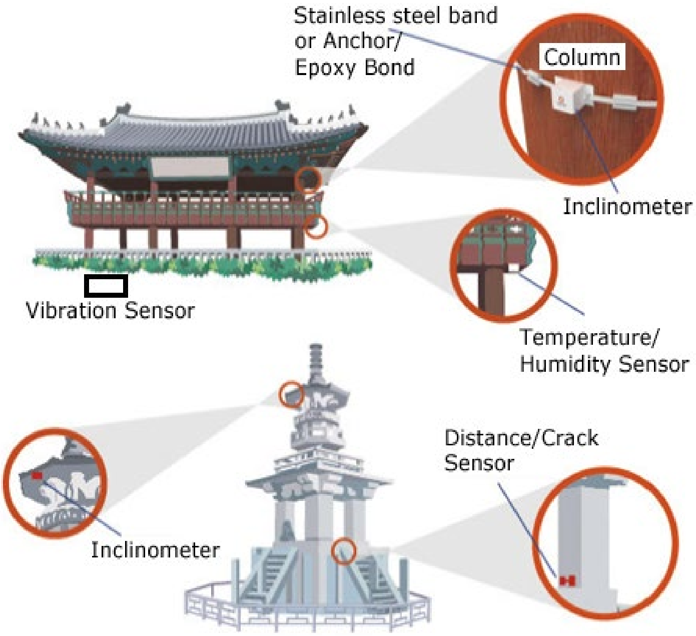


**Figure 31.** Sensor node installation diagram

### A.2.2. Temperature & humidity and vibration sensor node

Temperature & humidity and vibration sensor node have no restrictions to install them. We recommend installing them in places close to different sensors such as cracks or inclination sensors as much as possible. It is better to place them away from direct sunlight or rain.

A sensor node case consists of outer and inner boxes (Figure 32). The outer box aims to protect a sensor node against water in an outdoor installation, prevent a sensor node from being damaged or stolen, and provide convenience for repair and replacement in an indoor facility. Therefore, we recommend applying the outer box to a detector.

It is possible to separate both the outer and inner boxes using a cross-head Philips screwdriver.

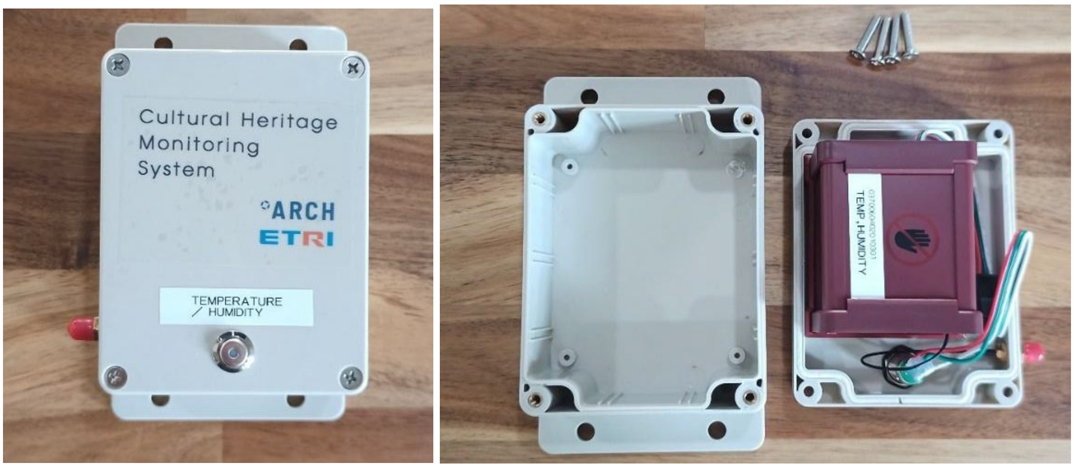


**Figure 32.** Temperature & humidity and vibration sensor node enclosure

The Printed Circuit Board (PCB) is shown in Figure 33 with internal enclosure. It includes the wireless modem Integrated Circuit (IC) for wireless communication, power supply IC, and the CPU IC for saving temporarily and processing collected data.

The white rectangle part on the right side is an antenna for wireless communication. The device has an antenna (without exposure to the outside) integrated into the PCB to reduce volume.

