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SERIES Y: GLOBAL INFORMATION INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS, NEXT-GENERATION NETWORKS, INTERNET OF THINGS AND SMART CITIES

Internet of things and smart cities and communities – Requirements and use cases

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Requirements of Internet of things based civil engineering infrastructure health monitoring systems

Recommendation ITU-T Y.4214

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Recommendation ITU-T Y.4214

Requirements of Internet of things based civil engineering infrastructure health monitoring systems

Summary

Monitoring the safety and integrity of civil engineering infrastructures using objective data collected from the infrastructures themselves with Internet of things (IoT) capabilities is an effective means to supplement inspection and diagnosis for advanced and efficient maintenance work on civil engineering infrastructures. In this Recommendation, an IoT-based system for this purpose is called a civil engineering infrastructure health monitoring system.

Recommendation ITU-T Y.4214 describes the requirements specific to the IoT-based civil engineering infrastructure health monitoring system for the purpose of maintaining civil engineering infrastructures.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T Y.4214	2022-02-03	20	11.1002/1000/14824

Keywords

Civil engineering infrastructure, infrastructure health monitoring, Internet of things, IoT.

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In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

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1 Scope

The term "civil infrastructure" is used to refer to an artificially constructed structure built to support human activities in cities and communities. The term "civil engineering infrastructure" used in this Recommendation specifically refers to the large-scale structures that make up roads, bridges and tunnels.

The maintenance of civil engineering infrastructures is mainly based on periodic visual inspections and diagnoses by specialists to maintain the safety and integrity of the infrastructure. These specialists need a high degree of experience and technical know-how, as maintenance requires relevant human resource allocation and specific education and qualifications. Utilization of objective data collected from the civil engineering infrastructure using Internet of things (IoT) capabilities leads to advanced and more efficient maintenance, while enhancing and rationalizing the human inspections and diagnostic work. In this Recommendation, an IoT-based system for this purpose is called a civil engineering infrastructure health monitoring system.

This Recommendation addresses IoT-based civil engineering infrastructure health monitoring systems specifying the following:

– A reference model of IoT-based civil engineering infrastructure health monitoring systems;

– Requirements specific to IoT-based civil engineering infrastructure health monitoring systems.

2 Reference

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T Y.4000] Recommendation ITU-T Y.4000/Y.2060 (2012), *Overview of the Internet of things.*

[ITU-T Y.4100] Recommendation ITU-T Y.4100/Y.2066 (2014), *Common requirements of the Internet of things.*

[ITU-T Y.4113] Recommendation ITU-T Y.4113 (2016), *Requirements of the network for the Internet of things.*

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 Internet of things (IoT) [ITU-T Y.4000]: A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies.

NOTE 1 – Through the exploitation of identification, data capture, processing and communication capabilities, the IoT makes full use of things to offer services to all kinds of applications, whilst ensuring that security and privacy requirements are fulfilled.

NOTE 2 – From a broader perspective, the IoT can be perceived as a vision with technological and societal implications.

3.1.2 IoT area network [ITU-T Y.4113]: A network of devices for the IoT and gateways interconnected through local connections.

NOTE – This definition is based on "Overview of the Internet of things" [ITU-T Y.4000], where clause 6.2 states "devices can communicate with other devices using direct communication through a local network (i.e., a network providing local connectivity between devices and between devices and a gateway, such as an ad-hoc network)".

3.2 Terms defined in this Recommendation

None.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

3D Three Dimensions

IAN IoT Area Network

IoT Internet of Things

SC&C Smart Cities and Communities

WAN Wide Area Network

5 Conventions

In this Recommendation:

The keywords "is required to" indicate a requirement which must be strictly followed and from which no deviation is permitted if conformance to this document is to be claimed.

The keywords "is recommended" indicate a requirement which is recommended but which is not absolutely required. Thus, this requirement need not be present to claim conformance.

The keywords "can optionally" and "may" indicate an optional requirement which is permissible, without implying any sense of being recommended. These terms are not intended to imply that the vendor's implementation must provide the option and the feature can be optionally enabled by the network operator. Rather, it means the vendor may optionally provide the feature and still claim conformance with the specification.

6 Overview of IoT-based civil engineering infrastructure health monitoring system

6.1 Necessity of IoT-based civil engineering infrastructure health monitoring

The maintenance of civil engineering infrastructures is mainly based on periodic visual inspections and diagnoses made by specialists. If any deterioration or damage is found during the inspections, proper diagnoses and appropriate measures are taken to keep the infrastructure sound and minimize the cost of maintenance. This requires a high degree of experience and technical know-how and requires allocating and training human resources.

