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Internet of Things (IoT) - Data format, value and coding for interoperability

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ISO/IEC 30178 has been prepared by subcommittee 41: Internet of Things and Digital Twin, of ISO/IEC joint technical committee 1: Information technology. It is an International Standard.

The text of this International Standard is based on the following documents:

Draft	Report on voting
JTC1-SC41/597/FDIS	JTC1-SC41/620/RVD

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

The language used for the development of this International Standard is English.

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.

INTRODUCTION

Digital transformation depends strongly on data. Within the field of Internet of Things (IoT), many leading organizations try to model physical entities and environments with structured data.

Digital twins, city and building information models, process industry, automation, automotive and even healthcare, are all technologies or fields in which data models are developed to accommodate domain-specific needs.

Sensors form the backbone of live data generation and help synchronize the digital world with the real world. Numerous data and information models occur in the Information Technology (IT) and Operational Technology (OT) landscape, at various layers in digital systems. Some are verbose, text-based formats (e.g. XML or JSON) that come with more or less rich metadata, while some formats contain only minimal metadata.

The huge variability in how sensory data are represented poses a problem for all parties in the value chain – not least for the data producers themselves. This variability not only affects interoperability but also has significant economic implications. This often puts the economic viability of data collection out of reach, since low data accessibility for data consumers also means poor return of economic value for the data producer.

This has often limited large-scale data collection to domains in which there is a strong need for very specific data collection (such as the automotive industry), and favoured applications where a single data producer has a direct business agreement with the data consumer, and full control over the data model. The design of the data gathering process has often been guided by a single customer's need, with one fixed requirement for data quality.

General purpose data collection remains challenging in the context of Big Data.

The variability in format and inconsistency in data quality are issues that undermine new stakeholders' trust in third-party value chains. Where data might have been accurate enough, an insufficient amount of consistent data-source documentation dissuaded any potential new data consumers – further limiting the capital value of data.

In the end, it has proven difficult for data producers to generate data that is cost-effective to produce and consume – especially with data about physical environments.

This document provides guidance by outlining principles and technical solutions for overcoming this variability and proposes a fundamental representation of data points for sensors and physical quantities that can be used everywhere in the digital landscape to improve the consistency of how both data and metadata are to be interpreted by application logic. When applied correctly, with an agnostic attitude towards application requirements, these principles also help form a baseline for data quality and accessibility.

With the perspective taken in this document, sensory data (after their collection) are regarded as descriptions of a physical entity. This also includes any other physical measurement, such as the physical parameters of real-world objects and systems. The intention is to allow for sensory data to be possible to integrate seamlessly with other data points in physical models under a shared, homogeneous interpretation.

1 Scope

This document defines common formats, values, and coding for data interoperability and exchange among systems in the Internet of Things (IoT).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 20924, *Internet of Things (IoT) and digital twin - Vocabulary*

ISO/IEC Guide 99, *International vocabulary of metrology - Basic and general concepts and associated terms (VIM)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 20924, ISO/IEC Guide 99 and the following 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

SI special names, pl.
names for compound SI units derived from the base seven SI units

EXAMPLE 1 Newton [N] equivalent to kilogram metre per second squared [$kg \cdot m/s^2$].

EXAMPLE 2 Pascal [Pa] equivalent to newton per metre squared [N/m^2] or kilogram per metre times second squared [$kg/m \cdot s^2$]

EXAMPLE 3 Joule [J] equivalent to kilogram metre squared per second squared [$kg \cdot m^2/s^2$].

Note 1 to entry: See BIPM [6] The international System of Units (SI) 9th edition (2019), 2.3.4 for further information.

3.2
data type
named category of data characterized by a set of values, a syntax for denoting these values, and a set of operations that interpret and manipulate the values

EXAMPLE 1 uint16 – A 16-bit wide, unsigned integer capable of representing the whole-number range from 0 to 65 535.

EXAMPLE 2 bool – A Boolean value with only two states (true and false).

EXAMPLE 3 float – A 32-bit approximation of a real number.

Note 1 to entry: Standardized representation of data types is essential for cross-platform interoperability.

Note 2 to entry: The total number of bits determine the maximum number of unique values the data type can encode.

