

## INVESTIGATION OF THE ONTOLOGIES IN THE DOMAIN OF THE INTERNET OF THINGS

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DOI: <https://doi.org/>

### Keywords

### Article History

Received on 20 Oct 2025

Accepted on 20 Nov 2025

Published on 31 Dec 2025

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### Abstract

The Internet of Things (IoT) has flourished remarkably, attracting the use of billions of heterogeneous devices that produce massive data volumes in various fields of application. The process of managing, integrating, and interpreting this data in a manner that is meaningful remains a major challenge due to differences in data formats, communication protocols, as well as semantic representations. Ontologies have become one of the primary facilitators to counter these issues through offering a common and machine-readable conceptualization of the entities, relationships, and processes of the IoT. This research work examines and classifies the various types of IoT ontologies, specifically focusing on popular standards like the Semantic Sensor Network ontology (SSN) and its lightweight version, the Sensor, Observation, Sample and Actuator (SOSA) ontology. The paper also studies a number of other domain-specific and cross-domain IoT ontologies other than SSN and SOSA, and identifies how these ontologies represent sensors, observations, actuators, platforms, and contextual information. Moreover, the paper will determine and discuss the essential requirements of ontologies in the IoT domain. Such needs are interoperability of different devices and platforms, support of sensitive data through security and privacy, seamless integration with other systems and standards, and flexibility to meet the changing application requirements. Lastly, the paper offers an analytical comparison of available ontologies of IoT by looking at the reuse of the core concepts in different models. The comparison is carried out with the aid of a set of characteristics such as energy awareness, security support, context modeling capabilities, reasoning support, ontology language, ontology type, and expert validation. Through this comparative analysis, the results will guide researchers and practitioners to choose, design,

and scale the ontologies that can be more useful in the scalable, secure, and interoperable IoT applications.

## INTRODUCTION

### 1. Introduction

The Internet of Things (IoT) term originated from a presentation in 1999 by Kevin Ashton of MIT (Ashton, 2009). The presentation states that the integration of Radio Frequency Identification (RFID) into regular objects is useful in the recognition of the objects. This concept leads to the creation of the term IoT. The name IoT is coined out of two terms: Internet and Things (Madakam & Ramaswamy, 2015). The first term, Internet, represents the platform of collection of computer networks. This platform uses the conventional Internet protocol suite (TCP/IP) to assist consumers around the world in communicating with each other. Every nation today is connected through the exchange of information, news, and ideas via the Internet. The number of Internet users is estimated at 5.5 billion worldwide, according to Bagdi et al. (2023). This figure of users indicates that 68 percent of the entire population in the world is on the Internet. Things is the second word that represents automated devices, foodstuffs, Tools, Equipment, Monuments, Breakthroughs, and Sculptures, and all the living and non-living things. Further, these things can be regarded as true things in this physical world.

Human beings are physical; similarly, our environment is also physical. It's assumed that the environment is based on concepts such as civilization, information, and budget, which are grounded in things. These things are important as well as the Ideas and information of our environment. Having devices that have the knowledge of everything about things through data (i.e., collected without the assistance of human beings), then things can be detected and counted. This significantly cuts down excess, damage, and expenditure, e.g., all things to be changed, mended, or recalled (Leonardo B. Oliveira, 2018). IoT is being applied in industrial products to smart appliances of the home, like Real-Time Systems, Cybersecurity, Manufacturing, Smart Homes, Retail Sector, Health, Smart Buildings, and Security (Ahmed, 2021 (Calvillo-arbizu & Reinosina, 2021) (Ait & Debauche, 2021) (Tariq & Khan, 2021) (Chataut et al., 2023). IoT is not only RFIDs but also has other hardware products within it, like sensors, actuators, and mobile devices. These are all seen to have the ability to act upon, be measurable, or offer amenities as per the real-world by modern vision (Hachem & Teixeira, 2011).

