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TECHNICAL REPORT

Internet of Things (IoT) – IoT-based management of tangible cultural heritage assets –
Part 1: Framework

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Draft	Report on voting
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Full information on the voting for its approval can be found in the report on voting indicated in the above table.

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This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1, and the ISO/IEC Directives, JTC 1 Supplement available at www.iec.ch/members_experts/refdocs and www.iso.org/directives.

A list of all parts in the ISO/IEC 30189 series, published under the general title *Internet of Things (IoT) – IoT-based management of tangible cultural heritage assets*, can be found on the IEC and ISO websites.

INTRODUCTION

Cultural heritage assets can include museums, historical landmarks, artworks, and other cultural artifacts. Effective management of cultural heritage is crucial for preserving these important assets for future generations. The cultural heritage management can include efforts to preserve and protect cultural heritage assets from damage, deterioration and theft.

The Internet of Things (IoT) technology can be used for management of tangible cultural heritage assets. In particular, IoT-based sensing, monitoring and location tracking can be performed for management of tangible cultural heritage.

In the status monitoring, IoT technology can be used to monitor the condition of cultural heritage or assets, such as the temperature and humidity of a museum. This is important because certain environmental conditions can cause damage to and deterioration of valuable cultural assets. By monitoring these conditions in a real-time manner, it is possible to take corrective action to prevent damage and ensure that the assets are being preserved in optimal conditions.

In the location tracking, IoT technology can be used to keep track of various cultural assets. By applying appropriate IoT sensors to these assets, it is possible to track their location and movement in a real-time manner. This can help prevent theft and ensure that valuable assets are properly protected. For example, if an artifact is removed from its display, the IoT sensor will trigger an alert, enabling museum staff to quickly take actions to secure the asset.

This document describes how IoT technology can be used to effectively manage a variety of cultural heritage assets. This document is purposed to provide useful information or guidelines for development of platforms or services on IoT-based management of cultural heritage.

In particular, this document focuses on management of stand-alone cultural heritage assets. A stand-alone cultural heritage is a single cultural asset that is not part of a larger collection or group of assets. Stand-alone cultural assets can be important to a particular community or group and can be preserved and protected in order to preserve the cultural heritage of that group. In the context of cultural heritage management, stand-alone cultural assets can be treated differently than assets that are part of a larger collection, as they possibly do not have the same level of institutional support or resources available for their preservation.

IEC TR 30189 consists of two parts.

– Part 1 describes a framework for the use of IoT technology for management of tangible cultural heritage assets, which includes the associated functional entities and information flows.
– Part 2 describes a set of use cases for IoT-based management of tangible cultural heritage assets, based on the framework, which include implementations and experimentations for the associated services.

INTERNET OF THINGS (IOT) – IOT-BASED MANAGEMENT OF TANGIBLE CULTURAL HERITAGE ASSETS –

Part 1: Framework

1 Scope

This document describes a framework for the use of IoT technology for management of tangible cultural heritage assets, which includes the associated functional entities and information flows.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1
cultural heritage
legacy of physical objects and intangible attributes of a group or a society that are inherited from past generations, maintained and protected in the present and preserved for future generations

[SOURCE: ISO 18461:2016, 2.1.3]

3.2
Internet of Things
infrastructure of interconnected entities, people, systems and information resources together with services which processes and reacts to information from the physical world and virtual world

[SOURCE: ISO/IEC 20924:2024, 3.2.8]

4 Symbols and abbreviated terms

CCTV	closed circuit television
CHM	cultural heritage management
GPS	global positioning system
IoT	Internet of Things
JSON	JavaScript Object Notation
JWT	JSON Web Token
MQTT	Message Queue Telemetry Transport
OAuth	Open Authorization
RDBMS	relational database management system
URL	Uniform Resource Locator

5 General

5.1 Cultural heritage management

Cultural heritage represents national or world-wide heritage that has been artificially or naturally formed. Among the properties that have been preserved for a long period of time and passed down to the present day, those with great historical, artistic, and academic value are designated as cultural heritage assets.

Figure 1 shows examples of the famous cultural heritage assets in the world. These cultural heritage assets exist indoors or outdoors, and their sizes vary greatly.

Figure	Name	Location	Indoor / Outdoor	Size	Era
	Statue of Liberty	New York City	Outdoor	Large	1886
	The Great Wall	China	Outdoor	Large	259 BC to 210 BC, 1368 to 1644
	Stupa of Buddhist Monk Soyo at Yeongoksa Temple, Gurye	Korea, republic of	Outdoor	Small	1650
	Seokguram Grotto	Korea, republic of	Indoor	Large	751 to 774
	Holy Crown of Hungary	Hungary	Indoor	Small	1000 to 1920
	Bracelet with Four Bells	Thailand	Indoor	Small	300 BC to AD 150

IEC

Figure 1 – Examples of cultural heritage assets

Cultural heritage management is the process of preserving and managing the material and immaterial aspects of cultural heritage assets that include historic buildings, archaeological sites, monuments, artifacts, and documents.