Note 3 to entry: For further information on data types see ISO/IEC 11404 [2].

[SOURCE: ISO/IEC 1539-1:2023 [1], 3.144, modified – the examples and notes have been added.]

3.3
type safety
software design principle that protects against representation-related errors such as unintended rounding or corruption of data by enforcing the consistent use of a *data type* (3.2) for some variable

Note 1 to entry: Type safety allows scalability by decoupling the design of separate software components while guaranteeing correctness within functional interfaces (such as APIs).

Note 2 to entry: Type safety is enforced by some programming languages.

3.4
floating-point format
digital *data type* (3.2) representing a fixed-precision approximation of a real number with a well-defined range and precision, composed of an exponential and fractional component, and a sign

Note 1 to entry: Floating-point format is supported by all major programming languages.

Note 2 to entry: Depending on the variant, floating-point format typically features at least 6 to 7 significant decimal digits for single precision, or 15 significant decimal digits for double precision.

Note 3 to entry: Definition based on ISO/IEC 60559:2020 [9], 3.6.

3.5
floating-point representation
unencoded member of a floating-point format, representing a finite number, a signed infinity, a quiet not a number (NaN), or a signaling NaN

Note 1 to entry: A representation of a finite number has three components: a sign, an exponent, and a significand; its numerical value is the signed product of its significand, and its radix raised to the power of its exponent.

Note 2 to entry: NaN means 'not a number' and is a special value of the floating-point representation that indicates invalid number assignments, such as when dividing zero by zero.

3.6
physical quantity
property of some physical entity that can be measured in some physical dimension, characterized by a number and a unit

3.7
serialization format
format of representing structured data in a serialized sequence of bits that can be exchanged between two computer systems

EXAMPLE 1 XML – Extensible Markup Language[1], a text-based format using tags to encode nested elements and structures.

EXAMPLE 2 JSON – JavaScript Object Notation[2], a format for representing basic values with named identities and nested structures, in cleartext. JSON is considered a less verbose alternative to XML.

EXAMPLE 3 CBOR – Concise Binary Object Representation[3], a binary serialization format optimized for small code size and message size.

Note 1 to entry: Serialization format is sometimes based on cleartext for representation, with a syntax to encode structure.

Note 2 to entry: Serialization format is sometimes based on concrete data types for representation.

3.8
sensor
Internet of Things digital device that converts a physical measurement into a digital sample carrying a quantity and a unit

Note 1 to entry: The sensor usually transmits the sample coded in some *serialization format* (3.7).

3.9
data point
datum that carries an individual meaning regardless of representation

3.10
release-time
period of time during which an instance of some software or hardware, such as an IoT sensor, operates after deployment

Note 1 to entry: Release-time is typically separate from, and non-overlapping with, design-time.

Note 2 to entry: Release-time constitutes part of that instance's operational lifecycle.

3.11
design-time
period of time during which a piece of software or hardware is designed

Note 1 to entry: Design-time precedes, is typically separate from, and non-overlapping with, runtime.

Note 2 to entry: After the end of design-time, the design and its dependencies are not possible to modify.

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1 XML is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO or IEC of this product.

2 JSON is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO or IEC of this product.

3 CBOR is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO or IEC of this product.

3.12
oversampling
action of collecting multiple measurement samples and averaging their values into a single sample

Note 1 to entry: Oversampling typically decreases temporal resolution.

Note 2 to entry: The number of samples converted into a single sample is called OSR, or "oversampling ratio".

Note 3 to entry: Oversampling often implies sampling at higher rates than the Nyquist (IEV 723-10-28) rate to satisfy the Nyquist criterion.

3.13
discrimination
measurement interval of a measured signal smaller than what a sensor is unable to uniquely register

Note 1 to entry: Discrimination is often expressed interchangeably with measurement resolution, which means segmenting a pre-defined measurement range into discrete steps.

3.14
context broker
middleware for exchanging contextual data

Note 1 to entry: A context broker is typically required for smart data standards like NGSI.