Civil engineering infrastructure health monitoring is the act of measuring the state of these infrastructures, acquiring and comparing the data to understand the occurrence and progress of deterioration over time. IoT-based civil engineering infrastructure health monitoring is an effective means to obtain the information necessary for the inspection and diagnosis of infrastructures, and it is expected that streamlining for infrastructure maintenance and management work would be a method to supplement inspection and investigation work.

6.2 Reference model of IoT-based civil engineering infrastructure health monitoring system and associated sites

The IoT-based civil engineering infrastructure health monitoring system (hereafter "the system") collects, accumulates and processes objective data on civil engineering infrastructures subject to health monitoring, and provides the data to applications that support the maintenance and operation of the infrastructure. The system has two specific characteristics compared with other IoT systems.

The first characteristic is that the data measured by a sensor alone is meaningless unless the information of the structure being monitored is associated with the measured data. The second characteristic is that civil engineering infrastructures are operated over a very long term, usually up to several decades. During this long-term operation, the system is required to accumulate data continuously.

A reference model of the IoT-based civil engineering infrastructure health monitoring system and associated sites is shown in Figure 1.

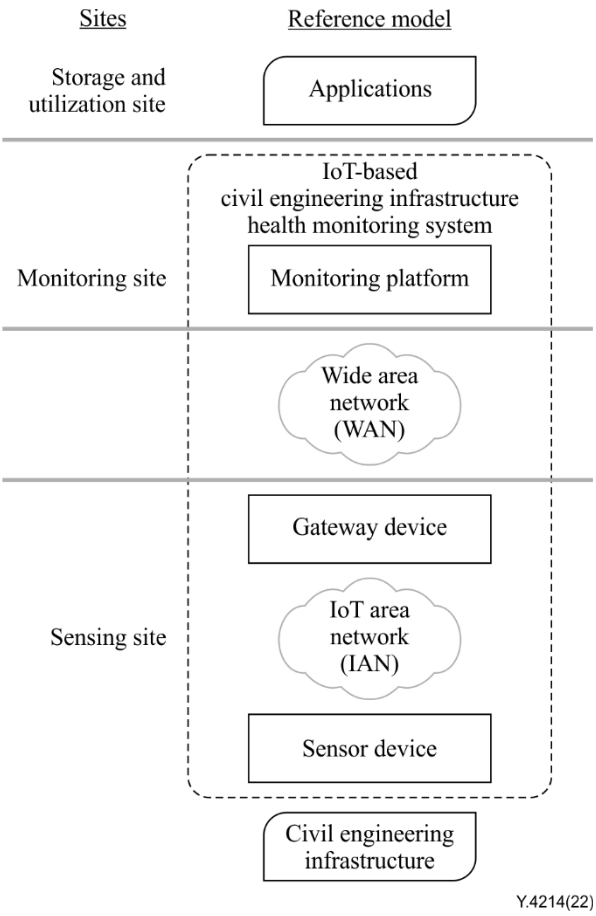

Figure 1 – Reference model of the IoT-based civil engineering infrastructure health monitoring system and associated sites

6.2.1 Reference model

The reference model of the IoT-based civil engineering infrastructure health monitoring system is composed of five components, a sensor device, gateway device, monitoring platform and the networks connecting these components, i.e., the IoT area network (IAN) and the wide area network (WAN). The dotted line shown in Figure 1 demarcates the reference model of the IoT-based civil engineering infrastructure health monitoring system. Civil engineering infrastructure(s) and applications are outside the system.

- Civil engineering infrastructure: Represents large-scale structures such as roads, bridges and tunnels that are subject to health monitoring.
- Sensor device: Represents a device that measures health monitoring indicators (including original data that can be converted into indicators). The sensor device is not only a sensor but also includes assisting devices for communication, temporary storage of data, data processing, and position measurement (e.g., a physical marker or a laser irradiation equipment for calculating an absolute position from a relative position in image data).
- Gateway device: Represents a communication device that aggregates the data measured by one or more sensor devices and transmits them to the monitoring platform. A gateway device is not always permanently at the sensing site. There are cases where a vehicle with a gateway device patrols the sensing site, and cases where the inspector hand-carries the data temporarily stored in the sensor device offline.
- Monitoring platform: Represents servers that accumulate the data measured at the sensing site, search and display the accumulated data, perform simple alert detection such as threshold crossing and convert this to data that can be analysed by applications.
- Applications: Represents servers that compare/analyse data collected in chronological order at a sensing site based on available reference data (e.g., data collected at other sensing sites under similar conditions) to predict deterioration and/or to evaluate the repair method.

  NOTE – Digital twin technology may be used to support these goals.
- IAN: Represents a network composed of a gateway device and multiple sensor devices. Which technology is used for transmission within the IAN is outside the scope of this Recommendation.
- WAN: Represents a network for transmitting the data measured at the sensing site to the monitoring site. Which technology is used for transmission within the WAN is outside the scope of this Recommendation.