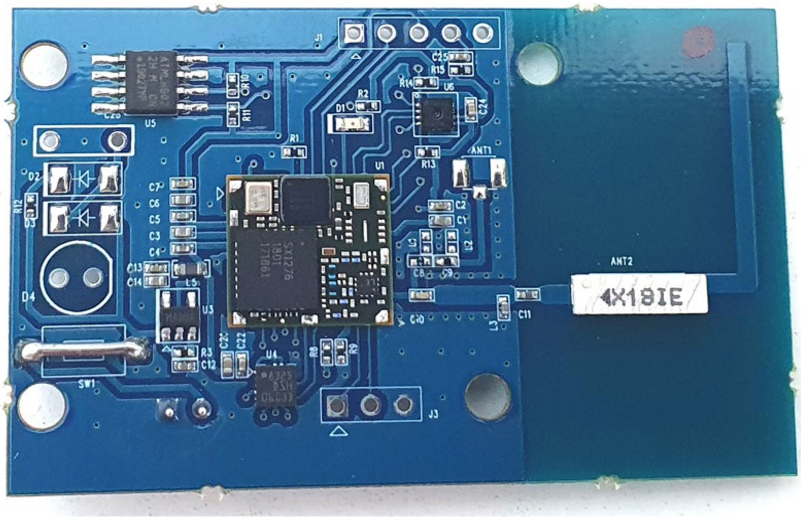

**Figure 33**. Communication board PCB

The outer box has a Power ON/OFF button, Radio Frequency (RF) Tx Indicator, and the Light Emitting Diode (LED) for wireless communication status Indicator. The button is waterproof and works outside. To install a sensor node, perforate a wall or ceiling surface and firmly fix the device using more than two anchors. The anchors are shown in Figure 34.

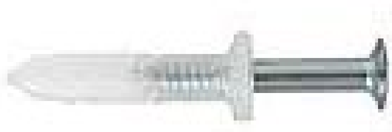

**Figure 34.** Anchor (UK English: wall plug)

An example of the sensor node mounted on a wall is shown in Figure 35.

**Figure 35.** Example of wall-mounted sensor node

If no perforations are unavoidable, it is possible to mount a sensor node using an epoxy bond. After separating the sensor node case, keep the sensor node cover and the sensor node separately.

Apply an epoxy bond sufficiently to the back of the sensor node case and fix the object. After that, temporarily fix it with adhesive tape or strip (Figure 36).

After the hardening time of Epoxy passes (Epoxy is hardened completely), take off the tape or strip, and put together the sensor node cover, the sensor node, and the case.


**Figure 36.** Example of epoxy bond, epoxy putty products

### A.2.3. Tilt (inclinometer) sensor node

We can install an inclinometer in the same way as mounting a temperature & humidity sensor node or vibration sensor node. In this case, however, the top and bottom of the device are distinguishable (Figure 37).

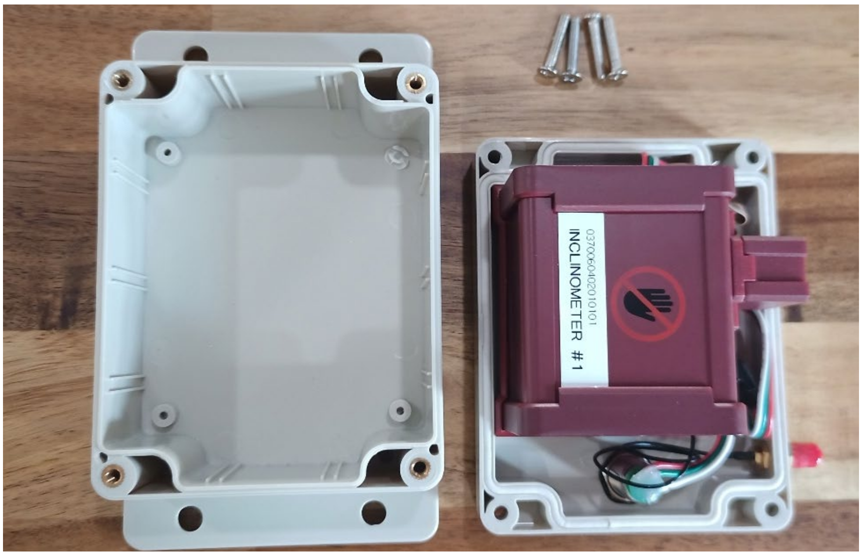


**Figure 37.** Tilt (inclinometer) node

It needs to be made a stand up with the power button underneath. In short, we should not install the device on the ceiling or the floor. For this reason, we use it to measure an inclination of a column or wall. ' UPPER SIDE' is written in a sensor node's inner and outer box. For assembly, match these parts and make sure to put the description part upward (Figure 38).


**Figure 38.** UPPER SIDE of the outer and inner box

### A.2.4. Crack (Distance) sensor node

We can install a crack sensor node in the same way as mounting a temperature & humidity sensor node or vibration sensor node (Figure 39). However, the device includes a measuring magnet. The horizontal measurement line enclosed should be installed as well. The distance between the magnet and the outer box should be 3 to7 cm.