4 Abbreviated terms

ADC	analog-to-digital converter
AI	artificial intelligence
API	application programming interface
BIM	building information model
CBOR	concise binary object representation
CPU	central processing unit
DTw	digital twin
GIS	geographic information system
GNSS	global navigation satellite system
I2C	inter-integrated circuit
I3C	improved inter-integrated circuit
IT	information technology
IoT	Internet of Things
JSON	JavaScript object notation
LPWAN	low power wide area network
LSB	least significant bit
MEMS	micro-electromechanical systems
ML	machine learning
OPC	open platform communications
OPC-UA	OPC unified architecture
OSR	oversampling ratio
OT	operational technology
PCB	printed circuit board
QUDT	quantities units dimensions and data types

RMS root mean square

SenML sensor measurement lists

SI SI-unit *(Le Système International d'Unités)*

SiP system in package

SPI serial peripheral interface

XML extensible markup language

5 Background

5.1 Overview

5.1.1 General

Today's increasingly digitized technology is founded on sensory measurement. Among the IT/OT environments underpinning an information-based society, there is a wide range of structured and semi-structured data models that characterize the data shared between IoT-based systems.

While the sensors that operate out in the field measure physical quantities according to well-defined specifications, most often the measurements and the specification are not fully available in the digital context.

Sensors operating in the field also have a limited interoperability with most other sensors – either in other domains or other digital ecosystems. Sometimes this limited interoperability is due to an inherent lack of data overlap, or even a lack of data completeness.

The range of IoT sensors varies in many respects, and a core assumption that can be made is that, at runtime, no one sensor has complete compatibility with every other sensor. This is both due to the actual information content (i.e. meaning) of data, and a lack of consistent interpretation. When IoT sensors operate in separate ecosystems as individuals, they very often adhere to different conceptual domains or product families. It is therefore necessary to ensure that a baseline for interoperability[4] can be created, and relied on, when embarking on system or data integration projects.

Reducing the engineering cost revolves to a significant degree around predictability. Being able to plan ahead allows system architects to reduce development and integration costs over long timespans.

Many IoT-based exchange formats define semantics and data types to cover the most essential primary data, and accompanying metadata to some degree. For sensory data, this often includes some representation of the sensory value (magnitude) itself and its unit of measurement, which can belong to any standard or non-standard choice of scale.

Variations in how data are encoded, structured, or serialized, bring with them a need for data to be translated or adapted (through interpretation) before they can be used by a third party. This is sometimes hampered by how data are recorded, which can limit how much useful information it can carry.

Common drawbacks of many clear text-based serialization formats include arbitrary rounding or truncation of measurement values (which can permanently strip away numerical precision), and a lack of unambiguous representation of measurement units.

4 In practice this means establishing a set of universally applicable principles that provide inherent interoperability when adhered to.

Translating data between different formats therefore often requires ad-hoc integrations that perform custom one-time conversion with or without safeguards for data integrity.

Variations in data representation in general can also constitute a challenge, since aggregating a heterogeneous set of data sources (e.g. combining sensor data from weather stations and traffic sensors with differing sampling rates and units) requires many separate conversions.

Taken together, it is therefore hard for IoT data models, which often are very well defined within their own domain (or scope of application), to make assumptions about what data points:

a) it is necessary to provide to satisfy any future integration with a third-party data model,

b) will be available for import from third-party data sets,

c) meet the quality requirements for every specific implementation.

Essentially, the lack of universally available data points (e.g. unit, range, accuracy) in an arbitrary sensor's data output is limiting its potential value to future applications. Consequently, it will be necessary for any applications to which its data will be reusable to assess the data sources' suitability – often through human intervention.

This is a costly process, and scales in proportion to the number of integrations with that data source. For data with indefinite lifecycles (such as statistical, historic data about environments) that should be kept for posterity, this is a cost that accumulates over time.

Reducing the cost of each integration beforehand is therefore in the interest of every involved party.

5.1.2 Sensor-related data

While IoT data models vary greatly in characteristics and scope depending on domain and application, every sensor with a digital interface that measures a physical quantity constitutes a data source with some universally applicable characteristics, as summarized in Table 1.