This reference model complies with the IoT basic model specified in [ITU-T Y.4113]. The sensor device, gateway device, monitoring platform, applications and WAN in this Recommendation can be mapped to the device, gateway, IoT platform, IoT application server and the combination of core and access network in [ITU-T Y.4113].

6.2.2 Sites associated with the reference model

The locations of operative responsibility for a part of the system are called "sites" and can be categorized into the following three types: the sensing site, monitoring site and storage and utilization site.

- Sensing site: This manages one or more parts of the civil engineering infrastructure(s) and measures objective data for infrastructure health monitoring by sensor devices. It transmits measured data as appropriate to a corresponding monitoring site. A sensing site has one or more civil engineering infrastructures under its control. Figure 2 shows the aggregation relationship between a sensing site and the civil engineering infrastructure.

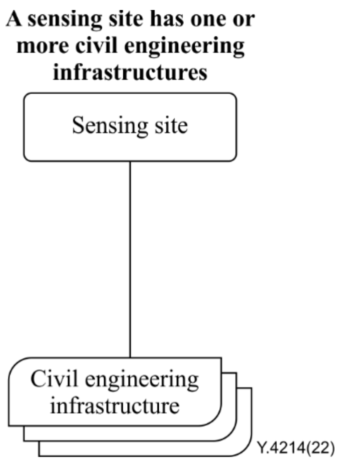

Figure 2 – Aggregation relationship between sensing site and civil engineering infrastructure

- Monitoring site: This administers one or more sensing sites and maintains the parts of infrastructures subject to monitoring. A monitoring site has one or more sensing sites under its observation. Figure 3 shows the aggregation relationship between the monitoring site and sensing site.

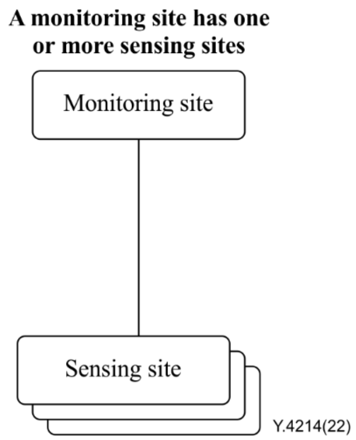

Figure 3 – Aggregation relationship between monitoring site and sensing site

- Storage and utilization site: This provides the data to applications and ensures long-term storage of the data as appropriate. A storage and utilization site collects data from one or more monitoring sites under its control. A monitoring site may not be required to be connected to any storage and utilization site (e.g., when functionalities implemented in the monitoring site are sufficient for users) or can be referred from one or more storage and utilization sites. Figure 4 shows the aggregation relationship between a storage and utilization site and monitoring sites.

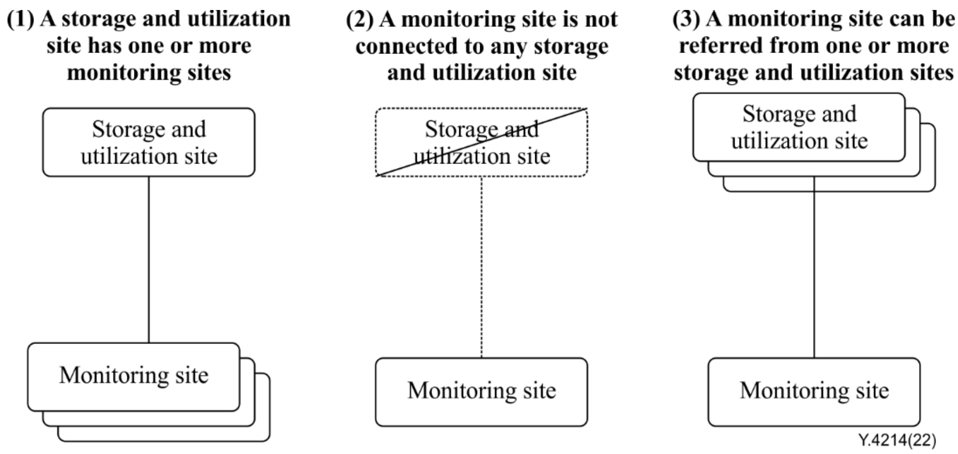

Figure 4 – Aggregation relationship between storage and utilization site and monitoring sites

7 Requirements of IoT-based civil engineering infrastructure health monitoring system

High-level requirements of IoT are identified in [ITU-T Y.4000]. Common requirements of IoT are identified in [ITU-T Y.4100]. Requirements of the network for the IoT are identified in [ITU-T Y.4113].

