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| IALA Guideline |

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Use of Simple IoT Sensors on Physical AtoN

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1. Introduction 6

1.1. Background 6

1.2. Aims and Objectives 6

1.3. Scope 6

2. Functional Requirements 7

2.1. Essential Functions 7

2.2. IoT Sensors 7

2.2.1. Power Management Functions 8

2.2.2. Lighting Monitoring and Control Functions 8

2.2.3. Position Monitoring Functions 8

2.2.4. Structural Condition Detection Functions 8

2.2.5. Environmental Data Acquisition Functions 8

2.3. Communication and Data Transmission 8

3. Technical Requirements of IoT Sensors and Communication Modules on AtoN 8

3.1. Power Management Requirements 9

3.2. Lighting Monitoring and Control Requirements 9

3.3. Position Monitoring Requirements 9

3.4. Structural Condition Detection Requirements 9

3.5. Environmental Data Acquisition Requirements 9

3.6. Communication and Data Transmission Requirements 9

3.7. Device Integration and System Interface Requirements 9

3.8. Enclosure and Housing Requirements 9

4. Data Integration and Cybersecurity 9

4.1. Standardized Data Formats 9

4.2. Cybersecurity Risk Mitigation 10

5. Installation and Maintenance of Sensor Equipment 10

5.1. Installation Considerations 10

5.2. Maintenance Best Practice 10

6. Other Considerations 10

6.1. Cost of IoT Sensors and Local Transport Layer Interfaces 10

6.2. Communication Costs 11

6.3. Installation Complexity 11

6.4. Installation Approval and Licensing Requirements 11

6.5. Energency Situations 11

7. Acronyms 11

8. references 11

List of Tables

Table 1 Example of table with row headers 5

Table 2 Example of table with column headers 5

List of Figures

Figure 1 Example of wrapping in line with text 4

Figure 2 Example of wrapped square 5

Figure 3 Example of how to achieve right justified equation number 7

# Introduction

## Background

The development of Internet of Things (IoT) technologies is transforming the way physical Aids to Navigation (AtoN) are operated and maintained. By integrating IoT sensors and communication modules into AtoN infrastructure, it becomes possible to continuously monitor the condition of each AtoN in real time, enabling remote control, predictive maintenance, and automated diagnostics. This marks a shift from traditional methods, which rely primarily on manual inspections and AIS-based reporting, toward a more intelligent and proactive system of management.

With IoT technology, authorities can remotely collect data on the operational status of lighting systems, battery performance, structural integrity, movement, and environmental conditions. These capabilities contribute significantly to enhancing both the efficiency of AtoN operations and the overall safety of navigation. Furthermore, the ability to detect anomalies and respond promptly can reduce maintenance costs and support long-term reliability.

## Aims and Objectives

This guideline aims to provide technical and operational criteria for the effective implementation of IoT sensors and communication modules on physical AtoN. It defines:

* Functional definitions and technical requirements for IoT sensors
* Use of standardized communication protocols and technologies
* Requirements related to power efficiency, environmental resilience, and mechanical durability
* Basic considerations for data integration and cybersecurity

This guideline is developed in alignment with IALA’s digital transformation strategy and supports interoperability with international data standards, including the IALA S-200 series. It also ensures compatibility with broader maritime systems such as e-Navigation and smart AtoN platforms.

By providing a standardized framework, this guideline aims to assist competent authorities in implementing reliable, secure, and future-ready IoT solutions that contribute to the modernization of AtoN services.

The aim should also be to make the most of the benefits of remote monitoring and control.

* The costs of a remotely monitored safety device should not be higher than the costs of traditional route maintenance (inspection, maintenance, fault fix)

• Remote monitoring and control should not become a significant new source of failure

# xx BENEFITS OF REMOTE MONITORING AND MANAGEMENT

The benefits of remote monitoring and management can be divided into, among others, the benefits experienced by the customer, safety and fairway management:

* Safety device faults are known in real time (fault notifications, information, warnings)

• The operation and location of safety devices can be determined if necessary (e.g. buoy escape)

* Historical information is obtained from the device's operation (light burn times, energy consumption, location of floating safety devices, etc.)
* Predictability of safety device maintenance needs and timely maintenance measures reduce faults and safety device visits, and thus the costs of road maintenance
* Occupational safety risks are reduced by timely maintenance at difficult-to-reach locations
* Reducing inspection and maintenance visits at regular intervals with remotely monitored safety devices reduces costs and environmental impacts, such as emissions, disturbance of animal nesting, etc.