In general, cultural heritage management is associated with identification, conservation, and public engagement. Identification of cultural heritage is the first step in cultural heritage management. This involves identifying and documenting the cultural assets within a community. This process can be achieved through surveys, inventories, and other data collection methods. The identification of cultural heritage is essential to understanding its value and significance, as well as determining appropriate management strategies. Next, the conservation is the process of preserving cultural heritage for future generations. This involves a range of activities, such as stabilizing, repairing, digitizing, and protecting cultural assets from damage, decay, and deterioration. Conservation can also involve preventive measures, such as climate control, security, and monitoring. Finally, the public engagement is a critical aspect of cultural heritage management. This involves the development of partnerships and collaborations with communities, stakeholders, and other organizations. Public engagement is essential for ensuring that cultural heritage management is responsive to the needs and aspirations of the community, and that it is sustainable over the long term.

5.2 Management of stand-alone cultural heritage assets

Cultural heritage assets are the common heritage of humankind and thus it is important that they are preserved and protected for a long time. However, these cultural heritage assets can be damaged for various reasons.

Figure 2 gives some examples of damage to tangible cultural heritage assets. A cultural heritage can be damaged for various reasons such as natural damage (e.g. worn-out), destruction (e.g. broken), and theft. Such damage will lead to a great loss of value. To preserve cultural heritage assets and prevent damage to the cultural heritage assets, it is important that a variety of services for cultural heritage management is used, as shown in Figure 2. These management functions include the status monitoring of cultural heritage assets, the surveillance of cultural heritage damage by humans or animals, the prevention of intentional theft, and the location tracking for stolen cultural heritage assets.

Figure 2 – Management for conservation of tangible cultural heritage assets

Most famous cultural heritage assets are usually registered with a cultural heritage management authority (e.g. cultural heritage administration), and are located and managed in a relevant place (e.g. museum or tourist attraction). On the other hand, a number of cultural heritage assets are not under the management of cultural heritage management authority. These cultural heritage assets are referred to as "stand-alone" cultural heritage assets in this document.

The conservation of stand-alone heritage assets is a critical aspect of cultural heritage management. Stand-alone heritage assets refer to historic buildings, monuments, and other structures that are not part of a larger historic district or cultural landscape. These structures can be vulnerable to deterioration, neglect, or inappropriate development, and require specific conservation strategies.

Stand-alone cultural heritage can exist independently. However, it is important to preserve and protect cultural heritage because it helps to preserve the unique identity and history of a group or society. Some stand-alone cultural heritage can be owned and managed by a private or unofficial organization, rather than an official or public authority. In particular, such stand-alone cultural heritage assets are more vulnerable to damage (e.g. worn-out, broken, theft) than the famous cultural heritage in a museum. Accordingly, it is important to give special management to the stand-alone cultural heritage assets for conservation of cultural heritage assets.

It is important to consider the condition of a stand-alone heritage in cultural heritage management. The condition refers to the physical state of the structure, including its materials, construction, and architectural features. The condition of a stand-alone heritage can impact its significance, as well as the type and extent of conservation interventions required.

5.3 Considerations for IoT-based management of cultural heritage assets

5.3.1 General

The Internet of Things (IoT) can be used to manage tangible cultural heritage assets. Cultural heritage management can be implemented based on the general IoT system. The key concepts for IoT-based management of cultural heritage include sensors and data analytics.

– Sensors are a critical component of IoT-based cultural heritage management. Sensors can be used to monitor environmental conditions, such as temperature, humidity, and light levels, as well as structural integrity, such as movement, vibrations, and settling. Sensors can provide real-time data that can be used to inform conservation and management decisions. For example, sensors can be used to monitor the temperature and humidity of a museum's climate-controlled storage room to ensure that the artworks are being kept in the optimal environment. Sensors can also be used to monitor the structural integrity of a historic building to detect any signs of damage or deterioration.
– Data analytics is another critical concept in IoT-based cultural heritage management. Data analytics involves the analysis of sensor data and other digital data sources to identify patterns, trends, and anomalies. Data analytics, including predictive analytics, can help to identify potential threats and risks to cultural heritage sites, as well as inform management and conservation strategies. For example, data analytics can be used to identify patterns of visitor behaviour that could potentially damage artworks. Data analytics can also be used to identify areas of a historic building that are at risk of collapse.

The framework is designed to be flexible and adaptable to the specific needs of different cultural heritage sites. It can be used to manage a wide range of cultural assets, from small artifacts to large buildings.