The ontology term has been borrowed based on the field of philosophy that refers to the nature of being (R, 2019). Researchers in the field of Artificial Intelligence later applied ontology as a concept in developing simulations using computers and automated reasoning rules. The IT side of the case defines ontology as a collection of explicitly defined depictive primitives in the field of knowledge (Keet, 2020). The primitives having certain boundaries can be part of a collection, such as classes, relationships, and other properties. A wide variety of diverse programming languages and schemes can be used to depict ontology, such as Ontology Interchange Language (OIL), DARPA Agent Markup Language (DAML), Web Ontology Language (OWL), and Resource Description Framework (RDF) (Anitha & Devi, 2018). Nevertheless, OWL is the most widespread Ontology language in the information stack of the Semantic Web (Ameen & Head, 2019). Description logics have given rise to the OWL language to make the right semantics of perceptions and associations. The W3C technologies information stack includes RDF ontology as well. The

RDF is based on a threefold form, subject-predicate-object, where each form represents the semantics of a domain. A domain semantics represented in the subject-predicate-object form or OWL language can be retrieved using a query language called SPARQL (J. Perez & Arenas, 2009), which syntactically is similar to the SQL query language. Semantic Web Rule Language (SWRL) is another ontology language based on OWL. It is an extension of the existing OWL axioms to consider Hornlike instructions in order to provide additional explanation (Mehla & Jain, 2019).

This paper is divided into several sections. In the introduction section, the IoT background, ontologies, and motivation of the ontology in IoT domain are explained. Section 2 presents a literature review that helps understand existing work on IoT ontologies. The next sections present the famous IoT ontologies, IoT requirements, and a detailed analysis of ontologies in IoT. The last section concluded the study with some future research directions.

## 2. Literature review

The contextual relations are in no way neglected because the various user positions are offered in the ontology provided by (S. I. Kim, 2015). This ontology has a reasoner to evaluate and identify the positions. The outcome shows that the suggested reasoner in the ontology has a more advanced position precision system in comparison with the conventional GPS positions. This is achieved by identifying the position that will be agreed upon to illustrate services in context-aware atmospheres using ontology developed in Cabrera et al., 2022. It provides a standard ontology of the location concepts, on behalf of device-based facilities within the ubiquitous computing environments. The different responses of location are categorized using Cartesian coordinates and numerical evaluation techniques to explain the data about location, which leads to abstract mathematical simulations. In most of the IoT applications, however, sensor data is used to gather location data.

The different models mentioned are as follows:

- i. Cartesian coordinates are in symmetrical models.
- ii. The location is set-theoretic models, i.e., Cellular position and WiFi AP location.
- iii. The graph-based models represent positions in a physically-grounded network and a social network.
- iv. Semantic models determine locations that are described with the help of human-friendly notations.

## 3. IoT ontologies

As shown in Figure 1, this section outlines some well-known ontologies used to address meaningful information exchange challenges in the IoT domain.

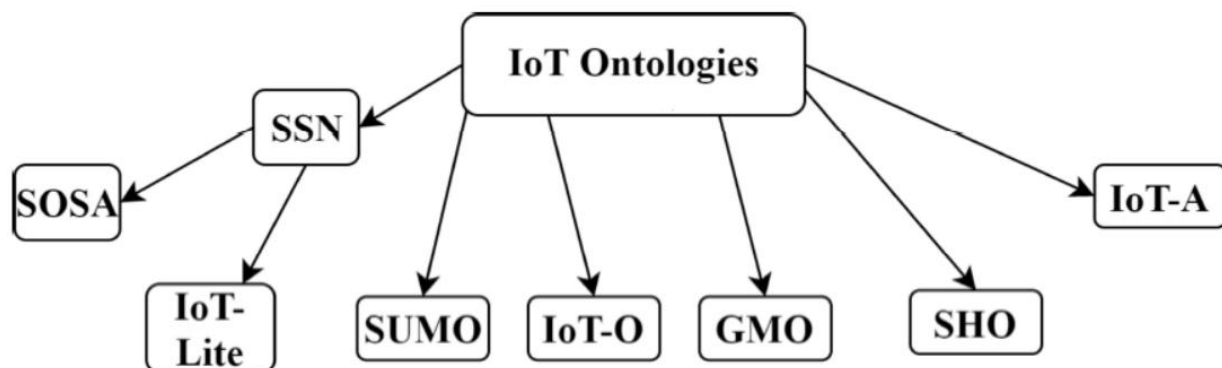


Figure 1: ontologies in the IoT domain

The ontology representing the links or associations between sensors, stimuli, and observations is the Semantic Sensor Network (SSN) Ontology (Armina & Krzysztof, 2019). There are 4 perspectives through which the SSN ontology could be known.