• The visibility of remotely controlled safety devices improves when light output can be adjusted according to the conditions (fog, snowfall, backlight, etc.)

## Scope

This guideline applies to the use of IoT sensors and communication modules installed on physical AtoN.

Applicable to buoys, beacons, lighthouses, and other fixed AtoN.

Exclusions: AIS AtoN only covered where relevant for communication

1. Integrated module (sensor+communication modules)
2. Distinct IoT controller + modem
3. Hybrid

텍스트, 스크린샷, 디스플레이, 도표이(가) 표시된 사진

AI가 생성한 콘텐츠는 부정확할 수 있습니다.

# Functional Requirements

## Essential Functions

IoT T sensors and communication modules designed for use on physical AtoN shall support the following essential functions to enable effective remote monitoring and safe, reliable operation:

* Power management: Monitoring of battery voltage and current, charging/discharging status, solar panel efficiency, and control of power consumption
* Lighting monitoring: Monitoring of lighting status (on/off), brightness level, and support for remote on/off control (condition tracking?) Flasher ID, photocell threshold, light range
* Position monitoring: GNSS-based tracking of floating AtoN to detect displacement or drift
* Structural condition detection: Detection of shock, tilt, and vibration, with alert functionality
* Environmental data acquisition: Measurement of temperature, humidity, atmospheric pressure, wind speed, and wave height
* Fault alerts

## IoT Sensors

To support the above essential functions, IoT sensors for AtoN shall be equipped with the following capabilities:

### Power Management Functions

* Measurement of battery voltage and current
* Detection of battery charging/discharging status
* Measurement of solar panel generation and efficiency
* Automatic power control based on energy status

### Lighting Monitoring and Control Functions

* Monitoring of lighting on/off
* Detecting lamp failures
* Real-time measurement of brightness (luminous intensity)
* Remote on/off control capability
* Logging operational hours
* Flashing symbol display -> light characteristic status
* Photocell thresholds -> luminous intensity
* Light range

### Position Monitoring Functions

* Real-time position tracking based on GNSS data
* Alerts for mooring failure or movement outside defined coordinates

### Structural Condition Detection Functions

* Detection of shock events (structural stress?)
* Measurement of tilt angles
* Identification of abnormal vibration frequencies

### Environmental Data Acquisition Functions

* Measurement of temperature, humidity, atmospheric pressure, and wind speed
* Measurement of wave height, water temperature, salinity
* Measurement of air quality

## Communication and Data Transmission

LTE-M, AIS, EMTC, Lora , wifi, NB-IoT

MQTT, AMQP, DDS, XMPP, CoAP, IEC 61162-1

Maybe need to consider the characteristic of each transmission mode including:

• data rate

• latency

• error detection/correction

• reliability

• availability

• transparency

• capacity

# Technical Requirements of IoT Sensors and Communication Modules on AtoN

Each of the following subsections defines minimum technical performance standards.

## Power Management Requirements

The power supply for sensors should comply with relevant specifications, including requirements for voltage, frequency, and stability. It should ensure adequate voltage, current, and overall power capacity to support sensor operation under intended conditions.

As sensors are deployed on physical AtoN, their overall energy consumption must be carefully considered. Factors that may influence the energy demand of IoT sensors include, but are not limited to:

* The technical characteristics of the IoT device (e.g., central processing unit (CPU), memory capacity, signal processing level, operating system, battery capacity, and processor power consumption).
* The network topology of the IoT sensor system, which affects the volume and routing of data transmission.
* The functional characteristics of the device, including the type of data transfer protocols used, security requirements, and encryption methods applied.
* The frequency and volume of data collection and transmission cycles.

A risk-based assessment may be conducted to determine the most appropriate power solution based on operational, environmental, and reliability requirements.

Extremely high or low temperatures may affect the performance of power systems. In particular, when sensors are intended for deployment in extreme marine environments, careful selection of battery technology is essential. Further guidance may be found in IALA Guideline G1067.

## Lighting Monitoring and Control Requirements

Lighting source detection equipment and control terminals should enable remote monitoring and control of AtoN lights, including parameters such as brightness, color, and flashing characteristics. Lighting performance may be adjusted according to pre-programmed settings or remote commands, with the objective of optimizing the visibility, range, and operational efficiency of lights.

