



IEEE Standard for General Requirements and Interoperability for Internet of Clothing

IEEE Consumer Technology Society

Developed by the
Emerging Technology Standards Committee

IEEE Std 2786™-2023

STANDARDS

IEEE Standard for General Requirements and Interoperability for Internet of Clothing

Developed by the

Emerging Technology Standards Committee
of the
IEEE Consumer Technology Society

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IEEE SA Standards Board

Abstract: Definitions, terminologies, and architectural framework of the Internet of Clothing (IoC) system are developed in this standard. Data scheme, information modeling, and key technological requirements are also defined to help ensure interoperable and agile IoC network solutions and service delivery for apparel industry and end-use applications.

Keywords: architectural framework, data scheme, IEEE 2786™, internet of clothing, interoperability, technological requirements

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Introduction

This introduction is not part of IEEE Std 2786-2023™, IEEE Standard for General Requirements and Interoperability for Internet of Clothing.

This standard defines the technical specifications of IoC system. The system includes information identification, sensing system, middle platform, and applications. The clothing information is gathered by sensing system, and communicated to the middle platform that can then be made accessible to the internet. With this being the case, any application in the world with access to the internet could potentially see data about the clothing. IoC is about optimizing systems and business processes by capturing and using clothing data to make better decisions. Not only is clothing visible to the internet, but what clothing is doing is also visible on the internet. IoC will enable businesses to achieve levels of performance operationally and financially not seen before. All of that is possible with better visibility into the clothing as it moves across the whole life cycle. The technical specifications formulated in this standard include data collection, management of information resources, and discovery of information services.

The main contents include the following:

- Architecture framework: Defines the function of entity units and the interaction relationship between them. The information interaction between entity units is clearly expressed in the reference information model.
- Data requirements: Specifies the coding formats of clothing and a mechanism that shall perform translation between different data formats. The unified data scheme provides users with an end-to-end method of sharing clothing information, and provides users with a method of accessing IoC core services and other related shared services.
- Sensing system: Standardizes the way to detect and collect information and transmit it to the platform. It defines a general set of technical specifications about physical interface, logical interface, networking modes configuration of the sensing system. It is about to connect clothing to the internet throughout the whole life cycle.
- Middle platform: Standardizes the construction of the platform to form a closed loop between the sensing system and intelligent applications. It defines the way of device connection and management, data processing, and analysis. A general standard of interaction interface is also defined to allow applications to access query services including basic clothing information, statistical data, and intelligent analysis. It eventually realizes the ‘servitization’ of data that meets internal and external requirements for IoC.

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IEEE Standard for General Requirements and Interoperability for Internet of Clothing

1. Overview

1.1 Scope

This standard provides the definitions and terminologies, data structure and encoding scheme, reference information model for Internet of Clothing (IoC) system. Architectural framework, protocols, and interface requirements are also defined to help ensure interoperable, agile, and scalable network solutions as well as service delivery that are able to be implemented and maintained in a sustainable manner.

1.2 Purpose

This standard addresses interoperability, scalability, and collaborative operation of IoC system as well as provides framework and requirements that outline technologies and the processes to help ensure agile, reliable, and sustainable solutions for the evolution of IoC. This standard facilitates the development of IoC products and solutions that can be integrated horizontally and leverage current instrumentation and devices used in industry, which provides for flexible IoC networks with reduced cost and complexity.

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{6,7}

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IEEE Std 2413™-2019, IEEE Standard for an Architectural Framework for the Internet of Things (IoT).^{8,9}

ISO/IEC 18000-63:2021, Information Technology—Radio Frequency Identification for Item Management—Part 63: Parameters for Air Interface Communications at 860 MHz to 960 MHz Type C.¹⁰

ISO/IEC 29167-1:2014, Information Technology—Automatic Identification and Data Capture Techniques—Part 1: Security Services for RFID Air Interfaces.

ISO/IEC 30141:2018, Internet of Things (IoT)—Reference Architecture.

ISO/IEC/IEEE 42010:2011 (withdrawn), Systems and Software Engineering—Architecture Description.