In this Recommendation, requirements specific to the IoT-based civil engineering infrastructure health monitoring system are identified.

7.1 Generic requirements

7.1.1 Long-term operation

- It is recommended that the system be designed for long-term use.

  NOTE – Civil engineering infrastructures such as roads, bridges and tunnels have been used for more than 50 years, and it is recommended that the operational life of the monitoring system also be significantly longer than general IoT systems.

- It is recommended that the semantics of data not depend on a particular technology, a platform architecture, a manufacturer, etc.
- Data continuity is required to be maintained in the case of replacements or model changes of sensor devices during the operational period.

7.1.2 Measured data

- The system is required to have features to collect and store data used for infrastructure health monitoring, such as length, frequency, tilt angle, brightness, infrared, radiation, image, voice, weather data, etc.
- The system is required to collect and store not only the raw data collected by the sensor device but also the processed data calculated or converted from the raw data by the sensor device, the gateway device or the monitoring platform.
- The data measured for the same purpose is required to be handled in the same way even if the measuring method is different. There are various methods for measuring data used in health monitoring, but the data measured by any method should be handled as (or converted to) the same data. For example, the displacement can be measured by using a displacement gauge or calculating from a laser, an image, an accelerometer, etc. This equipment should produce the same type of data using the same measurement units and with the same precision.

- The measured data is required to be handled in the same way even if the transmission technology or platform technology is different. Data should be handled in the same way whether the sensor device installed at the sensing site sends data to the monitoring platform via a network or a storage medium containing data is manually carried.
- The system is required to associate data sets as related to the same event if the target data is composed of data elements measured by multiple devices. For example, in the case of using an auxiliary device to specify relative position information when installing a sensor device, relationship information between the device and the position should be stored.

7.1.3 Information model

- The specifications of the information model used for processing and storing data are recommended to be followed, in order to enable data continuity and data sharing with the applications or different systems.

  NOTE – The information model used is not specified in this Recommendation, and the data formats and communication protocols are left to the implementation of each system.

7.1.4 Location and installation

- The system is required to record installation information, such as the position, direction and installation method of the sensor device.
- The system is required to record the association between a sensor device and an element of civil engineering infrastructure.
- It is recommended that the system record the association between a sensor device and an element of civil engineering infrastructure by using the 3D model representation created during the construction of the civil engineering infrastructure.

7.2 Sensor device requirements

- The sensor device is required to measure data used for health monitoring. For example, data used for infrastructure monitoring is commonly classified as the following types:
  - Physical quantity: length, frequency, tilt angle, etc.
  - Electromagnetic quantity: brightness, image, infrared, radiation, etc.
  - Electrical quantity: current, voltage, etc.
  - Media data: voice, image, video, etc.
- The sensor device can optionally have features for communication, temporary data storing, data processing and primary analysis such as conversion of sensor data.

  NOTE – The sensor device may implement all the above features in one or more physical devices.

7.3 Gateway device requirements

- The gateway device is required to aggregate data measured by the sensor device installed at the sensing site via the IAN and is required to transmit these data to the monitoring platform via the WAN.

  NOTE 1 – The gateway device may not be used if the sensor device communicates directly with the WAN or if the data temporarily stored in the sensor device are collected manually.
- The gateway device is required to receive instructions from the monitoring platform and is required to perform management of the IAN and the sensor devices.
- The gateway device can optionally have mobility features.

  NOTE 2 – The gateway device is generally installed in a fixed location at a sensing site. However, it may be moved to other locations in some scenarios, e.g., when it moves across sensing sites via a vehicle which patrols the sensing sites.

- The gateway device can optionally have features for temporary data storing, data processing and primary analysis such as conversion of sensor data.

7.4 Monitoring platform requirements

- The monitoring platform is required to have a feature to store data in a specified format.
- The monitoring platform is required to have a feature to search data by any key.
- The monitoring platform can optionally have a feature to view data on a display or on paper in a human-readable format such as graphs or tables.
- The monitoring platform is required to manage the sensor device, the gateway device and the IAN in the sensing site and is required to send instructions to the gateway device and/or notifications to the administrator as needed.
- The monitoring platform can optionally have features to perform simple alert detection such as exceeding a specific threshold and notifying the administrator.
- The monitoring platform can optionally have features to convert the data collected at the sensing site into a specific format that can be analysed by the application.

7.5 Network requirements

- The IAN and the WAN are required to provide the functions needed by the system and operate in a reliable way.

  NOTE – The IAN and the WAN may be a private network, a public network or a combination of both.

Appendix I

Use cases of IoT-based civil engineering infrastructure health monitoring

(This appendix does not form an integral part of this Recommendation.)