- i. A sensor point of view: tells what and how the sensor senses.
- ii. An observation perspective: identifies observed data and related metadata.
- iii. A system view: discusses the composition and implementation of the sensor system.
- iv. A feature and property view: talk about what is perceived by the sensors on the property.

In (Janowicz, 2018), a novel ontology, namely, Sensor, Observation, Sample, and Actuator (SOSA) ontology, is defined. SOSA provides a lightweight semantics about things, including sampling, observation, and actuation. SOSA concepts include W3C SSN ontology concepts and additional concepts. Thus, it is based on the reuse of the SSN concepts, understanding technical needs, and facilitating a definite audience. SOSA can be applied as an alternative to the SSN-based SSO principle. IoT-Lite can be used to expand the SSN ontology to represent key concepts of the IoT. It allows IoT concepts to be interoperable and experience the mix of sensory data within a mixed IoT context through lightweight semantics (Bermudez-Edo & Elsaleh, 2017). The ontology was generated using ten (10) rules that had been defined by the authors of IoT-Lite to design a semantic model that is worthy and scalable.

These rules include:

- i. The design must be scalable.
- ii. Users who will utilize the semantics and arrange their requirements.
- iii. Provide means of updating and changing the semantic notes.
- iv. Prepare validation and interoperability analysis tools.
- v. Generate thesaurus, hierarchical structure, and meaningful data.
- vi. Reuse existing ontologies like SSN.
- vii. Link data and descriptions with other current concepts.
- viii. Establish rules and principles of providing value to everything.
- ix. Make it simple.
- x. Code real processes, programs, and APIs to manipulate and execute the semantics.

Suggested Upper Merged Ontology (SUMO) was created through a combination of a number of existing upper-level ontologies (Pease & Niles, 2002). It includes various parts in order to define ontology in general. The first part is the structural ontology, which denotes the relationship descriptions. These descriptions provide the framework for describing ontology correctly. The second part is known as the base ontology, in which key ontological concepts are included, including abstract objects and the separation of objects and methods. Simple set abstract knowledge is found in a special section of the SUMO ontology, namely, the Set/Class Principle. The numeric part of the ontology reports about simple arithmetic problems, and the temporal part of the ontology establishes connections according to the temporal relations of Allen. The authors of (Alaya & Medjiah, 2015a) present the IoT-O Ontology, which is composed of five components, namely: sensor, observation, actuator, actuation, and service models. To reduce IoT-O to the concepts and relations that are relevant to sensors, the creators of ontologies chose to include only these aspects in their ontology, and this explains why it has been picked in several areas and by third parties. In addition, ontology is flexible as well as facilitates reusability. There are four broad perspectives on it. A sensor perspective mostly introduces sensors that encompass what it is sensing,

the manner it is sensing, and what is sensed. The second perspective focuses more on observations and the metadata related to each observation and is named the data perspective. A system perspective is concerned with the type of systems of sensors to be implemented. A property viewpoint focuses on what has been interpreted concerning a property or senses a particular feature.

The home devices (including households, electricity components, computers, biometric or security devices) are simulated through the Smart Home Ontology (SHO) in Berat Sezer & Dogdu (2015). The devices are modeled via a Master-slave model in SHA, and the simulation is carried out through this model. All the devices that are demonstrated are connected together through a message queue. The main computer can be considered as the Master node, and all the devices connected with the main computer are the slave that follows a command issued by the main computer to perform.

The IoT-A ontology has two primary classes: resource and service (Akasiadis & Tzortzis, 2015). The data about hardware modules, including wired or wireless devices and sensors) is represented via the resource concept of IoT-A. Service, on the other hand, explains how its corresponding resource works in the world. The services may be provided in software and web, detailing what the service is able to accomplish and the extent of the impact of the service. For instance, a smart home service impact is measured. Similarly, other areas' services, such as a farming region or an industrial region, can be defined, and their impact can be calculated. In addition to resources and services, the IoT-A has different sections. The theoretical aspects related to graphs are covered in the Graph Theory section. The Unit of Measure section gives an explanation of the systems of units. There are other ontology sections that give sub-hierarchies and axioms, which connect to process types, object types, and attribute types.