**Figure 39.** Crack sensor node with a magnet

For installing, make sure to set the magnet in line with the mark (*black triangle, "▲") described in the left surface of the outer box, as shown in Figure 40.

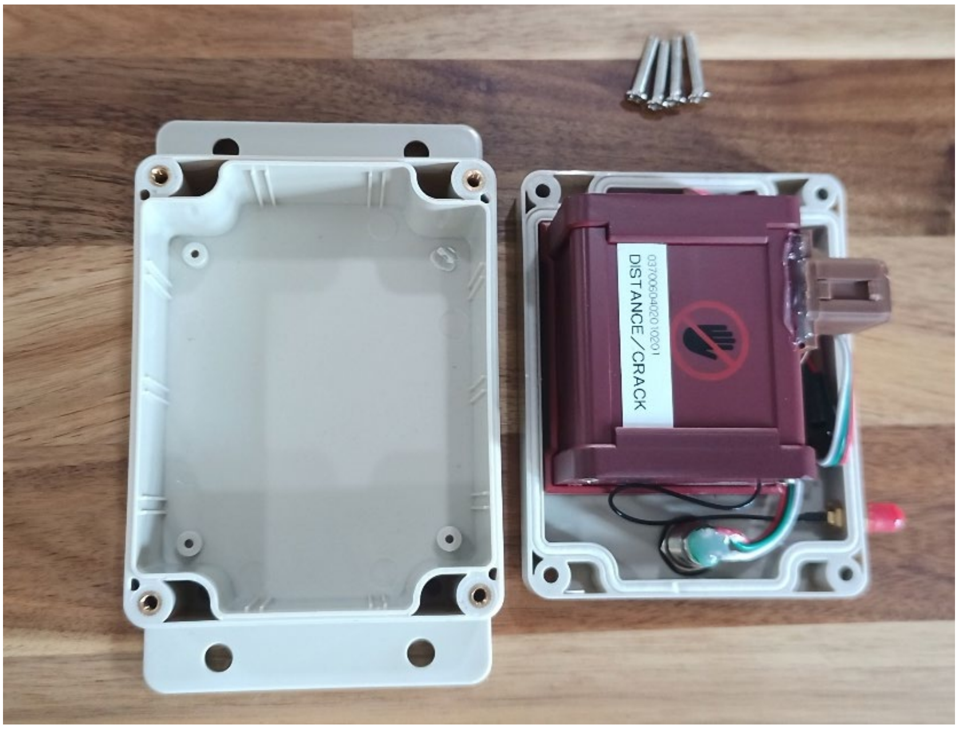


**Figure 40.** Crack sensor node inner box

It is possible to fix the magnet with anchors or an epoxy band. In the case of an epoxy band, there is no need to separate the case. Apply an epoxy band. Figure 41 shows the appearance of the crack measuring part located in the inner box.

**Figure 41.** Crack measuring part

### A.2.5. Initial run

After a sensor node is installed in a structure completely, push its power button. As we supply the power, the LED of switch flickers. When the sensor node accesses a server, the LED is turned off and flickers once in a sensing cycle of five minutes.

It is possible to check sensor data in monitoring system (Figure 42). For more details, see 3.*4. Data Monitoring* section of this document.