ITU-T Recommendation X.800-1991, Security Architecture for Open Systems Interconnection for CCITT Applications.¹¹

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.¹²

adaptability: The characteristics of the information collection system of IoC presenting new structure, state, or function according to different application scenes.

application: Functional unit in the IoC that is specific to the solution of a problem. The application of the system can be, but not limited to intelligent logistics, intelligent inventory, intelligent washing, intelligent recycling, etc. Note that an application may be distributed among resources and may communicate with other applications.

architecture framework: Conventions, principles, and practices for the description of architecture established within IoC.

NOTE—See ISO/IEC/IEEE 42010 for details.¹³

authentication: The process of determining whether a tag or interrogator is who it claims to be.

data: Representation of facts or concepts of IoC system in a digitization manner suitable for sharing or processing, including clothing information, event or result of intelligent analysis, etc.

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¹³Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

event: Includes raw data captured from data carriers and contexts of business processes.

filtering: The process of rejecting the collection or processing of certain data.

intelligent analysis: Analysis method of discovering knowledge from data by using data analysis tools such as statistics, pattern recognition, machine learning and data abstraction.

internet of clothing: A system of entities (including cyber-physical devices, information resources) that exchange clothing related information by sensing and processing information.

interoperability: The ability of different systems, products, devices or applications under IoC communicating, exchanging data, or services with one another seamlessly irrespective of manufacturer and platform.

interrogator: The device composed of receivers and transmitters that read and write data to and from tags.

reference information model: An abstract framework for understanding significant information interaction relationships among the entities of IoC.

scheduling: The act of specifying the order and allotted time for each device or algorithm.

time series data: Also referred to as time-stamped data, is a sequence of data points indexed in time order.

traceability: The ability to trace the history, application or location of an entity by means of recorded identification.

3.2 Acronyms and abbreviations

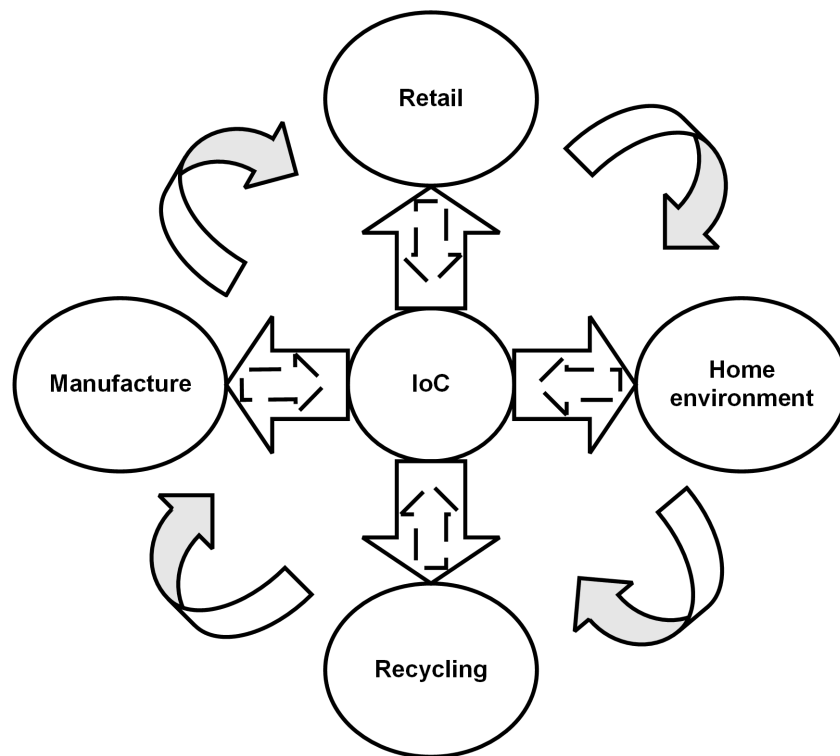
AP	access point interface
CRC	cyclic redundancy check
EPC	electronic product code
ERP	effective radiated power
EX	exciter interface
GHG	greenhouse gases
GS1	globe standard 1
GTIN	global trade item number
INT	interrogator interface
IoC	internet of clothing
IoT	internet of things
MSB	most significant bit
OID	object identifier
OLAP	online analytical processing
OLTP	online transaction processing
PPC	production planning control
PRE	proxy re-encryption
RFID	radio frequency identification