The meaningful vocabulary and basic concepts of a service-oriented architecture are described in the SOA Ontology (Zimmermann et al., 2015) to enhance collaboration between the business and the IT societies. The architecture ontologies (other than SOA) exchange the information on the basis of clearly defined concepts; therefore, a common dictionary among the enterprise architects is needed. However, authors of the SOA ontology include the possibility of inducting transitive knowledge automatically. Web of Objects (WoO) ontology describes data, information, and knowledge (Y. Kim & Lee, 2014). The difference between information and knowledge is that the metadata (i.e., meanings to the data) is described as information, whereas knowledge assists in the selection of the information among the various sources of information to meet the requirements of users, services, and the environment.

#### 4. Requirements for an IoT Ontology

This section addresses the requirements of ontology for the IoT domain. This information is very useful in the analysis of the requirements of IoT. As illustrated in Figure 2, the requirements of IoT are subdivided into five segments, namely, interoperability requirements, integration requirements, privacy requirements, application requirements, and other requirements.

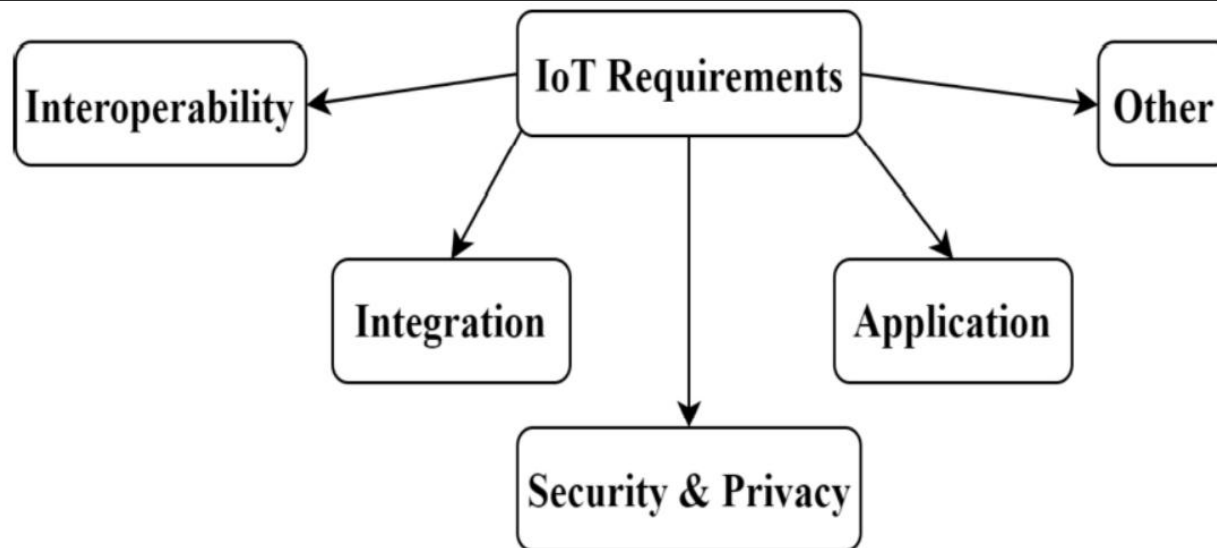


Figure 2: Ontology requirements for an IoT domain

#### 4.1 Interoperability Requirement

The work (W. Wang and De, 2012) has given an exposition of the approach to an entire ontology in the description of knowledge in the area of IoT. It also discusses how it can be utilized in supporting duties like analysis, service finding, and dynamic configuration. On the one hand, Fruhwirth and Kastner (2018) suggest reusing the current ontologies, and on the other hand, creating reusable ontologies is also investigated. (Gyrard & Datta, 2018) attempt to evaluate and analyze the current situation of using software tools with the help of ontology. This knowledge facilitates the semantic interoperability of software tools. The authors suggest building a platform that will bridge various ecosystems with the so-called semantic interoperability as a service to the IoT platform.

A novel approach that uses ontology for understanding the context, facilitates interoperability in a meaningful manner, along with blockchain methods, is suggested in (Kashevnik and Teslya, 2018). SEG 3.0 should be recommended for use in IoT, namely, with the smart cities scenario, as evidence of conception (Gyrard and Serrano, 2016). First of all, the features required by the methodology are established. Secondly, different formal stages and methods are outlined. Finally, the arguments in favor of using this technique are provided. A semantic exchange information model was proposed in (Willner and Loughnane, 2015). The paper explains methods of formally defining coalitions and the life cycle of the services. Such services form a foundation for future research on distributed semantic source management. One of the extensions of the SSN ontology, according to Bermudez-Edo and Elsaleh (2017), is the IoT-Lite, which introduces relevant concepts in the IoT using lightweight semantics to enable interoperability and sensory data detection in different IoT platforms. Here is a technique of interconnection between the physical device, smartphone, and WoO application server (Kibria and Chong, 2015).