The IoT-based management of cultural heritage is a complex undertaking. It requires a deep understanding of the unique attributes of cultural heritage management, as well as the latest IoT technologies.

5.3.2 Device

The IoT devices for management of cultural heritage are designed to monitor and track the condition and movement of cultural heritage assets, such as artifacts and works of art. These devices can be applied to the heritage assets themselves or placed in the environment in which the heritage assets are housed.

Unlike general-purpose IoT devices that are commonly used for continuous environmental monitoring, cultural heritage management devices possess unique requirements. The following are the distinctive requirements of IoT devices for cultural heritage management.

– Purpose: IoT devices for cultural heritage management are designed to provide monitoring and tracking capabilities for the preservation of cultural assets. This means that it is important that they are able to collect and transmit data that is relevant to the condition and movement of the assets, such as temperature, humidity, light levels, and vibration. They can also be equipped with sensors that can detect specific threats to the assets, such as unauthorized access or tampering.
– Shape: It is important that the shape of IoT devices for cultural heritage management are compatible with the specific needs of the heritage being monitored. For example, the need for a device that is attached to a delicate artifact to be small and lightweight, and the need for a device to be designed to be non-intrusive so that it does not damage the artifact.
– Location: IoT devices for cultural heritage management can be located indoors or outdoors. It is important for the devices to withstand the environmental conditions of the location where they are being used.
– Sensors: IoT devices for cultural heritage management are equipped with a variety of sensors that can collect data about the condition of the assets and the environment around them. These sensors can include temperature sensors, humidity sensors, light sensors, vibration sensors, and tilt sensors.
– Power supply: The power supply for IoT devices for cultural heritage management depends on the location of the devices and the type of sensors they are equipped with. Indoor devices are typically powered by others, but outdoor devices require independent power. Therefore, solar power, such as solar PV (photo voltaic), can be useful for the sensors used to manage cultural heritage, in addition to the electric power supply.
– Functionality: The devices used for cultural heritage management provide functions for status monitoring of cultural heritage, intrusion detection by animals or humans, and location tracking for stolen cultural heritage in addition to transmission of sensor data to a platform.

5.3.3 Platform

The cultural heritage management platform is responsible for collecting and processing information collected from devices located near cultural heritage assets in real time and delivering it to applications that require the information. In order to provide a smooth service, it is important that the cultural heritage management platform provides the following functions.

– Cultural heritage data management: This function entails the identification, description, location, and status of individual cultural heritage assets, and registering them within a database. This helps in systematically classifying and managing various cultural heritage assets according to type, era, importance, and other related factors. The documentation on a tangible cultural heritage asset, including its history and where it comes from, is important in the IoT-based management of cultural heritage assets, which often determines the asset's value. It is important to manage the relevant information with an appropriate database in the platform.
– Device management: The platform is responsible for managing the devices that are used to collect data from cultural heritage assets. This includes tasks such as registering devices, assigning devices to cultural heritage assets, and monitoring and configuring devices.
– Application and service management: The platform is responsible for managing the applications and services that use the data collected by the platform. This includes tasks such as registering applications and services, assigning applications and services to cultural heritage assets, and access management to collected data.
– Data collection: The platform collects data from devices on cultural heritage assets to monitor their condition. For example, information such as temperature, humidity and tilt, as well as media data such as video and audio, are collected to determine the condition of cultural heritage.

– Condition report: To ensure prompt responses to specific events, it is important that the platform has the capability to detect these occurrences and relay notifications to the relevant application or service. To achieve this, the platform can be equipped with an interface designed to seamlessly accept event request messages from the application or service and, in turn, dispatch notification messages accordingly.

Within the cultural heritage management framework, it is important that various entities such as devices, platforms, and applications maintain continuous connectivity. The robust connection is essential to enable real-time prevention or response to situations where cultural heritage can be at risk. It is important to ensure robust connectivity between entities for cultural heritage management.

5.3.4 Application or service

The application or service serves as a dedicated interface, delivering tailor-made services for users engaged in cultural heritage management with the help of the platform. It can either be integrated within a centralized control centre or take the form of an application.

In the viewpoint of functionality, it is important that IoT-based management of cultural heritage provides monitoring and tracking. For example, it is important that the application or service for cultural heritage management provides the following functions.