Clause 8.9 of [b-ITU-T Y-Sup56] introduces the following four examples of civil engineering infrastructure health monitoring as smart cities and communities (SC&C) use cases.

1) Crack monitoring with camera images;

2) Crack monitoring with a displacement meter;

3) Crack or strain monitoring with optical fibres;

4) Deformation monitoring with accelerometers.

This appendix shows system configuration examples when the reference model in this Recommendation is applied to these use cases.

1) Crack monitoring with camera images

In crack monitoring using camera images, the bottom surface of the floor slab of the road is captured from the ground under the bridge with a camera, and the state of crack(s) on the bottom surface of the floor slab is recorded. The system can monitor the progress of cracks and evaluate the damage status by comparing multiple shots taken at intervals.

- A digital camera is used as the sensor device to capture a picture of the bottom of the road floor slab from the ground under the bridge.
- Since the size of the crack is very small compared with the civil engineering infrastructure, dozens or hundreds of images are taken for one infrastructure element.
- Each captured image contains distortion and must be converted to an orthographic projection image for quantitative monitoring. Auxiliary devices such as physical markers, structural feature points and laser irradiators are used as reference points for this conversion. These auxiliary devices are handled as sensor devices.
- The monitoring platform proceeds to apply the orthographic projection conversion to each captured image as described above, and merges these overlapping images into a single image.
- The monitoring platform reads and stores the shape and width of the crack from the merged image of the bottom of the floor slab.
- The application can utilize and analyse the crack information stored in the monitoring platform to detect damage, calculate the degree of damage, predict future damage progress and share data with other systems.

Figure I.1 illustrates crack monitoring with camera images.