RIM	reference information model of IoC system
RN	random number
SGTIN	serialized global trade item number
STA	station interface
UII	unique item identifier
XPC	extended protocol control

4. IoC system

4.1 Overview

With IoC digital capabilities being built into everyday apparel so that any garments can become a data-generating object creates opportunity for ground-breaking new consumer experiences. Basically, IoC involves an entire ecosystem of various capabilities and services that must come together to deliver a solution throughout whole life cycle of clothing, including manufacture, retail, home, and recycling scenarios as shown in Figure 1.



NOTE—The collection, processing and sharing of data should strictly comply with local laws and regulations.

Figure 1—IoC ecosystem

Different studies have given different estimates on the total number of garments produced worldwide, falling between 80 billion to 150 billion pieces a year. Billions of pieces of clothing will have a unique ID and be assigned a personal profile in the IoC ecosystem. This profile can connect consumers to more information about a specific item, such as its lifestyle content, product details, and washing instructions. With the ability to share its data via the IoC with consumers, systems, and apps, it will allow each consumer to check if the item is

genuine, join after-sales loyalty schemes and recycling programs, connect with exclusive smartphone content, and re-order preferred products. The IoC solutions can help ensure constant monitoring of manufacturing line, enhance the transparency and traceability, and reduce the need for human intervention in the production phase. This can help manufacturers eliminate waste, shorten manufacturing cycles, reduce material losses, and improve productivity. Retailers can provide personalized, real-time mobile experiences and content for each consumer. For instance, retailers can provide the following personalized content for consumers: personal styling suggestions, current fashion trends tips, and event invitations, which are helpful for the improvement of sales and conversion rates. Recycling becomes much easier for users when a garment can trigger specific information about what to do when it reaches the end of its life, including how to recycle for a second use or how to find the nearest recycling center.

On the clothing production line, each raw material and spare part has a unique identification. The detailed production data such as date, position, serial number, size, etc., are recorded accurately and uploaded to the IoC platform to realize the traceability of manufacturing process. With the increasing demand for customized and personalized clothing, IoC makes it possible for apparel manufacturers to design and produce products according to consumers' tastes and needs. This is able to not only significantly reduce unnecessary waste and errors in samples before finalization but also make necessary adjustments in real time. In addition, through the intelligent data analysis, IoC provides manufacturers with different value-added services (i.e., supply chain management, operational efficiency optimization, predictive maintenance, etc.).

IoC also changes the numerous aspects of the retail sector. It can help retailers implement user group segmentation, market trends analysis, sales forecasts, and targeted advertising. By using IoC, retailers shall optimize inventory management and adjust quantity leading to a reduction of stock-out and overstocks. In addition, retailers shall form a better personalized experience for their users based not only on in-store users' interactions with the clothing but also on their online browsing history. Most retailers face the same challenges in inventory management. Through the intelligent and information-based management of logistics clothing, IoC can realize the automatic recording of status, position, movements, and warehousing information. It helps managers monitor and track products in real time. The remote automatic identification technology can penetrate the packaging box and accurately identify each garment without unpacking. In addition, it can identify multiple items at the same time, make the numbers of physical objects and documents consistent, and improve the warehousing efficiency.

In the home environment, consumers' experience can be far more improved and prioritized. IoC provides consumers with smart services related to fashion recommendation, outfit suggestions, washing and caring, smart dressing, and other innovative applications. Consumers can correctly manage their clothing according to the information automatically recorded by their household facilities, making life easier. In addition, IoC provides the abilities to track the wearing frequency, share detailed information about the garments, as well as help consumers clean out their closets and donate old items to community public welfare undertakings. The platform serves as a natural extension of what consumers are already starting to anticipate from retailers in an increasingly digital world.

