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To cite this article: M S Gitakarma et al 2021 J. Phys.: Conf. Ser. 1810 012007

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Architectures, frameworks, and applications in IoT-based smart environment: a review

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1810 (2021) 012007

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Abstract. We are in a time when a large number of electronic devices influence human interaction with the environment. The physical place where these various devices interact with each other to provide useful services for end-users gives birth to the concept of a Smart Environment. The interaction of the multiple devices that make up a smart environment produces a large amount of information or Big Data problems, so the insertion of the Internet of Things (IoT) technology in the environment is essential. IoT integration and cloud computing technology are needed as the impact of evolution on the next generation of smart environments. Trends in research related to IoT and Smart Environments are increasing rapidly beyond the trend of Smart City that first emerged. This paper reviewed current trends about smart environments, architectural concepts, frameworks, and applications of IoT-based Smart Environments.

1. Introduction

Side effects from the development of technologies that are applied to smart environmental goals lead to increasingly large, extensive, and complex data, audio, and video streams. Natural phenomena and human interaction in the environment are measured using heterogeneous sensor network instrumentation and presented with the help of information and communication technology. Sensing data is shared and processed with various functions for specific purposes. Some private companies and organizations utilize this information data and package it according to business roles for market needs. With the growing data collection, this giant data management requires data analytics and the development of specific data management applications. Data storage architecture is crucial in managing smart environments.

Every second, there is 88 GB of data traffic on the Internet[1]. This data from sensors accustomed gather climate information, from posts to social media sites, digital footage and videos, etc. A lot of data coming from various sensors in a smart environment on the internet will cause Big Data problems[2]. IoT applications in the smart environment are expected to use Cloud architecture to overcome the big data problem.IoT is formed from nodes (things) that are intelligent, usually self-configurable, interconnected with each other in a dynamic global network infrastructure. Several surveys have been conducted on IoT and given an overview of the development of IoT going forward[3]–[5]. Here, we provide several additional reviews of architectures and frameworks that have so far been used in the IoT domain in Smart Environment (SE) applications.

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This paper outlines definitions, architectures, and applications in IoT-based Smart Environment research, which are explained in terms of paradigms, taxonomies, and supporting interdisciplinary technological developments. We presented an IoT-based SE paradigm followed by several general definitions and taxonomies associated with it. The processes in designing and the layered framework IoT-based SEare discussed in the next section. We discussed application domains in IoT-based SE with several projects related to its domain. Finally, we talked more about the IoTbased SE technologies and conclude the discussion.

2. IoT-based Smart Environment

The concept of a smart environment, which was first conceived by Weiser [6], is a physical world that is formed from dynamic and global networks, which are rich and invisible, interconnected with sensors, actuators, displays, and process components, embedded in everyday objects in our lives. Melzi*et al.*[7] said the environment could be said to be smart when heterogeneous wireless networks are implemented and linked together in networking.

The challenge in IoT development is to build a layered architecture consisting of several layers, such as sensing, networking, middleware, and applications[8]. IoT-based smart environment technologies include data sensing and collecting capabilities, communication and connectivity, automation of tasks and services for users, network-based embedded computing and processing capabilities (cloud computing and fog computing), and data security that ensures user privacy[5][9]. In Figure 1, we can see the taxonomy of IoT-based SE, according to IERC vision [10]. To determine each field is an IoT-based SE, there are at least five similarities, including sensors and actuators, semiconductors and electronics, sensors networks, knowledge creation, and future networks. With the development of increasingly sophisticated sensors and microcontroller technology, the convenience provided and the benefits gained by both users and service providers will increase.

Figure 1. Taxonomy of I-T-based Smart Environment.

Researchers' discussion trends in smart cities, smart environments, and the internet of things vary over time. Measurement of these trends can be seen in searches for the last ten years using Google Scholar, IEEE Xplore digital library, and DBLP computer science bibliography search shown in Figure 2.Articles containing 'smart environment' have improved significantly on Google Scholar

1810 (2021) 012007 doi:10.1088/1742-6596/1810/1/012007

searches. However, searching for technical documents on IEEE and DBLP shows that the term 'internet of things' dominates as an area ofresearch. It is because IoT is a global concept that encompasses both terms.