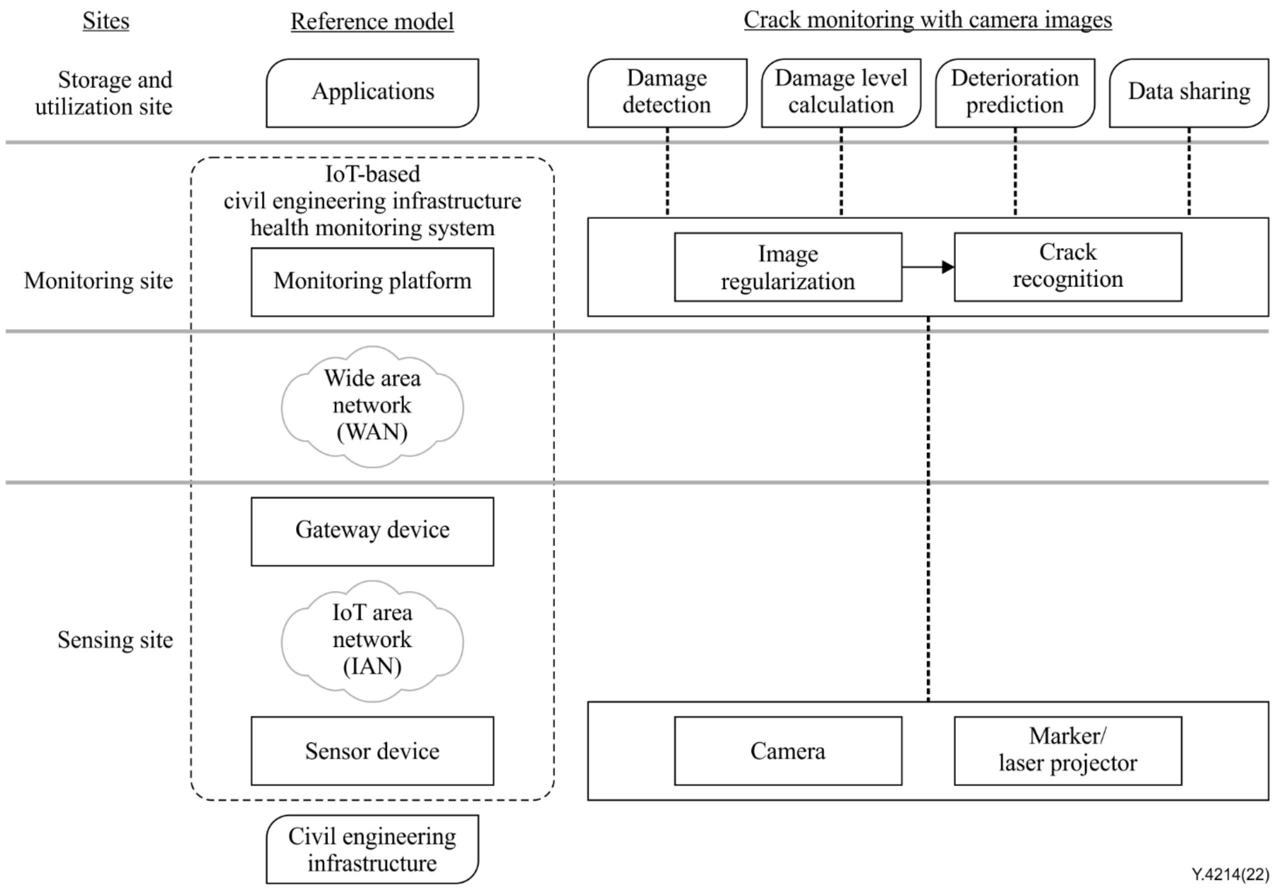

Figure I.1 – Crack monitoring with camera images

2) Crack monitoring with a displacement meter

Crack monitoring with a displacement meter measures the displacement between the floor slab where damage is found, and the immovable beam installed under the bridge. This monitoring indicates the damage state of the floor slab by determining the threshold to prevent accidents.

- A displacement meter is used as the sensor device to measure the displacement between the floor slab and the immovable beam.
- The monitoring platform can store time-series displacement data and alert when displacement exceeds a certain threshold. To detect changes in structural performance, the monitoring platform may perform natural frequency analysis from the displacement data.
- The application can utilize and analyse the displacement data stored in the monitoring platform to predict future damage progress, determine alert thresholds and share data with other systems.

Figure I.2 illustrates crack monitoring with a displacement meter.

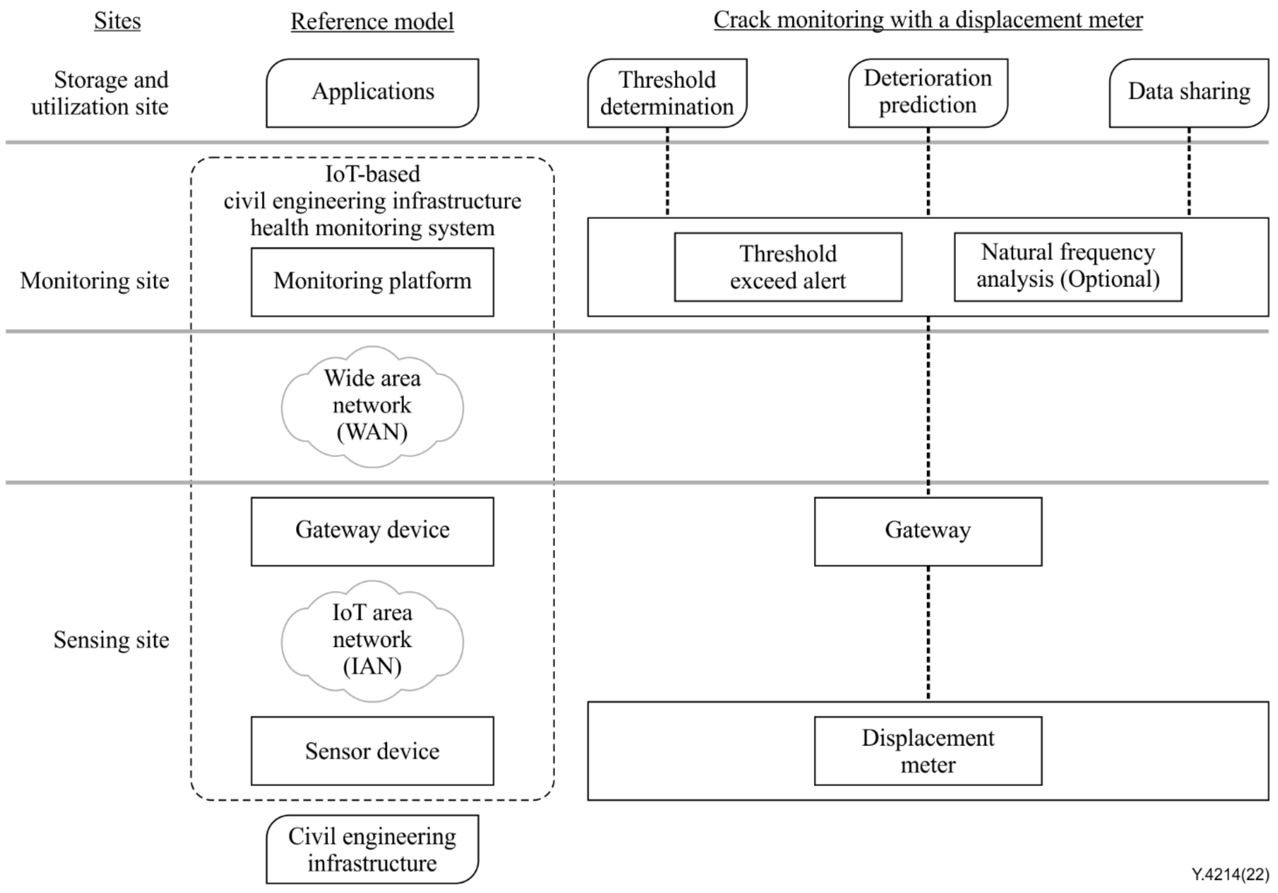

Figure I.2 – Crack monitoring with a displacement meter

3) Crack or strain monitoring with optical fibres

Crack or strain monitoring with optical fibres detects deterioration and distortion from changes in the transmitted light amount measured by optical fibres comprehensively installed on the underside of the floor slab.