IoC provides the service of intelligent recycling which can send old clothing recycling reminders to users. One of the most significant challenges to be solved in the clothing recycling stage is the classification and separation between different fiber types. In IoC, the automatic identification technology does not require a vision system to distinguish the fiber types. Clothing shall be classified, recycled, and reused according to the clothing fabrics traced from the production process. In addition, it shall link to more detailed information, such as the heterogeneity of the waste material in terms of different histories of each fabric, and the presence of dyes, finishes, and other chemicals in the material. This makes the full recycling of clothing, reduction of litter, and carbon emissions become a reality.

4.2 Architecture framework

Conforming to IEEE Std 2413™, the architecture framework of the IoC system is described in Figure 2. It consists of the following five layers: information identification, sensing system, middle platform, application and services, and key functions.

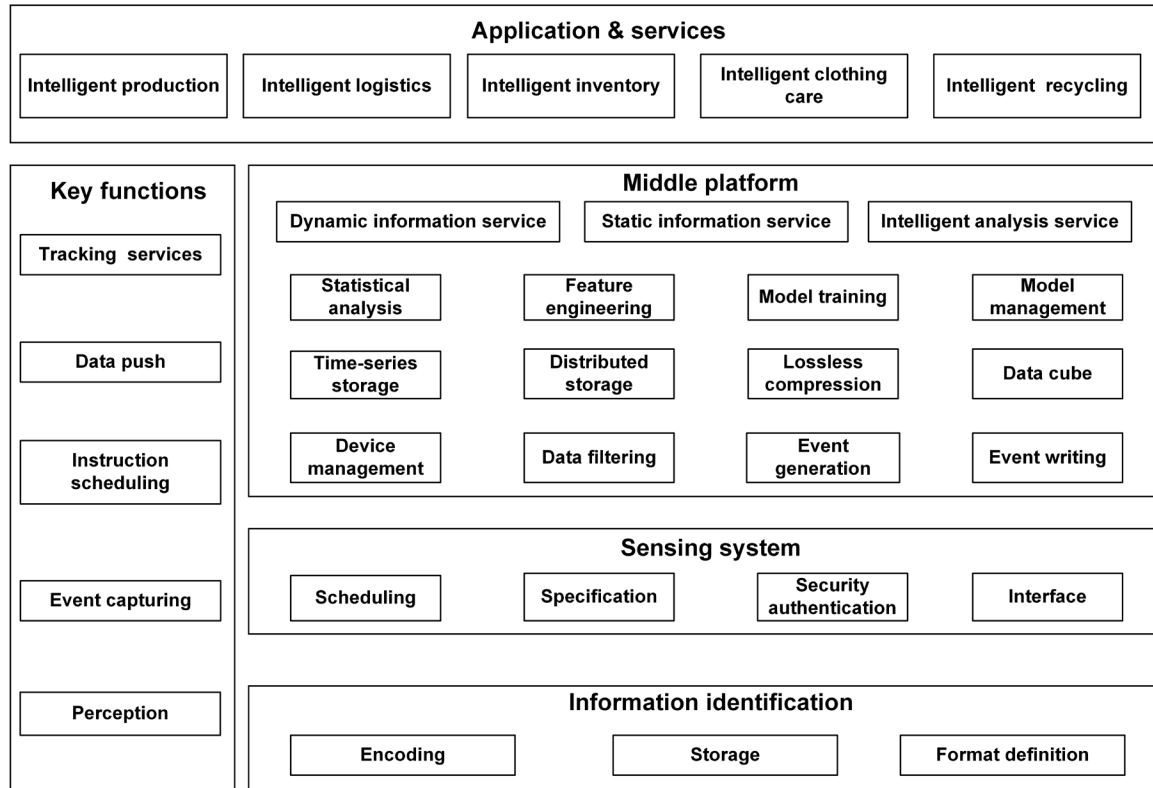


Figure 2—IoC architecture framework

Unified data scheme, processing mode, and interface are defined which can facilitate the interoperability of IoC. Different devices or applications in IoC shall communicate and exchange data with one another seamlessly, irrespective of manufacturer and platform.