According to (El Kaed & Ponnouradjane, 2017), the model-driven technique supports the inclusion of existing ontologies and knowledge bases to accelerate the application development in the IoT domain. The article (Szilagyí & Wira, 2016) focuses on a Semantic Web Stack of the IoT and indicates the failure of developing an IoT application or service. According to Khan & Ndubuaku (2018), the interoperability of smart home entities must have security regulations. In

this regard, a context-based ontology is developed to accommodate different views, including user and physical views. The article (Sgouropoulou & Koutoumanos, 2018) describes the implementation procedure of the AgRes ontology. It describes AgRes concepts and interoperability phases for the online application.

Suri & Gaaloul (2017) conclude that ontologies aid interoperability technologies in the establishment of services in a semantic manner, including the charging of devices and the discovery of their location, or the traffic management. In (X. Wang & An, 2015), the IoT environment of devices is identified with the help of semantics and ontology technologies. To begin with, to implement the device detection process, a typical structure of sensing network ontology is built, and subsequently, the major classes and the hierarchy are established. Subsequently, the elements and associations that are externally related to the sensor component are put together. The Wang & An are of the view that the suggested ontology provides the semantics according to which the elements of sensing IoT networks can be certainly learned and later collaborate. (Lam & Haugen, 2018) introduces a methodology, which is called automatic computing, to help in advancing interoperable IoT elements in a semantic way.

The methodology is evaluated through various performance parameters of a smart home situation. The IoT-based healthcare scheme is used in (Hussain, 2017), which seems to be useful in the water information system. Based on already separate ontologies, Alaya and Medjiah (2015b) introduce an ontology of IoT known as the IoT-O. IoT-O is constructed by justifying the concepts that can be used in the IoT environment. To analyze the data streams of the IoT, Elsaleh & Enshaeifar (2019) suggest a lightweight model of the semantic ontology that should be used to analyze the incoming data flow. The metadata descriptions representing the data types within the ontology are used in data search and discovery. The article (Tayur, 2019) offers an interoperability model of data between various sensors. It collects raw sensor data, which is then fed into the ontology and converted into knowledge. The heterogeneous data obtained through the design of two layers in (Yus & Bouloukakakis, 2019): the semantic and data exchange layers are interoperable. A universal, expandable metamodel within the semantic layer is proposed using the renowned ontologies SOSA and SSN (explained earlier). To achieve interoperability, the data exchange layer is specified, which characterizes the machine-level communication. (Sithole and Marshall, 2019) explain that interoperability of various devices is a factor to be considered when creating an IoT reference architecture. One of the ways to achieve interoperability is by providing a lightweight ontology that can be utilized in various IoT environments. The Hypercat descriptions can be enhanced semantically to enhance interoperability with a JSON-LD-based directory, as Georgiou and Tachmazidis (2019) propose.

#### 4.2 Integration Requirement

There is one way to add dynamic devices to the situation-aware structure of the IoT, as Potter and Brittes (2016) show. The method (called ContQuest) suggests multiple middleware capabilities to facilitate adaptive capabilities for the situation-aware applications.

Resource Agent mirrors a device in the ContQuest approach. Each resource agent is based on the suggested design that aims at simplifying the process of different device integration. The two articles (Sabri et al., 2018) propose ways to provide a visual data facility of different sensor data in

the subject-predicate-object form (i.e., RDF ontology) to facilitate integration. Both methods generate SPARQL that includes dynamic and automatic query statements based on the situations that the end-users select.

It is also possible to use the method to make the semantics based on the instructions provided by the consumers individually. (M. Kim et al., 2017) suggest a peculiar concept of integration of machines through semantic technology. The integration concept comprises ontology and machine learning rules of the proposed concept of semantic filtering. (Gao and Ali, 2017) introduces a middleware called an automated complex event implementation system (ACEIS). The ACEIS has two key functions, namely, seeking and assembling the data generated by the IoT devices in the urban setting and generating queries from the stream of IoT-generated data to monitor the demanded complex events. (H.s. According to Choi and Kang, 2016) cross-domain cases of interchangeability of data format are possible and can be eliminated and unified through shared metadata descriptions. The article (Akasiadis and Tzortzis, 2015) examines the problem of integration as perceived by a developer. The authors paid special focus on the real-world examples regarding smart meeting rooms to develop ontology, including the use of ontology to estimate the number of people in a smart meeting room.