- The sensor device is an optical measuring device that transmits pulses of light over an optical fibre at regular intervals to measure the diffuse reflection return time.
- The monitoring platform converts the measurement results to physical quantities (displacement, strain, etc.) and stores the data.
- The application can utilize and analyse the data stored in the monitoring platform to predict future damage progress, determine alert thresholds and share data with other systems.

Figure I.3 illustrates crack or strain monitoring with optical fibres.

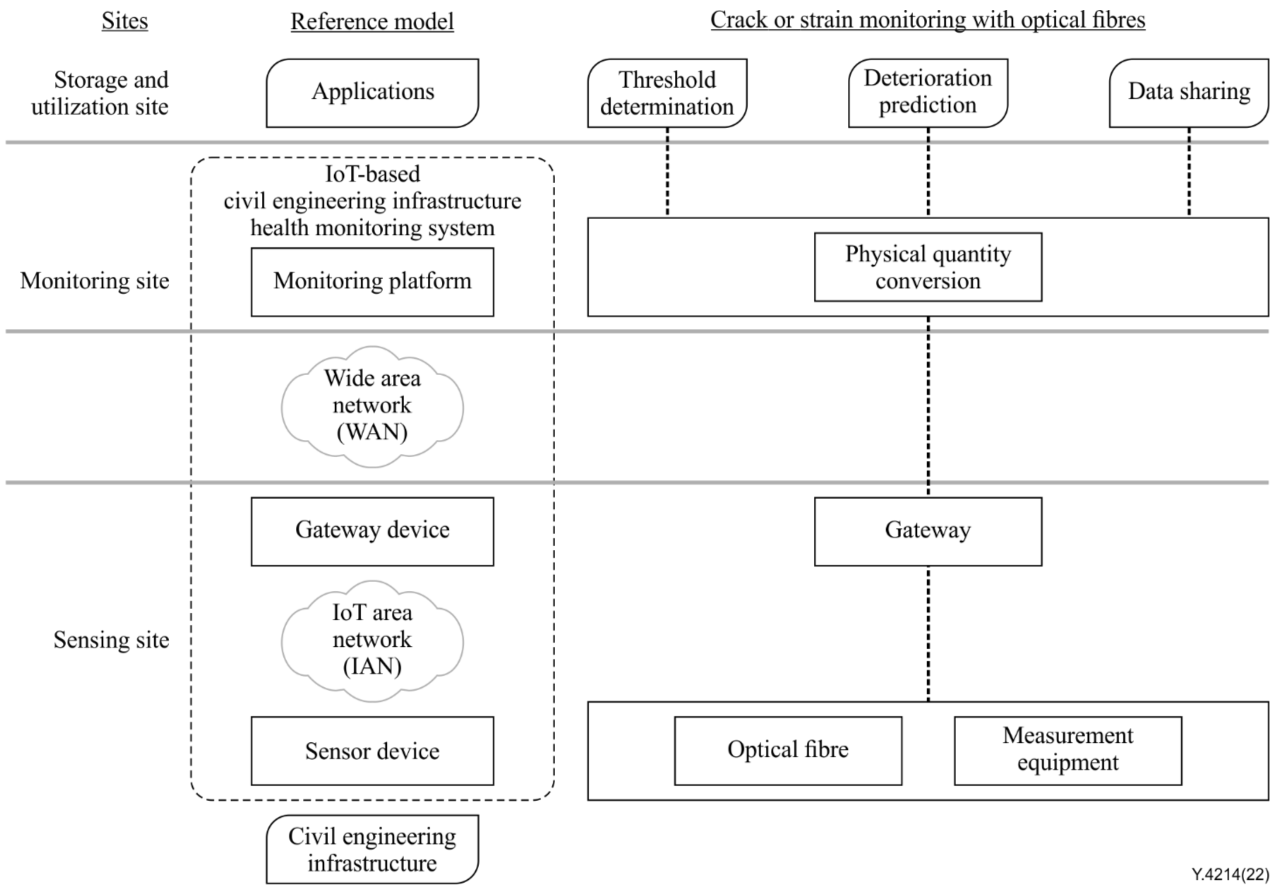

Figure I.3 – Crack or strain monitoring with optical fibres

4) Deformation monitoring with accelerometers

Deformation monitoring with accelerometers monitors changes in structural performance by the natural frequency or vibration mode of the structure measured by accelerometers installed in the structure.