The system should be able to collect relevant operational data from the AtoN light. The control terminal should be capable of receiving instructions from a remote control center and implementing them accordingly. Typical control functions may include:

* Switching between the main and backup light units;
* Enforcing on/off control of the light;
* Modifying light characteristics such as intensity or flash rhythm.

Additional remote control functions may be integrated based on operational needs.

The light monitoring unit should continuously collect operational data, track the status of the AtoN light, and store this information locally. Collected data should be transmitted at appropriate intervals to a remote monitoring center, allowing continuous observation of light performance and supporting subsequent remote control operations.

## Position Monitoring Requirements

Position monitoring for physical AtoN should ensure accurate detection of movement or displacement, enabling reliable identification of buoy drift or mooring failure. The positioning system should be capable of maintaining high accuracy and updating positional data in real time or at appropriate intervals, depending on operational needs, or location upon request.

Positioning and orientation devices may utilize Global Navigation Satellite System (GNSS) public service signals, such as GPS, GLONASS, Galileo, and BeiDou (BDS).

The position monitoring function should include the following capabilities:

* Signal reception: The device should be capable of receiving signals from multiple satellite navigation systems to enhance availability and robustness.
* Positioning: The device should be capable of receiving navigation and positioning signals, processing them, and outputting information such as position, speed, and time.
* Orientation: When required, the system should be capable of determining and outputting directional or heading data.

To improve the accuracy and continuity of positioning data, various techniques may be considered, including differential correction methods, augmentation systems, and the use of multi-frequency receivers. Furthermore, data fusion approaches that integrate information from high-precision GNSS, LiDAR, and other relevant sources may enhance overall reliability and completeness. Such integration supports more effective monitoring of floating AtoN positions under diverse marine environmental conditions.

## Structural Condition Detection Requirements

The following aspects may be considered when specifying structural condition detection capabilities:

* Vibration monitoring: Sensors should be capable of detecting vibration levels typically encountered by floating AtoN due to waves, currents, or operational impacts. Consideration should be given to frequency ranges and acceleration thresholds relevant to expected marine conditions.
* Shock and collision detection: The system should be capable of identifying sudden high-impact events, such as vessel contact or mooring failures, and withstand such events without performance degradation.
* Impact response and alerting: When abnormal shocks, excessive tilting, or structural stress are detected, the system should be able to trigger alert notifications and make relevant data available for further analysis.

Where applicable, multi-axis measurement capability may support enhanced situational awareness. The selection of appropriate sensing technologies should consider AtoN type, operational environment, and national or organizational risk assessment practices.

## Environmental Data Acquisition Requirements

Environmental data acquisition for AtoN is typically carried out using multi-purpose sensors installed in the relevant marine area to provide information on hydrological and meteorological conditions. As these sensors are frequently exposed to harsh marine environments, such as salt spray, high humidity, and temperature variations, they should be selected and implemented with consideration of the following aspects:

* Measurement scope and suitability: The measurement range, resolution, and indicative accuracy of the selected sensor should be appropriate for the specific environmental monitoring objectives (e.g., hydrological, meteorological, or atmospheric conditions).
* Stability and reliability: Sensors should maintain stable performance over prolonged exposure to environmental factors such as temperature fluctuations, humidity, salinity, and corrosion. Long-term operational durability should be considered based on expected deployment environments.
* Responsiveness and continuity: For real-time hydrological or meteorological applications (e.g., wind direction or tide variation), sensors should be capable of providing timely and continuous data outputs to support operational monitoring and decision-making.
* Compatibility and standardization: The output format of the sensor should be compatible with subsequent data processing, storage, and transmission systems. The use of standardized interfaces and data formats is encouraged to ensure interoperability and facilitate maintenance and system upgrades.

The selection of sensors used for hydrological or environmental monitoring should comply with applicable national or organizational measurement practices and operational requirements. Where image-based monitoring is used, the resolution and frequency of visual data capture may be determined based on operational needs and data transmission capacity.

## Communication and Data Transmission Requirements

The communication system used for IoT sensors on AtoN should support reliable transmission of monitoring and control data under various marine environmental conditions. When specifying a communication solution, the following considerations may apply:

* The communication system should support sufficient bandwidth and low latency where real-time or near-real-time data transfer is required.
* Power-efficient communication technologies may be considered to support long-term operation on energy-constrained AtoN.
* The system should maintain reliable connectivity and provide mechanisms to resume data transmission following temporary interruptions, with optional data buffering or automatic retransmission capabilities.
* Communication technologies should offer resistance to electromagnetic interference and signal attenuation commonly present in marine environments.
* Integration with existing maritime systems (e.g., VTS, AIS, or centralized monitoring platforms) may be considered to enhance operational efficiency and enable unified digital data exchange.