– Environmental monitoring: This functionality is essential in maintaining a real-time overview of the environmental parameters surrounding the cultural sites. It collects metrics such as temperature, humidity, air quality, noise, and ambient light levels. Gathering this data helps to identify potential hazards to the cultural assets, enabling preemptive measures to counteract potential damage.
– Condition monitoring: This function measures and predicts the physical and structural state of the cultural heritage assets based on the information from environmental monitoring. By continuously assessing factors such as wear and tear, moisture content, or any visible structural anomalies, it provides a holistic view of the heritage's health.
– Preventive maintenance: This function leverages the data derived from condition monitoring to determine the maintenance needs of cultural heritage assets. By tracking the gradual wear or degradation patterns over a period, it can forecast when a particular asset might need attention. This proactive approach ensures timely interventions, averting severe damage or expensive restorations in the future.
– Object detection: It is important that the platform provides object detection from sensors and cameras to detect wildlife or people in the area of cultural heritage. This can help to prevent wildlife and people from damaging the heritage, such as by chewing on wooden beams or scratching graffiti on walls.
– Location tracking: Location tracking can be used to monitor the movement and location of artifacts and other cultural heritage objects. By applying IoT sensors to these items, it is possible to track their movement in real-time and ensure that they are not lost or stolen. This can be particularly useful for museums and other cultural institutions that have large collections of valuable artifacts.

6 Functional entities

6.1 General

The IoT-based CHM system consists of cultural heritage, device or sensor, network, platform, and application or service, and user, as shown in Figure 3.

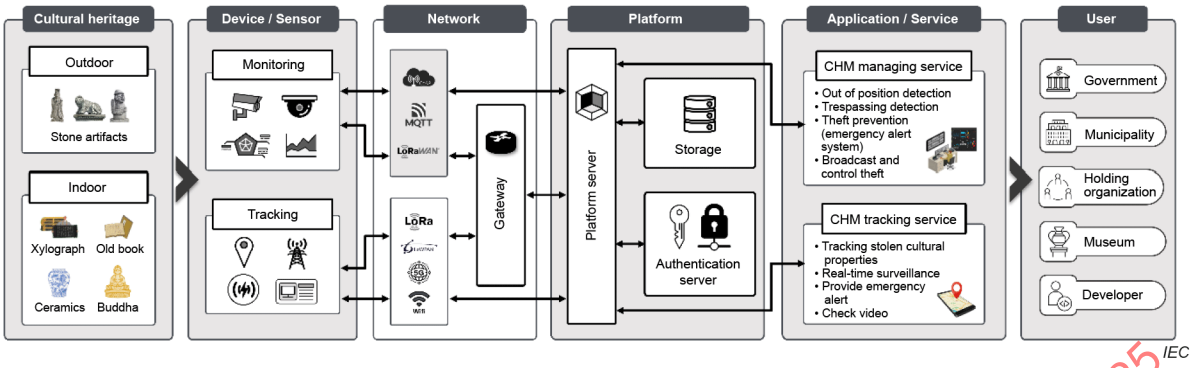

Figure 3 – System model for IoT-based management of cultural heritage

According to their location, cultural heritage assets can be categorized into outdoor and indoor types. Outdoor heritage generally consists of larger artifacts such as stone statues, and its associated sensing devices can require an independent power source, such as solar power. On the other hand, indoor heritage assets, such as woodblocks, old books, pottery, and Buddha statues, are generally smaller in size.

One or more devices and sensors can be used for IoT-based management of tangible cultural heritage. For example, sensing devices can be applied to cultural heritage assets to measure parameters such as temperature, humidity, or vibration. Monitoring or tracking devices, such as CCTV and GPS, can also be used to monitor cultural heritage assets. The data collected by these devices are then delivered to the IoT-based platform through a gateway using communication networks such as 5G cellular, LoRa, or Wi-Fi.

The IoT-based CHM platform includes various servers and databases required for cultural heritage management, such as device management and data or information management. The platform can provide advanced CHM services using artificial intelligence and big data analysis techniques. The platform's main function is to receive and store data from the sensors and devices, and to provide application or service with real-time information on the status of cultural heritage assets.

The platform functions are provided through either the platform server or gateway entity. The platform server entity has all platform functions, while the gateway is a networking device that connects many devices to the platform using a variety of wired or wireless communications and only has device interworking and CHM functions. The gateway collects data information from many devices and delivers such information to the platform server.

The service or application component provides a variety of CHM services to users such as CHM-related organizations or experts, owners of cultural heritage, and developers. In a dedicated office or control centre, the IoT-based CHM system can be established to monitor and manage multiple cultural heritage assets. These services or applications can be defined according to the specific purpose of the user.

In summary, IoT-based CHM systems provide an efficient and effective means of managing cultural heritage. The system model includes cultural heritage, device or sensor, communication network, platform, and service or application components. It allows for the collection and transfer of data to a centralized platform for advanced management and analysis. The system can be customized based on specific user requirements to better manage cultural heritage. The preservation of cultural heritage is essential for our cultural understanding, and an IoT-based CHM system can provide a promising solution for achieving this goal.