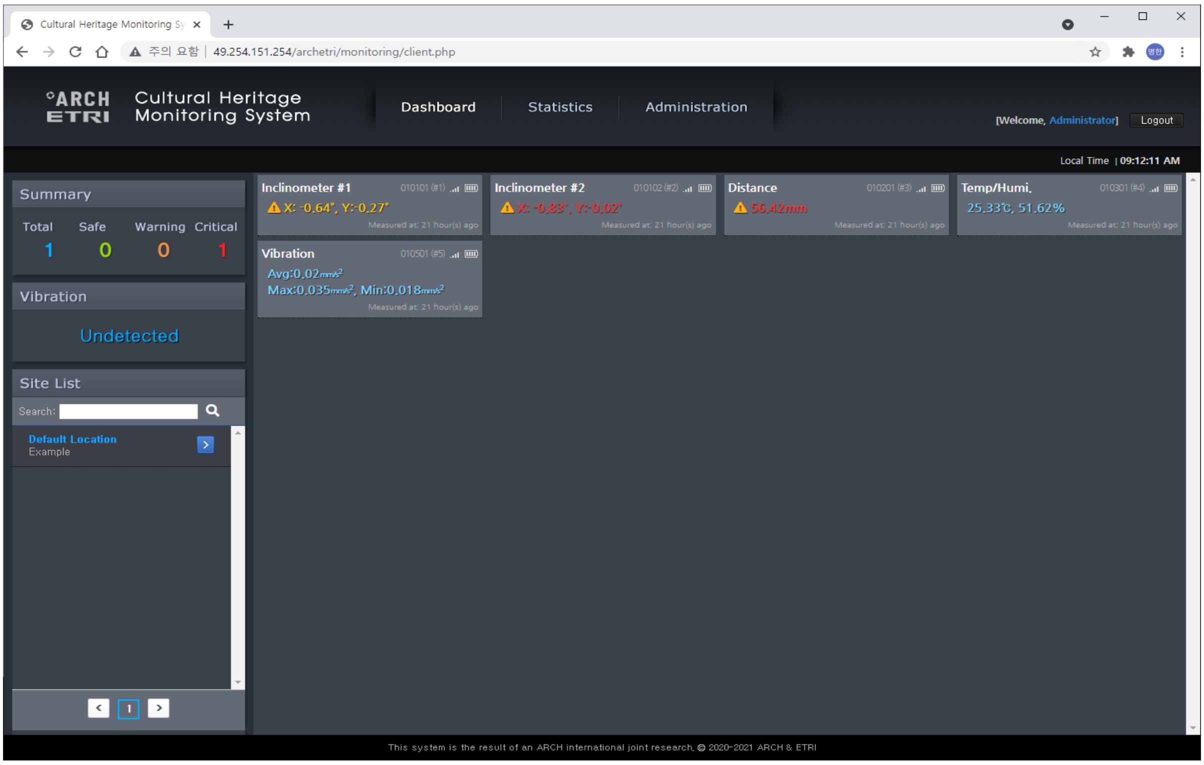


**Figure 42.** Screenshot of monitoring system webpage

We need to set up alignment after installing a crack sensor node or inclinometer sensor node. It shows the procedure for setting an angle and a distance to 0.0 degrees and 0mm, separately, after a sensor node is initially installed or maintained.

In the UI of monitoring system, see 'Alignment Setup' and RAW Data Table on the bottom of the detailed statistics window (Figure 43). To register new zero information, click the link 'Align Zero Here' in the Row of relevant data. After that, click 'OK' in the popup window.

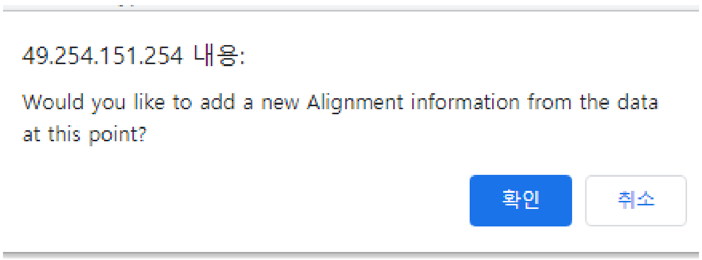


**Figure 43.** Popup window content

After reloading the window by clicking the 'Retrieve' button again on the top, you need to check that the data of 'correction date & time' matches with the current date & time. The date & time is based on Greenwich Mean Time (GMT) (Figure 44).

| Alignment History | | | |
|---|---|---|---|
| Value | Input Date | Status | Comment |
| -5.85, -0.83, , , , , , | 21-07-22 09:14 | ACTIVE | |

**Figure 44.** Alignment of setup history

## A.3. Maintenance

### A.3.1. Battery replacement and reinstall

We should push the power button on the external case and shut off the power to replace the battery (Figure 45). And then, we should open the outer box of a sensor node. There is a separate brown box on the case cover. For safety, disconnect the power button connector.

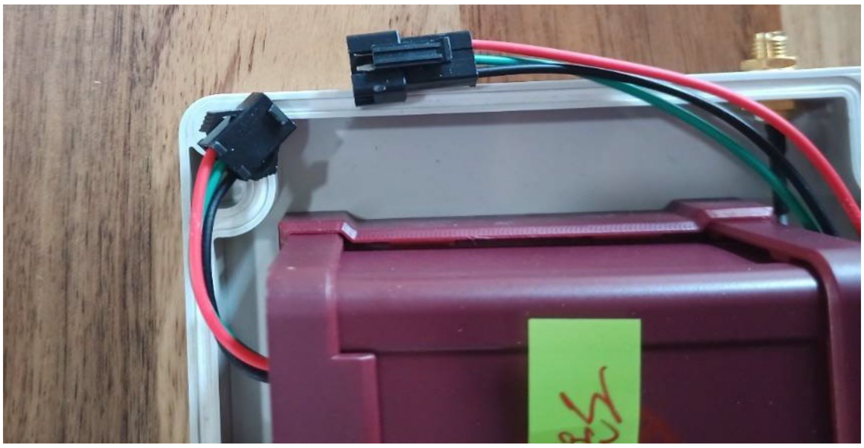

**Figure 45.** Disconnection of the power connector

The next step is to separate the inner box from the outer tube using a flat-head screwdriver (Figure 46).