Figure 2. Trends for terms IoT, Smart Environment, and Smart City.

3. Architectures and Frameworks of IoT-based Smart Environment

In designing the software architecture in the IoT-based smart environment, there are three main processes or tasks: Perception, Reasoning, and Acting. Fernandes-Montes *et al.*[11] explained each part of the task well, but if we make a unity, which is a collaboration of the circle as a whole, it can be seen in Figure3. Perception indicates reasoning to the state of the environment obtained by utilizing electronic devices with embedded sensors. The reasoning is accompanied by actions on the actuator until the expected environmental situation is achieved.

Figure 3. Three main tasks in designing IoT-based Smart Environment.

Many research in IoT-based Smart Environments provide architectural advice by involving common technologies in developing integrated software. However, no standard can integrate the functionality and services that can be offered. Some of these technologies are used separately and hybrid, such asService Oriented Architecture (SOA)[12], Architectural Layers (AL)[13], Event-Driven Architecture (EDA)[14], Internet of Things (IoT)[15], Combined Architectures (e.g. IoT-AL, IoT-SoA, IoT-SOA-AL, IoT-EDA, IoT-EDA-SOA, IoT-SOA-AL-EDA) and Internet of Everything (IoE)[16].

The main focus of IoT-based Smart Environment applications lies in sensors and actuators' ability to be integrated into a system that can be adjusted manually or autonomously in conditioning an environment. The applications developed are expected to be contextual and adaptive in three-time phases: design time, configuration time, and execution time. G Lehmannet *al.*[17] proposed an approach that represents three different layers of context information processing (situation model layer, context model layer, and hardware layer). According to M Ma *et al.*[8] and V Jerald *et al.*[4], the layered framework for IoT-based SE generally consists of four layers; they are perception layer, a middleware layer, a network layer, and application layer, as shown in Figure4.

Figure 4. The layered framework for IoT-based Smart Environment.

4. Applications

For home and industrial applications, wireless technology has been used and should work well for different types of environments. Table 1 presents a rough comparison between the different wireless technologies commonly used in various are as within IoT-based Smart Environment applications. IoT-based SE platforms are designed to be meant for particular application-specific domains. As discussed earlier and from Figure1, eight different domains are selected based on which most of the IoT-based Smart Environment platforms are currently evolving into the IT market, as follows:

- 1. **Smart Cities**. There are eight smart features, which are the evolution of smart cities, including Smart Mobility, Smart Economy, Smart Energy, Smart Buildings, Smart Planning, Smart Governance, Smart ICT, and Smart Citizens. There will be 26 smart cities globally, with 50 percent in North America or Europe [18]. IoT on smart city integrates people, processes, and knowledge to enable collective intelligence for smart decision-making and provide real-time awareness [19].
- 2. **Smart Homes**. IoT enables designing a smart home by various tasks like controlling appliances, home security, emergency identification, and other similar applications [20]. Modern homes enable the development of energy-aware smart homes equipped with smart meters, smart

appliances, smart power outlets, and sensing devices. One of smart home research was conducted on a Home Automation System (HAS) project via a Bluetooth connection in [21]. In the implementation of IoT in smart homes, systemized monitoring is required so that the facilities in the smart home can provide comfort and ease of use especially for the elderly[22].