Table 1 – Data source characteristics of a sensor

Sensor characteristic	Data analysis impact	Example
Sensors measure a physical quantity, which by definition will include a numerical magnitude and a unit	Determines the dimension of measurement in which an observed variable can vary	A thermometer measures temperature in degrees Celsius, Kelvin or Fahrenheit
Sensors have an inherent accuracy of measurement	Determines the minimum error of a sample's value from the actual value	A GNSS device with ± 3 m accuracy
Sensor measurement samples are recorded with some numerical precision	Determines the smallest possible variation of a sample's value	A scale that records weight to the nearest 0,1 kg
Sensors are able to make distinct measurement samples by some minimum sensitivity	Determines the measurement sample's highest sampling resolution	A voltage sensor with an effective measurement resolution of 0,5mV
Sensor measurements are collected over some period of time	Determines the maximum time-resolution[a] of the sample's value	A heart rate monitor collecting data every second
Sensors output measurement samples at some maximum sample rate	Determines the time spacing between measurements	An accelerometer sampling at 100 Hz (100 measurements per second)
Sensors perform measurements within some maximum measurement range	Determines the range within which a sample's value can be considered valid	A temperature sensor measuring from -50 °C to 150 °C
Sensors transform the input signal in a certain way	The transformation outputs a scalar value in a given physical dimension	A pressure transducer voltage being converted into kPa

[a] When multiple samples are combined into an average value, the time resolution of the average is constructed from the sum of the time resolution of all the samples. In contrast, when the median value is extracted, it retains the time resolution of its original sample.

Each of these characteristics helps implementers determine how well a sensor suits a given application and, by extension, also how well its data do. The requirements imposed by the application are carried over to the physical design of the system at design-time. For one-off implementations, the characteristics of the data are merely determined to be sufficient for their application, and often just implicitly guaranteed by the design of the system itself.

Data without an explicit quality and characteristics benchmark make any quality guarantees implicit to the design of the system. This in turn makes a retrospective analysis of the system's quality metrics necessary to extract any quality guarantees downstream in the value-chain. Only by explicitly specifying quality and characteristics in digitally accessible metadata can it allow for future suitability analysis decoupled from the system's design.

To retain a high interoperability for a sensor and its data long-term, metadata should be easily accessible for authorized evaluation when necessary (see Annex B).

5.1.3 Source data collection

It is not unusual for IoT data to be collected by microcontroller devices – sometimes also with real-time computing requirements.

Measurements performed by peripheral circuits of such devices typically implement analogue-to-digital conversion with raw measurement values expressed as an integer value, where the least significant bit (LSB) corresponds to a step-wise discrimination (small fixed steps in measurement) between segments of the measurement range and the measurement resolution, as shown in Figure 1. This equates to an upper bound on the level of theoretical precision that is possible.

Manufacturers should consider these limits when defining sensor characteristics.

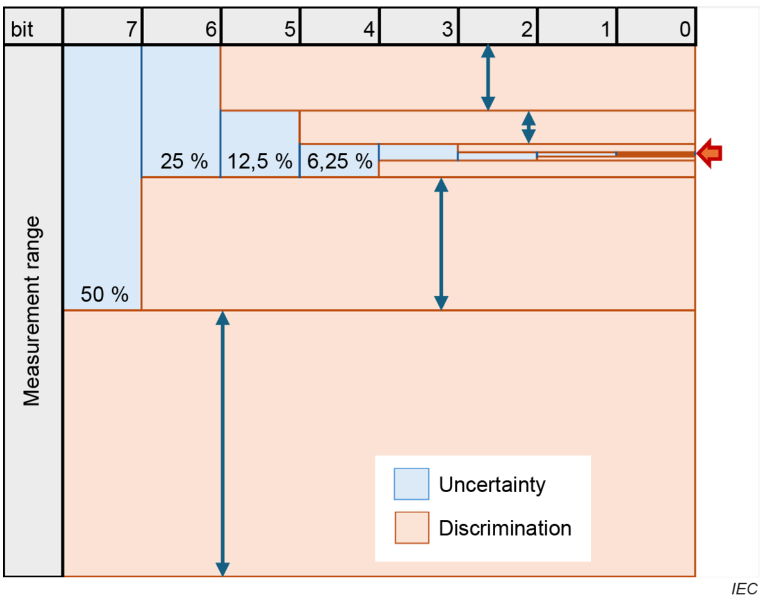

Figure 1 – Discrimination and reduction of uncertainty of each bit within the range of an 8-bit ADC