Look at the side carefully. First, we can use the clips on the side to fix the two boxes. Next, we should push the flat-head screwdriver to make four corners loosen and lift the inner box.

**Figure 46.** Separation of the inner box and outer box with a flat-head screwdriver

With a cross-head screwdriver (Philips screwdriver), take off four screws used to fix the inner box, and open the side of the inner tube (Figure 47).

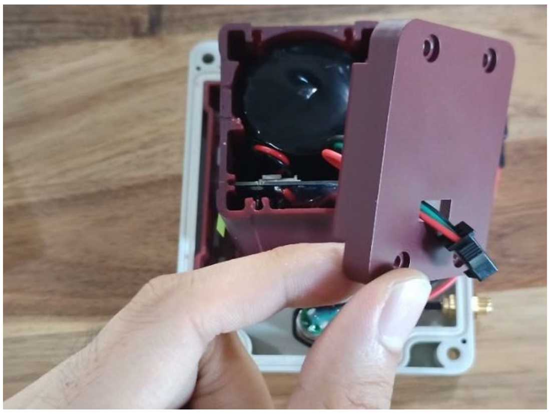

**Figure 47.** Opened side of the inner box

The next step is to replace the D-type 3.6V Lithium battery and assemble one in reverse separation order (Figure 48).

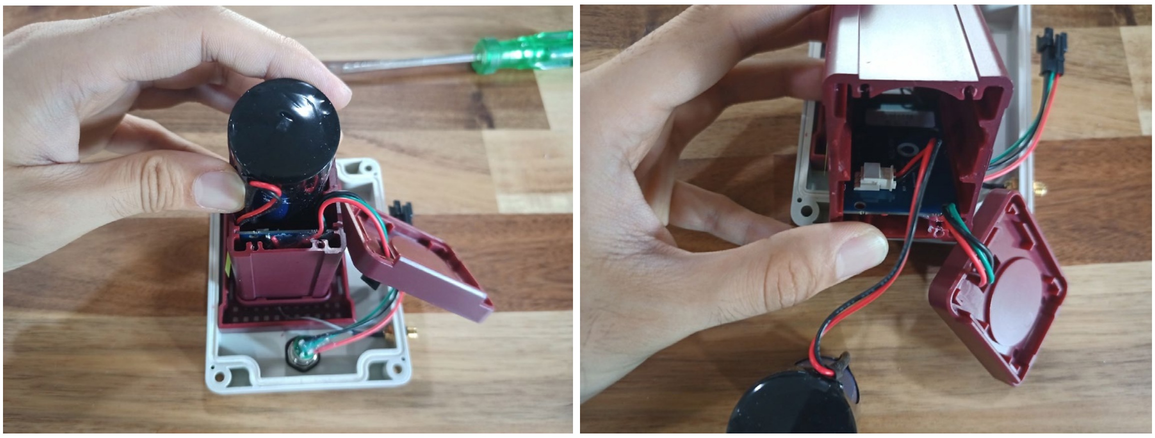

**Figure 48.** Battery replacement

And then, we should connect the power button connector. Finally, we should push the power button on the outer box. Then, as described in the above installation instructions, check that the sensor node accesses the DMS. Table 12 describes the specification of the battery for new installation or replacement.

**Table 12.** Specification of the battery

| Name | Specification | Name |
|---|---|---|
| Type | Lithium-ion primary battery | Type |
| Connector | 2-pin Molex 1.25mm pitch connector | Connector |
| Size | D Type cell (IEC R20) | Size |
| Output voltage | 3.6V (1.5V batteries including Alkaline are not allowed to use) | Output voltage |
| Capacity | 19Ah or more recommended | Capacity |

| Name | Specification | Name |
|---|---|---|
| Name | Specification | Name |
| Type | Lithium-ion primary battery | Type |

We need to be careful of battery polarities. Although a connector shape is equal, its '+' and '–' polarities can differ. For example, we can refer to Figure 49 with black and red cable and body of the connector.


**Figure 49.** 3.6V Li-ion Battery

### A.3.2. Other troubleshooting

If communication does not work smoothly, we need to reinstall the antenna. And then, we should install an external antenna for Industrial, Scientific and Medical (ISM) by turning it (Figure 50).


**Figure 50.** Installation of an external antenna

An external antenna should be as perpendicular to the ground as possible. Figure 51 shows an example of the antenna angle.