6.2 Device

The device used for CHM (CHM device) is used for status monitoring or location tracking of cultural heritage assets. CHM devices are categorized into monitoring (sensing) devices and tracking devices. A monitoring device or sensor (e.g. for measurement of temperature, humidity, vibration) is applied to the cultural heritage, and a tracking device (e.g. CCTV, GPS) is installed near the concerned cultural heritage).

The data information measured and collected by a device is delivered to the platform via the gateway (or network) for further processing. To maintain a connection between device and platform persistently, it is important that each device exchanges data or control messages with the platform periodically.

Each device can perform data communication with its platform in a periodic or event-based way. In the periodic communication, a device transmits measured sensing data to the platform periodically. Event-based communication can also be used where a device or gateway will initiate the request of data communication when an event occurs or a specific condition is satisfied.

6.3 Network

The data information measured and collected by a device is delivered to the platform via the gateway (or network) for further processing. To maintain a connection between device and platform persistently, it is important that each device exchanges data or control messages with the platform.

Each device can perform data communication with its platform in a periodic or event-based way. In the periodic communication, a device transmits measured sensing data to the platform periodically. In the event-based communication, a device or gateway will initiate the request of data communication when an event occurs or a specific condition is satisfied.

6.4 Platform

The platform is used to perform overall control and management of CHM functional entities and services. For this purpose, the platform provides appropriate interfaces with CHM devices and applications or services. The platform includes a variety of functions, servers and databases for device management and for monitoring and tracking of cultural heritage assets.

Figure 4 shows the functional components of an IoT-based CHM platform, which include application interworking function, device interworking function, data storage, authorization server, and CHM function.

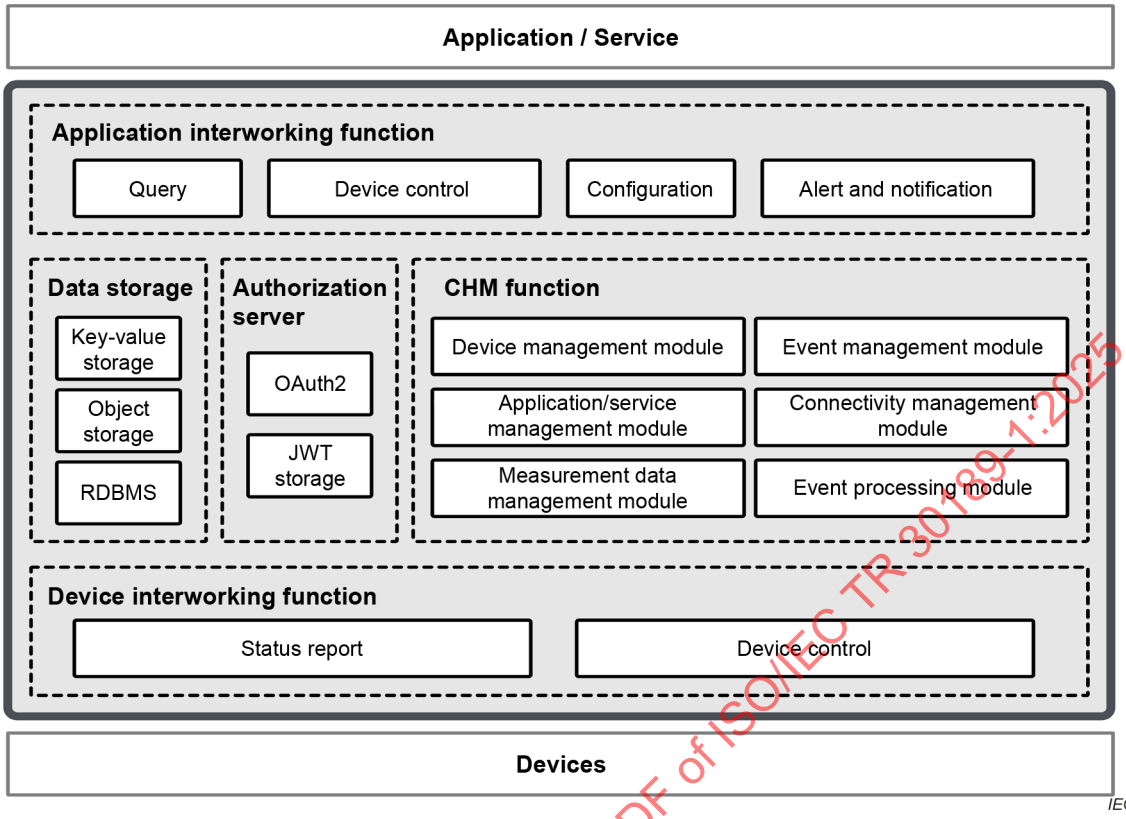

Figure 4 – Platform functions for IoT-based CHM

The platform features two interworking functions: the device interworking function and the application interworking function. These functions provide interfaces for both devices and applications or services. The device interworking function offers a status report interface to collect device status and measurement data sensed by monitoring and tracking devices, as well as a device control interface for taking appropriate actions for cultural heritage management. The application interworking function provides a query interface for obtaining device or cultural heritage information or measurement data registered on the platform, a device control interface for managing cultural heritage assets, a configuration interface for setting up devices, events, and cultural heritage, and an alert and notification interface for receiving information such as event occurrences.