- 3. Smart Grid. The development in the Smart Grid is expected to run a new concept of transmission networks that can efficiently direct the energy produced from distributed and concentrated plants to end-users with high quality and security of supply standards. Smart Grids are used to collect and analyze data obtained from transmission lines, distribution substations, and consumers[23]. Y F Wang *et al.*[24] classified and given examples of IoT-based smart grid applications.
- 4. **Smart Building**. Many corporations measure building platforms that integrate building automation with recreation, aid observation, energy observation, and wireless sensor observation within the home and building environments. There are five issues raised in the Green Smart Building (GSB),namely energy conservation, water conservation, waste management, material & system safety, and environmental safety[25].
- 5. Smart Transportation. Communication between vehicles in the transportation system using IoT will lead to the Intelligent Transportation System (ITS)[26].Smart transportation applications usually need a Moving Objects Database (MOD) to manage many trajectories and real-time GPS stream, as in smart transportation architecture in Parallel Distributed Network-constrained MOD (PD-NMOD) mechanism [27].
- 6. Smart Health.Smart health is a system that can provide health services, especially in urban cities. The smart health system supports smart cities' realization in terms of health insurance, speed of access, and excellent service [28]. By using smart health technology, people will learn more about their health and be educated on how to take better care of their bodies. The architecture of WSN Healthcare, designed by Y. Chen *et al.*[29], consist of four main parts, along with their respective functions, including monitoring project, monitoring healthcare centre, caregiver, and Public Communication Network (PCN).

Wireless Technologies	NFC	RFID	Bluetooth	Wi-Fi	UWB	WiMax	Zigbee	LoRa
Standard	IEEE 802.2	ISO 15693 and 18000-3	IEEE 802.15.1	IEEE 802.11 a/c/b/d/g/n	WiMedia Alliance	IEEE 802.16	IEEE 802.15.4	LoRaWA NR1.0
Operating Frequency	13.56 MHz	13.56 MHz	2.4 GHz	2.4/5 GHz (802.11n)	3.1-10.6 GHz	2 GHz – 66 GHz	868/915 MHz, 2.4 GHz	868/900 MHz
Data Rate	106/212/ 424 Kbps	26 Kbps minimum	3 Mbps (1– 24Mbps)	54 Mbps (1Mbps- 6.75Gbps)	110/480 Mbps	1Mbps-1Gbps (fixed) 50-100Mbps (mobile)	250 Kbps	0.3- 50Kbps
Range	<0.2 m	3 m	8-10 m	50-100 m	3-10 m	<50 Km	10-100 m	<30 Km
Complexity	Low	Low	High	High	Medium	High	Low	High
Power Consumption	Low	Low	Medium	High	Low	Medium	Very Low	Very Low
Modulation Type	ASK, PSK	Tagbacksca (tter (ASK, PSK)	GFSK	BPSK, QPSK, COFDM, CCK, M- QAM	TDMA	QPSK, 16- QAM, 64- QAM	BPSK (+ ASK), O- QPSK	CSS
D:1								

Table 1. Difference between wireless technologies and their applications.

Directional Comm. Two way One way Two way

Wireless Technologies	NFC	RFID	Bluetooth	Wi-Fi	UWB	WiMax	Zigbee	LoRa
Typical Applications	e-Tickets, Credit card payment, Membership card, Electronic identity documents	Tracking items, EZ- Pass, Access management, Toll collection payment, Smart dust	Communicate between phones,Home automation, Short-range transmission health sensor data	Wireless LAN connectivity, wireless internet, IP camera wireless networking	Streaming video, Home entertainmen t application, Short-range indoor applications	Data-centric and voice- centric in mobile applications, Smart grids, and metering	Sensor network, Building/ho me automation, Embedded sensing, Medical data collection	Assets tracking, agriculture processing, Smart parking, Industrial temp

- 7. Smart Industry. Michal Lom *et al.*[30] stated that after the first industrial revolution powered by steam, the second was characterized by mass production. The third was using the electronics and proliferation of IT. We are currently moving to the fourth industrial revolution (Industry 4.0), which is marked by linking sub-components of the production process via IoT. Shrouf*et al.*[31] presented an architecture for an IoT-based smart factory. Smart industry characteristics, such as automation, flexibility, end-to-end customization, energy management, and decision making.
- 8. Smart Energy. Smart energy products can provide energy efficiency in energy consumption both in housing and industry because these products serve digital visualization of energy usage measures to consumers. Smart energy services can be categorized based on superior services [32] such as energy supply & billing services (ES&B), monitoring & guidance (M&G), control & automation (C&A), energy trading (ET), demand response (DR), e-mobility services (EM), energy community services (EC), smart home & smart metering set up and support services (SH&SM), decentralized energy resources set-up & support services (DERS), and integrated energy management (IEM).