**Figure 51.** An example of proper antenna angle

If the sensor node is not powered on, or if the data received are abnormal (e.g., -255 Celsius degree of temperature), this occurs mainly when a cable becomes damaged in the way of putting together the outer box of a sensor node. Figure 52 shows an example of an improper sensor node case assembly.

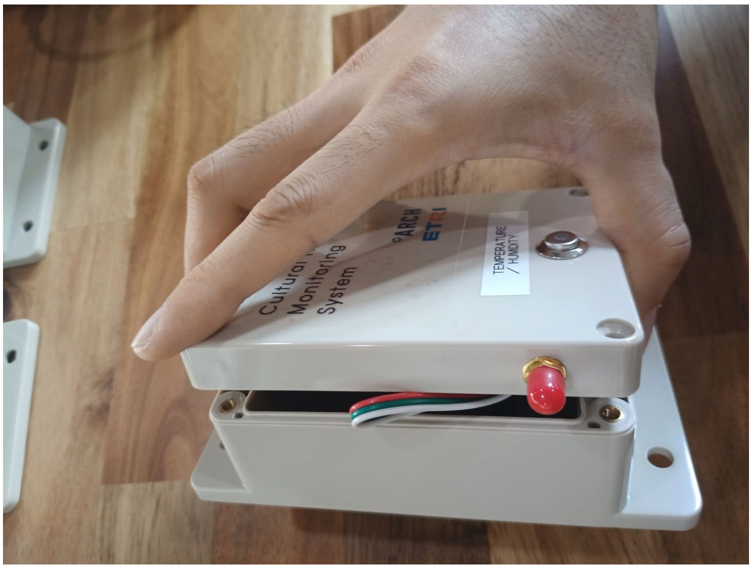

**Figure 52.** An example of the inappropriate sensor node case assembly

When assembling, be careful not to get any wires caught in between the case cover and the main body (Figure 53).

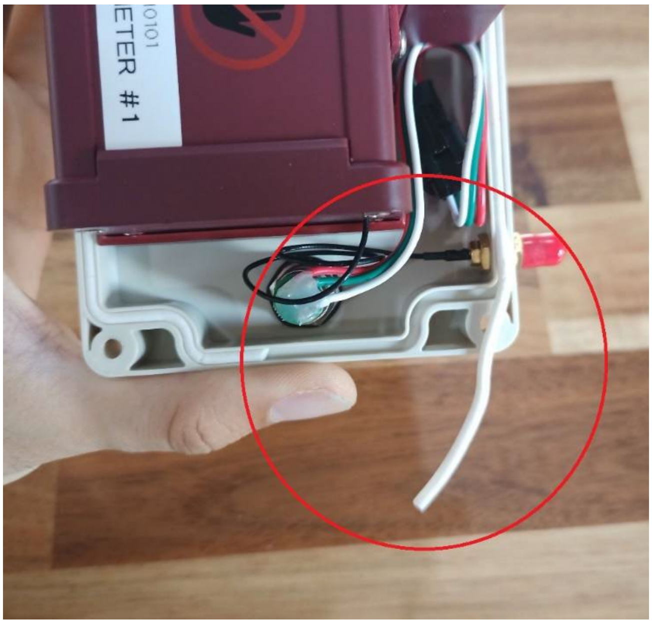

**Figure 53.** An example of inappropriate rubber packing connection

If the waterproof function has a problem, check the outer box's waterproof function. We should not take away a rubber packing from the groove of the sensor node case (Figure 54).

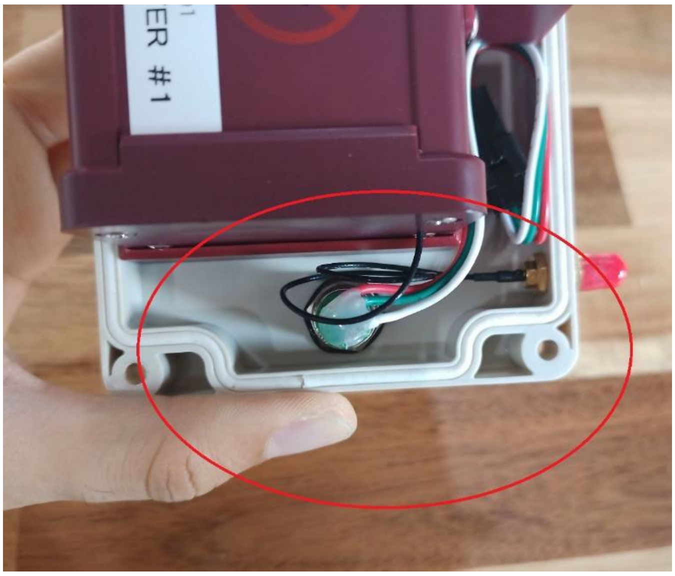

**Figure 54.** An example of an appropriate rubber packing connection

To reset and initialize memory, turn off the power and turn it on. A sensor node automatically initializes when power is on and clears all volatile memory contents.