One or more authentication servers can be employed for authentication of devices and users on cultural heritage assets. These servers can provide authentication functions using a variety of relevant protocols, such as OAuth 2.0 and JSON Web Token (JWT). The JWT is a compact URL-safe means of representing claims to be transferred between two parties, while OAuth 2.0 is an industry-standard protocol for authorization that focuses on client developer simplicity while providing specific authorization flows for web applications.

The platform also features a CHM function, which has the six sub-modules: device management module, event management module, application or service management module, connectivity management module, measurement data management module, and event processing module. Together with associated servers and data storage, these CHM modules provide the cultural heritage management function.

In device interworking function, the platform is responsible for the overall management of devices and gateways. During initialization, it is important that all devices and gateways are registered with the platform. The device management module manages the profiles and monitors the operational status of all registered devices. If an abnormal condition is detected during monitoring, the platform can send a notification message to the concerned application.

In application interworking function, each CHM device measures data for monitoring and tracking and sends the measured data to the platform via wired or wireless communications. The data type (e.g. video, text) and format (e.g. structured or unstructured) can vary depending on the associated CHM device and service or application.

6.5 Application or service

The CHM application or service is an entity that provides specific cultural heritage management services for CHM users, based on the functions provided by the platform. The CHM application operates over the CHM platform and can be implemented together with a control centre or as an application programme for smartphones. With the CHM application, a CHM user can monitor and keep track of a set of cultural heritage assets.

In the viewpoint of functionality, IoT-based CHM basically provides the sensing, monitoring and tracking functions. Based on these basic functions, a variety of IoT-based CHM services can be defined and provisioned, according to the specific requirement of the user. One typical service by using IoT-based CHM is sensor-based status monitoring. Sensors can be installed on cultural heritage sites to monitor temperature, humidity, vibration, and other environmental factors. This data can be used to detect any changes or damage to the artifacts and structures, and corrective measures can be taken to prevent further damage. IoT-based services can provide location tracking for cultural heritage artifacts and structures. This can help in preventing theft or loss of valuable artifacts and can also be used to track the movement of artifacts for exhibitions and research purposes.

Table 1 shows some examples of IoT-based CHM services. More specific examples are also given in Annex A.

Table 1 – Examples of IoT-based CHM services

Service	Sensor or device	Network	Platform (functionality)
object detection	radar	wired or wireless	object detection
status (damage) monitoring	temperature or humidity sensors	wired or wireless	sensor or data or policy management
movement detection	CCTV	wired or wireless	movement detection
location tracking	GPS	wireless	location tracking

In object detection service, a radar device is used to detect the movement of an object (human or animal). This service is useful to monitor whether there is an unauthorized human or animal near cultural heritage assets. The measured radar information will be delivered to the platform via wired or wireless communications, and the platform performs the object detection based on the delivered radar information.

In the status (damage) monitoring service, a set of sensors can be used to measure temperature, humidity, vibration, and so on. This service is useful to monitor whether there is damage (broken, worn-out, etc.) to cultural heritage assets. The measured sensing information will be delivered to the platform via wired or wireless communications, and the platform performs the status monitoring to determine whether there is damage to a cultural heritage, based on the collected sensing data with the associated policy information.

In the movement detection service, a CCTV device is used to detect the movement of an object (human or animal). This service is useful to monitor whether there is movement of unauthorised human or animal in the neighbourhood proximity of cultural heritage. The measured CCTV information will be delivered to the platform, and the platform performs the movement detection.

In the location tracking service, GPS sensor is applied to the cultural heritage. This service is useful to keep track of the location of the cultural heritage in the real-time manner. The measured GPS information will be delivered to the platform via wireless communications, and the platform performs the location tracking based on the delivered GPS information.

6.6 User

CHM user represents a human or an authority who benefits from the IoT-based CHM services. Examples of CHM users include individuals or authorities responsible for the management of cultural heritage, as well as individuals who own cultural heritage.

7 Information flows

7.1 General

The fundamental operations for IoT-based CHM can be divided into monitoring and tracking. The monitoring function is used to observe the status of a cultural heritage using devices or sensors, while the tracking operation is used to detect its movement and keep track of its location. Subclauses 7.2 and 7.3 describe the general information flows for both the monitoring and tracking operations.