- One or more accelerometers are used as the sensor device.
- The monitoring platform analyses the acceleration data measured by the accelerometer and performs natural frequency analysis or vibration mode analysis.
- The application can utilize and analyse the data stored in the monitoring platform, predict future damage progress and share data with other systems.

Figure I.4 illustrates deformation monitoring with accelerometers.

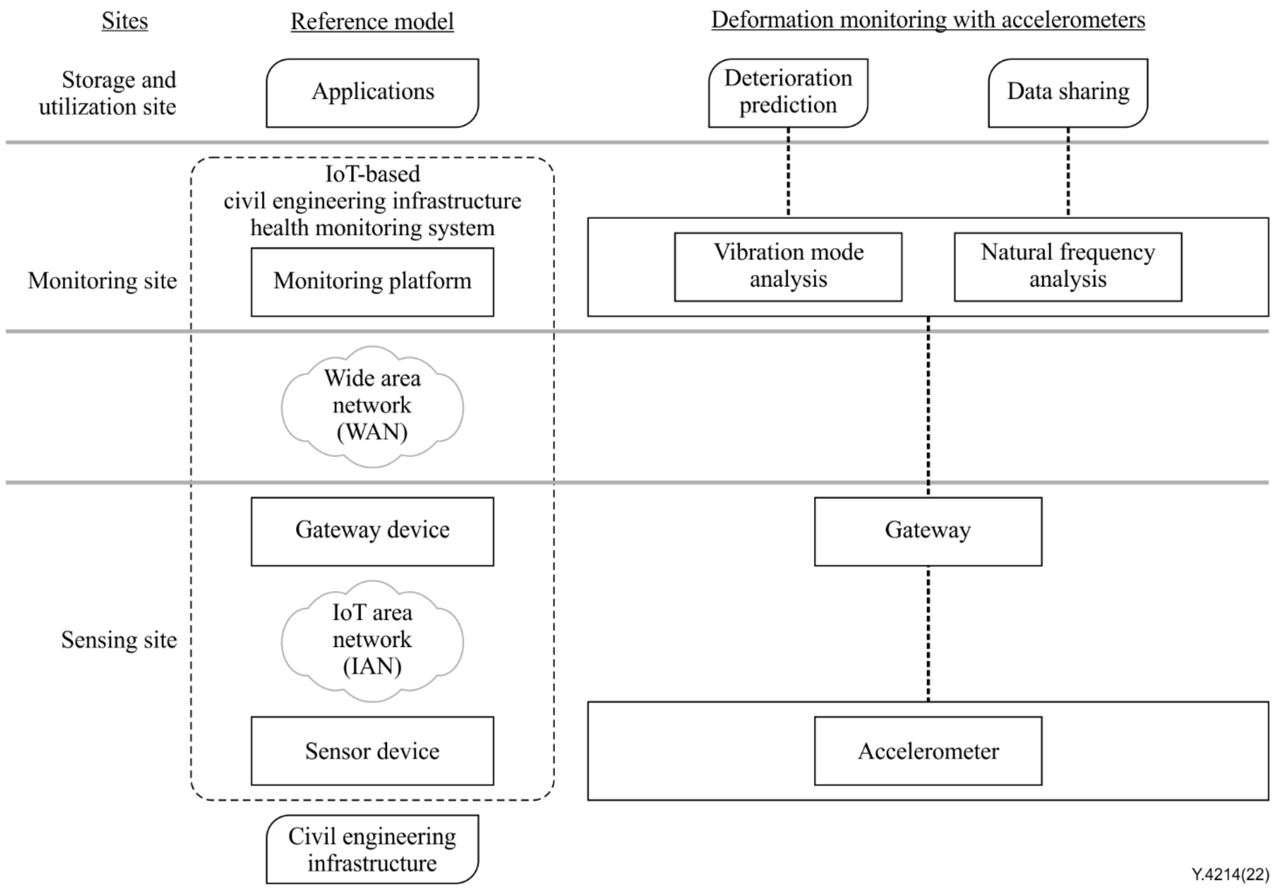

Figure I.4 – Deformation monitoring with accelerometers

Bibliography

[b-ITU-T Y.4213] Recommendation ITU-T Y.4213 (2021), *IoT requirements and capability framework for monitoring physical city assets.*

[b-ITU-T Y-Sup56] Supplement 56 (2019) to ITU-T Y-series Recommendations, *Supplement on use cases of smart cities and communities.*

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