Where appropriate, low-power wide area networks (LPWAN), satellite-based communication, cellular IoT networks, or radio-based systems may be selected based on deployment environment, range, coverage, regulatory conditions, and operational requirements.

### Data Transmission Protocols

A range of communication protocols may be used within an IoT ecosystem to enable device-to-device (D2D) or machine-to-machine (M2M) communication, real-time monitoring, and data integration. Commonly used protocols include, but are not limited to:

* MQTT (Message Queue Telemetry Transport): A lightweight publish/subscribe protocol suitable for telemetry exchange over ordered, lossless, bi-directional connections.
* AMQP (Advanced Message Queuing Protocol): An open-standard messaging protocol applicable to various IoT environments that require reliable message delivery.
* OPC UA (Open Platform Communications Unified Architecture): A vendor-neutral protocol widely used for industrial automation and system interoperability.
* CoAP (Constrained Application Protocol): A specialized protocol designed for constrained devices operating in low-power and lossy network environments.
* LwM2M (Lightweight Machine-to-Machine): A protocol designed to support device management, firmware updates, and configuration over the air (OTA).

The choice of protocol may depend on data volume, transmission frequency, energy constraints, interoperability needs, and security requirements.

### Data Transmission Considerations

When defining data transmission characteristics, the following factors may be taken into consideration:

* Data rate
* Latency
* Error detection and correction capabilities
* Reliability and redundancy
* Availability and coverage
* Service transparency and interoperability
* Transmission capacity and scalability
* Cybersecurity considerations
* Licensing or spectrum regulatory constraints
* Communication range requirements

These characteristics may vary based on operational scenarios, type of AtoN, and national or regional regulatory conditions.

## Device Integration and System Interface Requirements

How sensors and communication components should be integrated or interfaced with the AtoN system, including modularity and compatibility**. IALA spesification**

## Enclosure and Housing Requirements

In addition to complying with applicable ingress protection standards such as IEC 60529 (e.g., IP67 or above), the physical housing of IoT sensors deployed on marine AtoN should take into account the following considerations:

* The external surface of the housing should be free from sharp edges or corners to ensure safe handling during installation and maintenance. The enclosure should not exhibit deformation, cracks, excessive wear, corrosion, or contamination.
* The casing should provide adequate sealing performance to prevent dust, water, or foreign substances from entering and affecting internal components.
* The enclosure should have sufficient mechanical strength and stability to protect electronic components from shocks, vibration, or physical stress, particularly in floating AtoN applications.
* In marine environments, the housing should be weather-resistant and maintain watertight integrity under conditions such as salt spray, humidity, temperature variations, and corrosive exposure. In the event of temporary immersion, the device should retain its operational functionality.
* For light-related sensors, the housing or protective cover should provide high optical transparency to ensure accurate and stable performance.
* Environmentally responsible materials are recommended to reduce the potential environmental impact in marine ecosystems.

Before final material selection, an assessment of the intended deployment environment should be conducted to ensure that the chosen enclosure materials and construction can maintain required functionality and durability under expected operational stresses.

# Data Integration and Cybersecurity

## Standardized Data Formats

Data transmitted from IoT sensors installed on AtoN should comply with relevant IALA standards, such as the S-200 series, to promote data harmonization, interoperability, and consistency across global AtoN monitoring networks. These standards align with the IHO S-100 Universal Hydrographic Data Model, enabling seamless integration with wider maritime information systems such as e-Navigation, Vessel Traffic Services (VTS), and Electronic Chart Display and Information Systems (ECDIS).

Conformance to such standardized data models ensures that IoT data can be efficiently exchanged, interpreted, and utilized across different national authorities, operators, and platforms. As the role of Artificial Intelligence (AI) in maritime digital ecosystems increases, AI-based tools may be used to support automated data structuring, normalization, and quality assurance, thereby improving accuracy, efficiency, and interoperability.

## Cybersecurity Risk Mitigation

Measures required to ensure secure data transmission, protect devices from unauthorized access, and implement authentication, encryption, and network-level safeguards.

Security frameworks, authentication, encryption, firmware update integrity.

Guideline for intrusion detection and secure data storage.