The metamodel of objects integration into an IoT objects situation is novel and is introduced by Zimmermann et al. (2015). It is possible to enhance autonomy and flexibility in the production environment that is made feasible by authors (Kalogeras et al., 2015). This will eventually redefine the integration and interoperability of industrial products and ecosystems. A middleware known as SemIoT Platform is defined (Kolchin et al., 2017). The SemIoT makes use of ontologies, semantic web technology, and REST architectural patterns to support the integration requirements of an IoT environment. SemIoT characteristics are also evaluated by the authors using a use case.

#### 4.3 Security and Privacy Requirement Institute for Excellence in Education & Research

According to Kanaan and Mahmood (2017), the distributed ontology-based system is proposed to meet the privacy needs of the healthcare institute in terms of advanced IoT and electronic health records. The following ontology-based security framework is created to make decisions and enhance the secure information within industrialized systems (Mozzaquatro & Melo, 2016). It is proposed to use IoT-Sec ontology that will assist in securing the system with the help of queries obtained in the environment. As Mittal and Vijayal (2018) argue, the biggest issue the existing IoT systems have is the security issue. The article addresses different types of attacks on IoT systems, and its focus is on the ontology-based model as a solution to a wide range of attacks. Mohsin et al., (2017) provide an IoT-Checker tool that is utilized to record anomalies naturally in the configuration of the security of the IoT. Moreover, the instrument employs various Internet of Things ontologies in order to identify the threats associated with the IoT environment. The tool in general seemed to be easily scaled, configured, and much more effective in locating faults as opposed to manual analysis IoT configuration. The design of an agent-adaptor structure to be used in exchanging engineering services over the Internet is described (Sunny and Liu, 2017). It is the earliest engineering service communication approach via the Internet. It is stated that situation-aware cybersecurity is discussed in the context of IoT (Mozzaquatro and Jardim-Goncalves, 2018) with the help of a reference ontology. Ontology is applied to handle different situational models and security issues. A resource description model that is based on ontology is called to provide

credible evaluations of different detecting devices (Lan & Shi, 2019). The model represents the applications of IoT on the cloud and the privacy of the IoT devices.

According to Patel and Bhattacharyya (2020), there should be an element of trust among the IoT devices. To support this element, authors developed an ontology, namely trust ontology, to facilitate security requirements for IoT. It is possible that (Shaaban & Gruber, 2019) can be helpful in the initial stages of the development of the critical systems because it introduces an ontology-based security tool. The tool involves the use of ontology to ensure that the targeted security requirements are met. A way to merge devices would be recommended (Angelos et al., 2019). The method employs ontology and gives secure and safe warnings to individuals. The (Arruda, 2019) article gives a privacy layer (IoT-Priv) that is lightweight to simple IoT notions like device, measuring device, and service. The ontology proposal, IoT-Priv, establishes a correspondence between the requirements of the IoT and specific privacy terms, and the actions under various implications.

#### 4.4 Application Requirement

(Abatal & Khallouki, 2018) tells about a smart, cohesive healthcare-based system that connects the semantic web through cloud computing to allow real-time data collection and modeling by applying ontology. The visualization, broadcast, and allocation of medical records and accounts are done via the cloud. (Sabri et al., 2018) suggested to present the abstract view of physical or virtual electronic devices connected through the Internet. Further, the tools and cohesive techniques are recommended for managing the utilization and development of the framework-based Semantic IoRT method. (Kasnesis & Patrikakis., 2015) discussed an integrated platform, empowering dynamic addition of computerization rules based on semantic web technologies in a cooperative-based atmosphere of smart home systems.