7.2 Status monitoring operation

The status monitoring operation aims to prevent cultural heritage assets from being damaged by natural disasters and to protect them from intrusion or theft. To accomplish this, the platform offers a monitoring function that enables the service or application to retrieve the status of cultural heritage assets and notifications for abnormal situations in real-time. The monitoring function of the platform can be performed based on pre-defined events or status changes, which include detecting the following:

– unauthenticated objects (humans or animals);
– broken or worn-out cultural heritage assets;
– abnormal environmental conditions (e.g. temperature, moisture);
– low device battery levels;
– devices disconnected from the network.

Users or services or applications can create events on the platform with specific information such as event type, occurrence condition, relevant cultural heritage, and device profiles to be alerted by the event information. If events other than the pre-defined events are required, it is important to specify an application programming interface (API) that can process event occurrence conditions.

Figure 5 shows the high-level operation flows for status monitoring of cultural heritage assets, which include the three phases: registration, timer-based monitoring, and event-based monitoring.

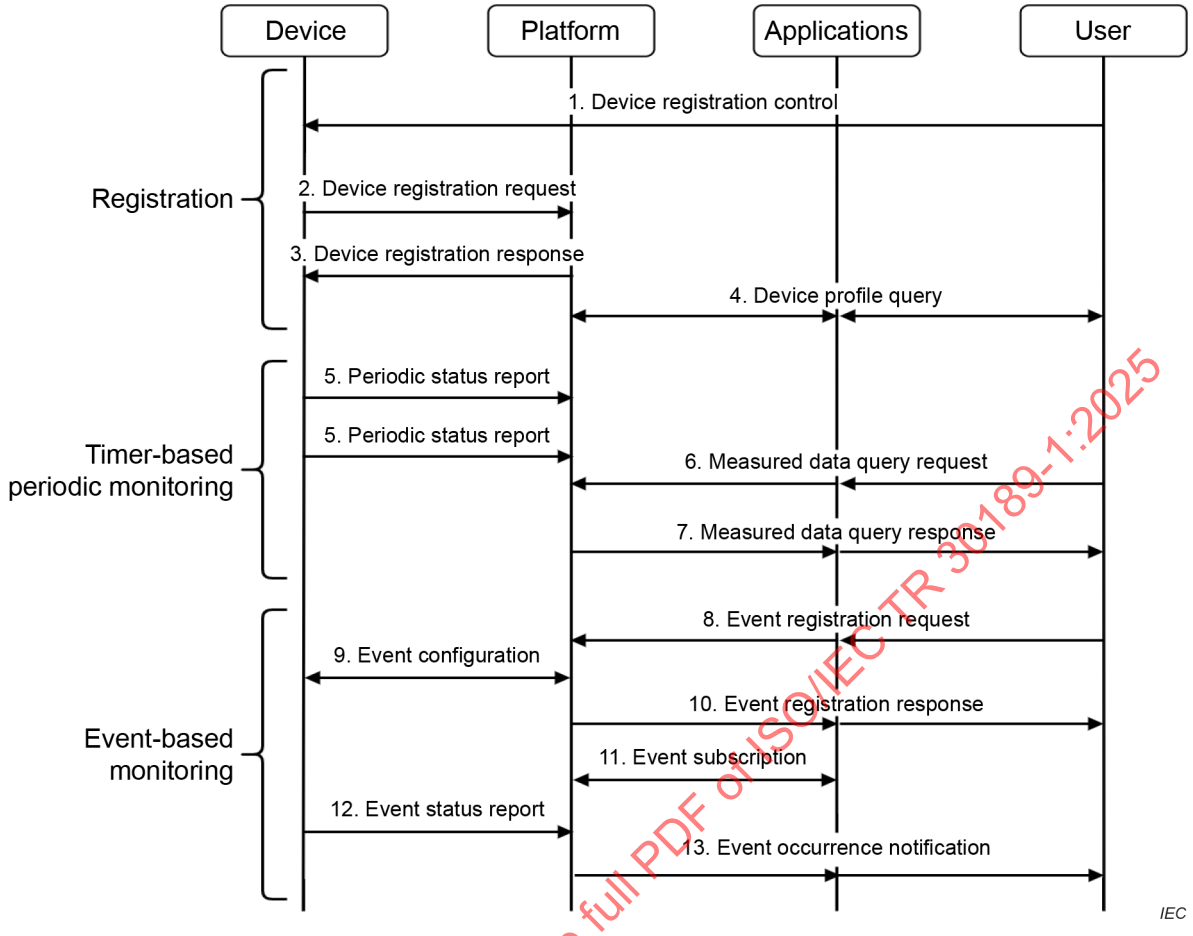

Figure 5 – Information flows for status monitoring operation

The process of registering a device involves the manager or authority user sending a device registration control message through the device interface to provide parameters required for registration such as the relevant cultural heritage and platform profiles, as well as an authorization key (1). The device then sends a device registration request that includes the received parameters (2). The platform verifies the validity of the received request message and responds with the registration results (3). If the registration is successful, the device profile can be queried by the authority users through the platform (4).