Cybersecurity is critical to ensuring the safe and reliable operation of IoT-based AtoN systems. As the number of connected devices increases, so does the potential attack surface, making IoT sensors vulnerable to threats such as unauthorized access, malware, phishing, data manipulation, and network disruption.

# Installation and Maintenance of Sensor Equipment

## Installation Considerations

The installation of IoT sensor equipment on AtoN shall be undertaken in a manner that does not interfere with the primary function of the AtoN. Equipment should be non-intrusive, compact, and lightweight to minimise structural load and simplify deployment, particularly on floating buoys or exposed structures.

Sensor devices shall be designed for ease of installation in appropriate positions on the AtoN structure, considering sea conditions, sensor coordination, and accessibility for future servicing. All components shall meet appropriate marine environmental protection standards, including water and corrosion resistance. In cases where equipment may be dropped into the sea, full submersibility and uninterrupted communication capability should be ensured.

Installation should be carried out by appropriately qualified personnel, following manufacturer specifications and relevant safety procedures. To reduce the frequency of on-site interventions, systems should also support remote configuration and calibration where practicable.

~~ proposed location of installation .

Testing and calibration after installation.

## Maintenance Best Practice

Given the continuous operation of AtoN, IoT sensors installed on them must be designed for long-term reliability. Continuous operation may result in performance degradation or failure; therefore, maintenance planning is essential to ensure ongoing functionality and resilience.

Sensor systems should incorporate self-diagnostic functions and enable continuous performance monitoring. Predictive maintenance features, such as battery status tracking, calibration scheduling, and fault forecasting, should be implemented to support timely and efficient maintenance actions.

Remote access to operational data and device health status should be available to allow operators to assess system condition in real time. This enables optimised inspection scheduling, minimises unnecessary site visits, and facilitates rapid response when issues are detected.

Through effective installation and maintenance strategies, AtoN authorities can enhance the reliability and service life of IoT sensors while ensuring the continued safety and efficiency of the aid to navigation system.

# Other Considerations

The following additional factors should be taken into account when implementing IoT systems in the maritime AtoN domain:

## Cost of IoT Sensors and Local Transport Layer Interfaces

When installing sensors on AtoN, consideration should be given to compatibility with existing transport layer interfaces. Interface mismatches and system integration challenges may arise due to differing technical standards. These potential issues, along with associated costs, should be addressed during the system design phase.

## Communication Costs

Due to the complex nature of the maritime communication environment, communication costs are typically higher than those for terrestrial applications. The high demands of IoT data transmission may also necessitate upgrades to existing maritime communication infrastructure, potentially leading to additional expenditure.

## Installation Complexity

Most AtoN are deployed at sea, and installing IoT sensor equipment requires careful consideration of both the installation location and ongoing maintenance requirements. In particular, when sensors are to be installed on floating buoys, the design must account for sea conditions and coordination between multiple sensor types to ensure operational effectiveness.

## Installation Approval and Licensing Requirements

The installation of sensors on AtoN shall be subject to approval by the competent AtoN authority. The approval process shall comply with applicable local laws and regulations. Additionally, the use of sensor-generated data shall also be authorised by the relevant authority, with appropriate measures in place for data management and backup.

## Energency Situations

In the event of a malfunction or failure in the communication terminal, emergency communication systems shall be employed to transmit alarm signals to the control centre, enabling timely intervention by maintenance personnel.

If equipment is damaged or lost at sea, such as through collision, positioning sensors and associated devices should promptly transmit location data to the control centre and maintain communication continuity. Where such communication is compromised, emergency signalling systems should be capable of relaying alerts without delay.

# Acronyms

IoT Internet of Things

MIoT Maritime Internet of Things

GPS

GLONASS

GNSS

Galileo

BDS

LiDAR

# references

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2. International Organization of Marine Aids to Navigation (2025) G1190 Harmonised IoT Protocol for Visual AtoN
3. G1067
4. International Organization of Marine Aids to Navigation (2022) R1024 Cyber Security for the IALA Domain
5. International Organization of Marine Aids to Navigation (2024) G1182 Cyber Security Specifics from an IALA Perspective
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Appendices should be started on a separate page and contain information that is directly relevant to the main body of the text at a certain point, but that would be too large or distracting to include at that particular point. There are four levels of appendix heading styles available in the **Style Gallery.**

* 1. Example of Appendix Head 1 style
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* a technical specification for a new piece of equipment;
* the content and structure of a new training module; or
* the detail associated with a new recommendation for an AIS.

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