For other kinds of malfunction or non-function, push the power switch of a sensor node to power it off, and then after about 10 seconds, power it on. Check the LED of the power switch when a problem is solved.

# Annex B. Installation and Maintenance of IoT Communication Gateway

## B.1. Installation requirements

Table 13 represents installation requirements for the IoT communication Gateway.

**Table 13.** Installation requirements for the IoT communication Gateway

| Name | Specification | Name |
|---|---|---|
| Power | AC100~230V, 50/60Hz | Universal voltage |
| Ethernet | 10/100Mbps | A DHCP server is required.<br>Internet access is required. |

## B.2. How to install

The entire hardware system, especially antenna, should be fixed as firmly as possible because the hardware system can fall and damage pedestrians in a gust or typhoon situation.

### B.2.1. The external appearance of Gateway

It isn't easy to install the Gateway inside of the cultural property. Therefore, it takes on a modern form. So, we have adopted various structures to select metal materials and improved waterproof performance by focusing on durability. Figure 55 shows the external form of the Gateway.

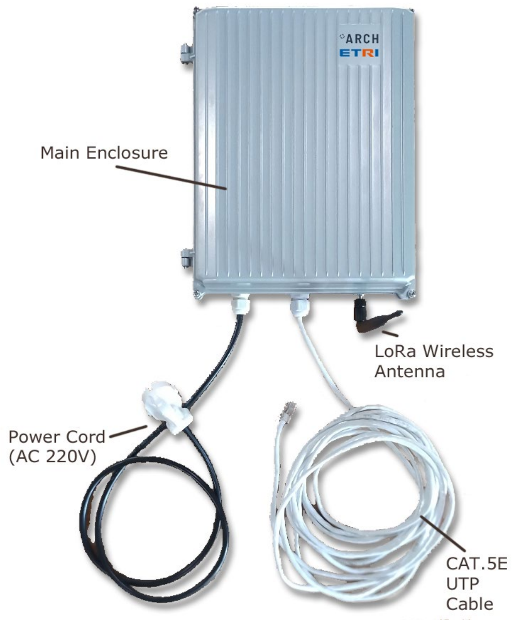


**Figure 55.** The external appearance of Gateway

- Main Enclosure: We should install it in a place that supports power supply and Ethernet-based Internet communication.
- Power Cord: We should connect it to the power part (AC power, 220V 50/60Hz, 100~120V)
- UTP Cable: We should connect it to an internet link. This device supports DHCP (Dynamic Host Configuration Protocol) only.

### B.2.2. Internal components

Figure 56 shows the internal components of the Gateway.


**Figure 56.** SMPS (AC-DC Power Supply)

As shown in Figure 57, the RF motherboard and Switching Mode Power Supply (SMPS) are essential components of the Gateway. A user should carefully install the device on a wall to prevent damage and avoid punching it.

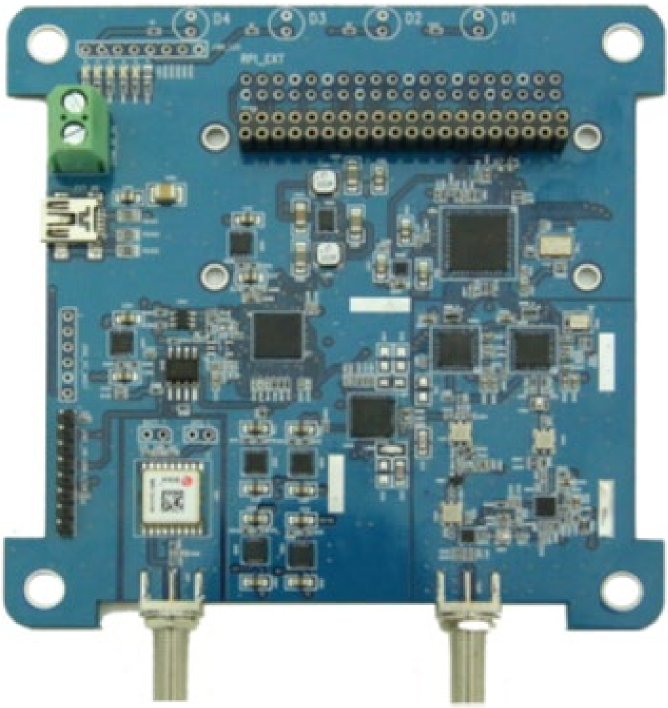

**Figure 57.** RF Motherboard

### B.2.3. Case and antenna fixing

If there is an exclusive pole:

- Fix it to the bar by using stainless steel bands.
- Apply other appropriate methods to fix it to the pole.