(Abreu & Velasquez, 2017) offers an ontology for the IoT structure according to the requirements of Smart Cities. Additionally, various kinds of tests were executed to confirm the accuracy of this ontology, containing potential setup optimization intentions like low latency and high flexibility. (Berat Sezer & Dogdu, 2015) talks about a smart home sensor ontology developed by themselves, a specific ontology based on the Semantic Sensor Networks (SSN) ontology. It also presents a computer-generated environment developed by themselves for a smart home case using ontology and discusses its early performance results. (La & Jung, 2015) describe a cloud platform that delivers an essential set of functionality required to empower our medical analysts over the network. The current platform makes sufficient basic functionality required for many kinds of individual healthcare IoT applications available. (Yang & Choi, 2015) describes the ontology to process environment information and provide services according to the required situations. The Generic Ontology Models (GOMs) are proposed for context service.

Further alarm service is used as an example to show how IoT ontology works. (Prasetio & Akbar, 2018) Utilized Smart Home as an example by IoT device manufacturers. IoT devices deliver the capability to describe, amend, and infer data using a semantic method for data handling. In (H. S. Choi & Rhee, 2014), an IoT-based user-driven capability demonstrating environment is proposed to form IoT services. The recommended situation is to set up a well-defined service for another user. Through the personalization and customization of the given service, the worth and distribution of the service are amplified.

In (Inna Sosunova, 2011), a method is proposed for an IoT-supported Waste Management Ontology for the information illustration technique. This method of creating the ontology, guidelines, and multistage data handling describes extracting knowledge about specific circumstances. The recommended method executes in the shape of a web application whose content is based on an ontology, and processing data happens according to the recommended algorithm. (Chougule & Jha, 2016) discussed computerized techniques for creating IPM ontology and clarified how it could be prepared and accessible to agriculturalists as an IoT application. (Rhayem & Mhiri, 2017) advocates two main services. The first one is by suggesting a HealthIoT ontology of medical-related objects, and their data is represented semantically. The second contribution is suggested to arrange for concrete backup using this ontology. To assess the HealthIoT ontology, an IoT Medicare method is recommended.

#### 4.5 Other Requirement

(W. Wang & Lee, 2017) explains a common standard architecture for the future of IoT. The GGIoT is suggested to meet the future 6A Connectivity requirements for IoT. The GGIoT is autonomous of electronic devices, platforms, network systems, fields, and applications. It can also reduce the communication message size of devices with lower abilities, such as submissive RFID labels. Therefore, it also minimizes physical size, price tag, and network overhead. (H. Zhang & Meng, 2014) presents a multi-aspect ontology-based IoT model to resolve dynamic feature issues. For resource administration, examining, and reasoning, this model distributes sources into four key conceptions: overall condition, adaptable feature, function, and implementation.

In (Kibria & Fattah, 2015), an information formation model that brings together a service logistics model and a computer-generated world information model based on a Web of Object platform has been suggested. An abstract semantic ontology model has been established, and a model has been executed for a use case situation of emergency service. (Ruy & Falbo, 2015) support using an Ontology Pattern Language (OPL) as the foremost factor of this ontological structure. An ISP-OPL (ISO-based Software Process OPL) is presented to act as the basis for coordinating software development related to ISO criteria, supporting reuse when constructing aligned particular software process ontologies for Software Engineering subfields. (Yan & Liao, 2018) explore a well-known software variation management method, different kinds of implicit knowledge are created that help in requirements change management.

### 5. Analysis of ontologies in IoT

This section analyzes the latest and prominent IoT ontologies to provide an in-depth understanding of existing IoT ontologies. Table 1 shows a comparison of concepts reused in existing ontologies.

Table 1: Finding Concepts between different ontologies

Name	SOSA	SSN	IoT-O
Device	√	√	√
Sensor	√	√	√
Observation	√	√	√
Actuator	√	X	√

Actuation	√	X	√
Procedure	√	X	X
Result	√	X	X
System	X	√	X
Platform	√	√	X
Feature of Interest	√	√	√
Property	X	√	√
Security	X	X	X
Energy	X	X	√
Context	X	X	X

In existing IoT ontologies, some concepts, rather than being redefined from scratch, are being reused from existing ontologies. Among them is the SSN, which reuses sensors, systems, the feature of interest, and property concepts (Armina & Krzysztof, 2019). Actuator, procedure, and result notions are reused from SOSA (Janowicz, 2018). Many IoT ontologies have reused the IoT concepts from existing IoT ontologies. The following section discusses in detail the reuse of existing ontologies in the development of IoT ontology.