4.2.1 Information identification

Each piece of clothing shall be assigned a unique identifier. These unique identifiers can be used for referring to or tracking clothing in IoC system. All information and service sharing of the IoC should be based on the identity of clothing. The SGTIN-96 coding scheme in the electronic product code (EPC) coding system is adopted in information identification layer to achieve strong universality. In order to facilitate the storage, transmission, and sharing of clothing information, the clothing identity has different data format in all levels of IoC. Three formats of clothing identity are defined in information identification layer, including binary format, gridpoint statistical interpolation (GS1) data transmission string format, and object identifier (OID) identification format shall be used for tags encoding, storing, and transmitting in the platform initiating query and retrieval of clothing information, respectively. The encoding method of each format and the conversion technique between them are also defined. See Clause 5 for details.

4.2.2 Sensing system

The scattered placement of clothes in manufacture or home environment may lead to serious interference between the continuously deployed interrogators. The traditional sensing system is limited by the communication range and the network capacity, so it is not suitable for wide range deployment of these scenes. For the passive RFID system, tags obtain RF energy through the energy acquisition circuit and do not have battery auxiliary power supply. The downlink communication range is limited not only by the sensitivity of tag demodulation circuit but also by tag energy acquisition efficiency. The communication range of downlink is generally within the range of a few meters. The uplink receiving equipment are interrogators, which generally have much higher sensitivity than tags. Therefore, the range of uplink communication is larger than that of downlink. In the traditional sensing system, uplink and downlink are integrated together to form a single interrogator and the communication range of an interrogator and a tag takes the minimum value of uplink and downlink, which limits the communication range of the system. Therefore, the system capacity shall be expanded by extending the uplink communication range. A traditional interrogator integrates a transmitter and a receiver, realizes the sending and receiving functions by one antenna which causes serious self-interference. The two channels shall be physically isolated in space by separating transmitters and receivers, which eliminates self-interference and reduce downlink link loss. Theoretically, the communication range of uplink can be expanded by 10 times up to 100 m compared with that of downlink, so as to expand the coverage of the system and applicable to IoC scenes. An IoC sensing system with large network capacity and strong scene adaptability is defined in sensing system. See [Clause 6](#) for details.

4.2.3 Middle platform

The IoC business applications are supported not only by basic clothing information but also by statistical data and intelligent analysis. Therefore, the IoC middle platform shall have the functions of data storage, processing, and intelligent analysis. The core data in the IoC ecosystem has time series characteristics such as timestamp, comparability, periodicity, and high collection frequency. The time series data is the main form of IoC data. The IoC time series database shall meet the requirements of being distributed, scalable, and easy to query and analyze. Furthermore, IoC time series database shall provide an efficient lossless compression storage solution, in order to save hardware costs and improve storage efficiency. The life cycle of various IoC events has the characteristics of long-time duration, unique application scenes, various data features, and large number of users. By virtue of the methods such as time series analysis and modeling, the high-dimensional data cube is constructed through parsing the massive time series event data reported by tags. To support the intelligent application of the IoC ecosystem, in addition to the IoC cycle phase and data cube, the IoC intelligent analysis and computation is built based on distributed machine learning and intelligent algorithm. It correlates the data of various IoC devices and user behavior to provide richer intelligent application to each linkage of the IoC and end-users. Due to the numerous ecological participants involved in the system, the requirements of data security protection arise. Based on blockchain, cryptography and privacy-preserving computation, the platform defines an IoC data security protection mechanism including data tamper resistance, secure data sharing and privacy-preserving computation. A unified open and secure platform is defined in middle platform layer. See [Clause 7](#) for details.

4.2.4 Application and services

The application layer includes various applications within the business scope of IoC, such as logistics tracking, clothing care and recycling. It provides various intelligent services for the whole life cycle of clothing.

Intelligent logistics improves the potential benefits of textile logistics and inventory management through reduction of inventory losses, increase of the efficiency and speed of processes, and improvement of information accuracy. Intelligent clothing care allows for the machine to automatically detect the fabric type and colors before starting the washing cycle. Measuring the type of detergent along with the types of clothing thrown into the machine, the settings are adjusted automatically before the machine starts itself. Intelligent recycling aids the clothing recycling industry in the tracking, work order management and repairs of waste containers, in addition to service verification and route management of waste vehicles.