If there is no exclusive pole:

- Install it in a nearby pole or handrail or a fixable position using screws and steel bands.
- Fix it to the outer wall with screws or nails.

### B.2.4. Power connection

In the case of the 220V AC plug, connect it to a safe socket on the wall. If power lines become changed, loosen the two cross-head screws on the top of the circuit breaker and change the lines (Figure 58).


**Figure 58.** Screws on the top of the earth leakage circuit breaker

And then, connect AC power lines and supply power. Next, turn on the circuit breaker by pulling up the button. Finally, pull down the button to turn it off.

### B.2.5. Antenna

We should put it on the antenna terminal on the bottom of the case and turn it clockwise to connect the antenna (Figure 59).

**Figure 59.** Antenna terminal on the bottom (antenna plugged in)

Next, it needs to turn tightly to prevent it from being loosened. Nevertheless, if we tighten the antenna too much, its connector can become damaged. So, turn it hard with your hand. If we use the Gateway without any connection of LoRaWAN antenna, Amplifier (AMP) of RF output can be damaged. Therefore, make sure to connect the antenna before use.

### B.2.6. Initial run

After we supply the power, LED becomes turned on as shown in Figure 60.

- SMPS: Internal green LED becomes turned on.
- RF Mother B/D: White '5V' LED at the first one from the left becomes turned on.

It takes 30 to 60 seconds to boot up the Gateway completely.

After we boot it, General Purpose Input & Out (GPIO) LED with white colour among GPIO LEDs of RF mother board is turned on within one second and then turned off. Now, it is possible to send or receive RF signals.

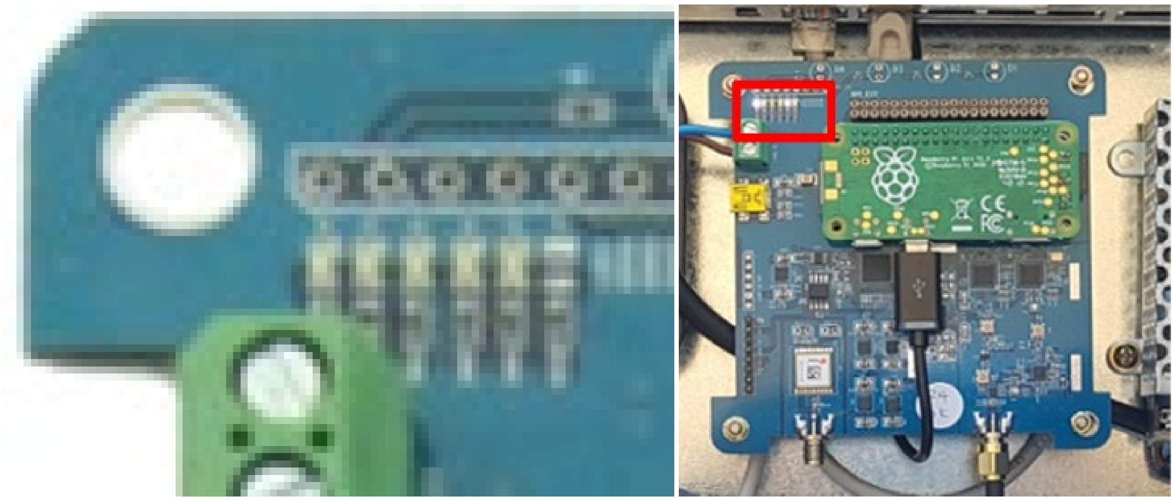

**Figure 60.** Status of LED

## B.3. Maintenance

A Gateway fault means a long-term failure of receiving LoRaWAN sensor data. If there is no problem with a server, check the external appearance of the device disconnection of the enclosure and flooding state at a site with the naked eye.

If we find nothing mentioned, we need to conduct the following analysis.

- LoRaWAN wireless communication failure: In the general interaction with a sensor, GPIO LED of RF motherboard regularly flicker. If there is no flickering for at least five minutes, power the Gateway off and on to reset.
- Power supply failure: If the white 5V LED of the RF motherboard or the internal green LED of SMPS fails to be turned on, we should check whether the power is supplied well. Check a power connection status and a voltage.

In particular, check if the enclosure is open after its initial installation or if the earth leakage circuit breaker becomes turned OFF due to torrent or unexpected flooding.