Table 2 describes different IoT Ontologies in the literature with the following characteristics: Energy, Security, Context, Type of Ontology, Language, Reasoner, and Expert. Energy supervision (i.e., first issue) is a crucial attribute of an IoT system. It is due to the type of operation of the devices and also the ruthless environment in which the devices are operating. The context includes information about the IoT devices, for instance, the location and time of installed devices. Time information tells about how smooth the IoT operation is running. Security is the most important aspect of an IoT system. Implementing an IoT system needed to answer questions such as: Which attacks are faced by the system? Which vulnerabilities enable the attacks on the system? Which security strategies protect against vulnerabilities and attacks? So, these concepts are checked to determine whether they are used in other ontologies. The type of Ontology is used to check whether the given ontology is a Domain-specific or a general-purpose ontology. The language option is used to check the language used to implement the ontology. The last two options are used to study the validation techniques used to validate their ontologies.

Table 2: Analysis of existing IoT Ontologies

Reference	Ontology Name	Energy	Security	Context	Type of Ontology	Languages	Reasoner	Expert
(Janowicz, 2018)	SOSA Ontology	No	No	No	General Purpose	RDFS	No	No

(Armina & Krzysztof, 2019)	SSN Ontology	No	No	No	General Purpose	OWL	No	No
(Méndez, 2018)	IoT-O Ontology	Yes	No	No	General Purpose	No	No	No
(Gyrard Datta, & 2018)	Software Ontology	No	No	No	Domain Specific	No	No	No
(Fruhwrth & Kastner, 2018)	Reusable Ontologies	Yes	No	No	Domain Specific	No	No	No
(Tayur, 2019)	CoIoT Ontology	Yes	No	No	General Purpose	SPARQL	Yes	No
(Gil & Santiago, 2019)	Automation I4.0 Ontology	No	No	No	General Purpose	OWL	No	No
(Gonzalez-Gil & Martinez, 2020)	DS4IoT Ontology	No	Yes	No	Domain Specific	JSON-LD	No	No
(Elsaleh & Enshaeifar, 2019)	IoT-Stream	No	No	No	General Purpose	RDF	No	No
(Weber & A, 2019)	Service Ontology	No	No	No	Domain Specific	RDF	No	No
(Angelos et al., 2019)	DESMOS Ontology	No	Yes	No	Domain Specific	No	No	No
(Nagowah & Abou, 2020)	Smart Classroom Ontology	No	No	Yes	Domain Specific	No	No	No
(Arruda, 2019)	Privacy Ontology	No	Yes	Yes	General Purpose	OWL	No	No

From the Table, it's evident that the energy concept is used in only 3 papers, and the rest of the papers do not use this concept. The security concept is used in 4 papers, and the rest of the papers do not use this concept. The context concept is used in 3 papers, and the rest of the papers did not use this concept. Out of 12 papers, in 6 papers, the type of ontology is general-purpose, while in 5 papers type of ontology is Domain-specific, and only 1 paper did not mention the type of ontology. The 3 papers used W3C W3C-recommended OWL ontology. In comparison, the other 3 papers used RDF language, and only 1 paper used SPARQL language. The rest of the 5 papers did not use any ontology language. The 2 papers used a reasoner to validate their ontology. In contrast, the rest of the papers did not use a reasoner. None of the papers uses the validation of ontology by experts. Therefore, the researcher uses the validation-by-expert method to validate the ontology.

## 6. Conclusion

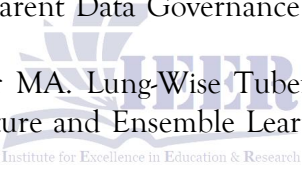
This paper discusses the Internet of Things and IoT ontologies. It also covers existing IoT ontologies. The literature survey discusses existing famous IoT ontologies that have been developed over a period of time. Further, it talks about IoT requirements of ontologies. There are Interoperability, Integration, and Security/Privacy Requirements. Further, it discusses the ontologies' support for reusability. Lastly, this paper gives an analysis of IoT ontologies in terms of five features, which shows the limitations in existing research. Most of the existing IoT ontologies did not use IoT concepts like energy, security, and context. Existing IoT ontologies did not adopt the most commonly used W3C-recommended language, OWL. On the other hand, most existing IoT ontologies, such as SOSA and IoT-O did not use the OWL language except for SSN. Therefore, in the future, a new, more general, and mature ontology is required that reuses previous IoT ontologies and incorporates the newly identified IoT concepts.

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