To maintain the connection, the device sends periodic status reports (5). The platform changes the interval between two messages in a series. The data delivered by the periodic status report is stored in the platform without triggering a notification. If a user wants to check the device status, they can query the device status stored in the platform through the service or application responsible for managing the device (6, 7).

If a user wants to be notified of a status change of a specific device or the detection of an abnormal situation, they can register an event through a related service or application. The user sends a request message to register a new event, including information such as the event type, event occurrence condition, relevant cultural heritage, and device profiles (8). The platform configures the device to handle the event when it receives the request (9) and responds with the interface for event notifications (10). The service or application sends a message to subscribe to the event notifications (11). When the event occurs, the device sends the event status report message to the platform (12). Unlike the periodic status report, the event status report generates and transmits the event occurrence notification to the user through the relevant service or application (13).

7.3 Location tracking operation

The IoT-based CHM provides a location tracking function that helps locate stolen cultural heritage. Figure 6 shows the high-level operation flows for location tracking of cultural heritage assets.

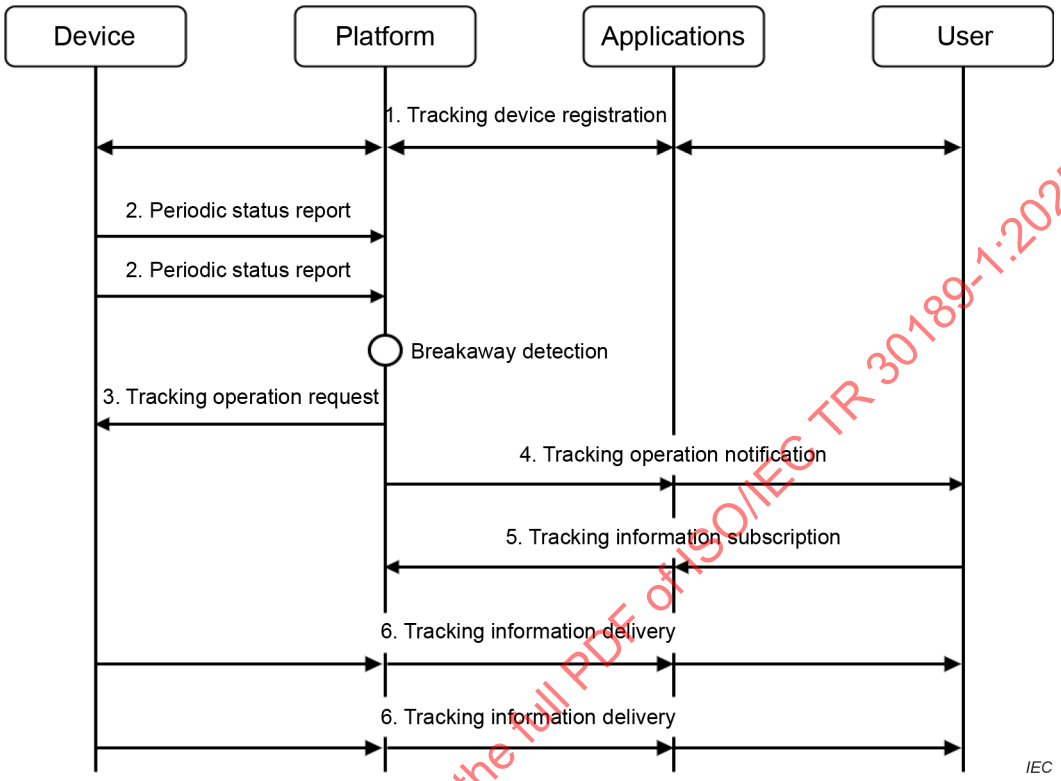

Figure 6 – Information flows for location tracking operation

After a tracking device is registered on the platform, it periodically exchanges messages with the platform to maintain the connection (1, 2). Since the tracking device only senses location information when triggered by an event (such as a control message from the platform or disconnection from the gateway), the periodic status report mainly includes device status information, such as battery levels.

When a breakaway of the cultural heritage is detected, the platform sends a control message to trigger the tracking device to sense the location (3). The platform then informs the user of the stolen event through an interface provided by the tracking function on the relevant service or application (4), and the user can subscribe to the tracking information using the interface (5). Once the subscription is successful, the user can receive the location of the cultural heritage in real-time (6). Quick recovery of stolen cultural heritage is crucial to preserve its value, and the platform's tracking function provides an effective means of locating and recovering stolen cultural heritage.