5. Discussions

A smart environment makes its "employment" easy and comfortable thanks to contained objects' intelligence, be it a home, a building, transportation, a city, a hospital, or an industrial plant. Sensors and actuators distributed in homes and buildings can provide convenience and comfort in life. The use of electrical appliances such as room heating, room lighting, alarm systems, and several other types can be adjusted to our conditions and desires. Setting conditions such as lighting, temperature, music played, and other conditions can also save energy with the system's ability to turn off electrical devices if it is unwanted or the owner is outside the home. Monitoring and surveillance systems in rooms and certain areas using network-based cameras and connected to the system are important things to pin on smart environmental systems.

There has been a rapid increase in IoT-based SE development in the Wireless Sensor Network (WSN) area in recent decades. WSN implementation in the environment can be categorized into urban areas, agriculture, noise pollution, climatology, natural disaster detection, etc. WSN, which is applied to the environment with an IoT-based monitoring and control system, can be integrated into a smart environment system. WSN implementations in the smart environment include vehicle tracking, detecting forest fires, smart parking, detection and measurement of cracks in buildings, etc. The development of architectures in IoT-based SE will continue to improve, with the ability to make it easier for users to get accurate, trustworthy, and easy to analyze information. In earlier subsections,

easier for users to get accurate, trustworthy, and easy to analyze information. In earlier subsections, some specific domain of IoT-based SE architecture works has been discussed. IoT-based SE trends can be seen from articles detected in Google Scholar, IEEE Xplore, and DBLP search engines.

Although many studies have offered useful architectures in the concept of IoT-based SE, significant development is still needed. Further developments in IoT technologies and applications are still very open with the help of the latest hardware technologies, such as drone technology, holograms, light, sensors, etc. IoT research still has many challenges in the coverage of smart environments in terms of technology, standardization, security, and privacy[3]. Especially security issues in large-scale environmental applications like smart cities, some of the strategies proposed by T K Priyambodo[33] can be used to create an e-government system. Future efforts are needed to overcome these challenges, examine different environmental characteristics, and ensure IoT device compatibility in a human-centered environment. Before IoT data is widely accepted and used in all domains, it requires sufficient understanding of environmental characteristic factors such as cost, security, privacy, and risk.

Technologies such as RFID, NFC, IrDA, Bluetooth, wearable sensors, WIFI, and wireless network technology, can be used to build heterogeneous networks that support the design of IoT-based SE.Some protocols are commonly used in smart environment implementations, such as: 6LowPAN, MQTT,CoAP, SOAP, RESTful,WebSockets, XMPP, and IPv6[34]. Web-based smart environment networks compiled in IoT form utilize database technologies, such as: MySQL, NoSQL, SPARQL, Postgre SQL, Database Graph, Hadoop Parallel Database, HBase, RDF, and OWL-oriented settings. Designing heterogeneous networks with the latest hardware and software technologies is a challenge in IoT-based smart environments in future research.

6. Conclusion

We have presented the trends and architectures in an IoT-based smart environment from many articles related to it. This concept requires convergence in several interdisciplinary technologies. Emerging trends throughout the last ten years related to IoT, smart environment, and the smart city is exciting to observe as the emerging trends of some document search engine will be different with the results of research related to it.Generally, there are three main processes or tasks (perception, reasoning, and acting) in designing the IoT-based smart environment architectures. There are many domains related to IoT-based smart environment platforms, such as smart city, smart home, smart grid, smart building, smart transportation, smart health, and smart industry. Based on those domains, many research and projects discussed in this article demonstrate the breadth of aspects developed in smart environments that use IoT technology. Moreover, an IoT-based smart environment's layered framework generally consists of four layers (perception layer, data conversion layer, network layer, and application layer). Wireless Sensor Network (WSN), which is applied to the environment with an IoT-based smart environment architectures offer further community insight and a reference to current critical thinking in affecting a thriving smart environment.

Acknowledgments

The authors expressed their gratitude to the Directorate General of Higher Education, Ministry of Education and Culture of the Republic of Indonesia, for the research of doctoral dissertation with contract number2085/UN1/DITLIT/DIT-LIT/PT/2020.

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