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The Role of Internet of Things (IoT) in Smart Cities: Technology Roadmap-oriented Approaches

Eunil Park [1], Angel P. del Pobil [2,3,*] and Sang Jib Kwon [4,*]

[1] College of Computing, Hanyang University, Ansan 15588, Korea; pa1324@gmail.com
[2] Department of Computer Science and Engineering, Jaume-I University, 12071 Castellón de la Plana, Spain
[3] Department of Interaction Science, Sungkyunkwan University, Seoul 03063, Korea
[4] Department of Business Administration, Dongguk University, Gyeongju 38066, Korea
* Correspondence: pobil@uji.es (A.P.d.P.); risktaker@dongguk.ac.kr (S.J.K.)

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Abstract: Since the concept of a smart city was introduced, IoT (Internet of Things) has beenconsidered the key infrastructure in a smart city. However, there are currently no detailed explanations of the technical contributions of IoT in terms of the management, development, and improvements of smart cities. Therefore, the current study describes the importance of IoT technologies on the technology roadmap (TRM) of a smart city. Moreover, the survey with about 200 experts was conducted to investigate both the importance and essentiality of detail components of IoT technologies for a smart city. Based on the survey results, the focal points and essential elements for the successful developments of a smart city are presented.

Keywords: internet of things; smart city; technology roadmap

1. Introduction

The term "smart city" refers to new industries utilizing information and communication technologies (ICT) along with the functions and environments of urban areas [1]. In a narrow sense, the term refers to the combination and integration between ICT and urban functions. However, the term smart city can also be described in a wide sense as the convergence of ICT, the ecological environment, energy technologies, and support facilities within urban and residential environments [2,3].

The concept of the smart city has emerged for good reason. First, because the majority of new jobs are being created in urban areas, the expansion of such areas is accelerating [4]. Second, to enrich the educational opportunities for their children, a large number of families in rural regions are moving to urban areas. For example, the population growth rate in urban regions in South Korea has been contributed to by a population outflow from rural areas [5]. With this trend, several significant problems have been occurring. To adopt such an influx of population, the infrastructure and facilities in urban areas should be expanded [6]. Moreover, solutions to respond to various problems such as environmental and transportation issues occurring in urban areas should be prepared [7]. Therefore, the concept of the smart city has been introduced to eliminate these problems. To prepare the basic infrastructure of a smart city, various sensors, support technologies, and background environments are essential and are being employed in urban areas. Among them, the Internet of Things (IoT) is considered one of the most important aspects for the successful implementation of a smart city [8].

IoT is referred to as "*a set of technologies for accessing the data collected by various devices through wireless and wired Internet networks*" [9]. Although there are notable differences in the definitions of IoT, a common explanation is the ability to provide valuable and beneficial information by various user devices through wireless and wired Internet networks.

In 2017, about 1.6 billion IoT components and devices were used in smart cities, an increase of 39% compared to 2015. Moreover, the numbers of IoT components and devices in 2017 and 2018 are expected to show an increase of 42% and 43%, respectively. By 2018, about 3.3 billion IoT components and devices are expected to be utilized in smart cities [10]. The basic concept of a smart city is summarized in Table 1.

Table 1. Fundamental concept of smart city [11].

Components	Descriptions
Policy and purpose	• Environmental sustainability: energy efficiency, environment pollution, and resources • Economic needs: public security, education, medical care and healthcare, and social stability • Well-being of citizens: investment, new job creation, and system innovation
Key industry	• Smart buildings, smart transportation, smart government, smart facilities, and so on
City infrastructure	• Operation systems, sensor networks, smart devices, and sensors • Telecommunication platforms, control systems, data analysis, and interactive web services

As presented in Table 1, IoT is considered key infrastructure in a smart city [11]. However, there are currently no detailed explanations of the technical contributions of IoT in terms of the management, development, and improvements of smart cities. Therefore, the current study describes the importance of IoT technologies on the technology roadmap (TRM) of a smart city. The remainder of the paper is organized as follows: Section 2 provides an overview of different IoT technologies. Section 3 presents the applied study method and results. Finally, Section 4 summarizes the findings and implications of the current study.

2. Literature Review

IoT in Smart Cities

Since the emergence of various types of networks, IoT has become one of the most important types of infrastructure in smart cities. For instance, to provide user-customized services, the data collected by electronic home appliances, including refrigerators, are shared and stored in a smart home environment [11,12].

Similar to the concept of a smart home environment, the smart city is an emerging market and an important part of future infrastructure. Because a smart city aims to utilize energy and electricity in an efficient manner, thereby providing a convenient and economically sound infrastructure for the well-being of society, the importance of IoT technologies is magnified. Therefore, after establishing the general infrastructure of a smart city, various services that need to employ and utilize diverse types of data collected in daily life can be provided. This means that various services utilizing IoT technologies in a smart city can bring about a sustainable and pleasant living environment for its citizens.

Therefore, to establish a sustainable urban environment, some notable industries are in collaboration and are considering the technological and social issues inherent to the future concepts implemented in a smart city. Table 2 summarizes the principal issues and agents for IoT technologies in a smart city. Moreover, prior studies summarized the key technical aspects of smart city technologies, and based on this summary, IoT technologies can be considered a necessary requirement [13].

3. Study Method

3.1. Data

This study employed technology roadmaps for a smart city environment, which were investigated and proposed by a consortium of the South Korean government, two research firms for patent analysis, and government-funded research institutes with a number of professors working in smart city-related fields. Tables 3–5 show a summary of the technology roadmaps for a smart city.

Table 2. Sectors, principal issues, and agents for IoT technologies in a smart city.

Sectors and Industries	Key Services	Principal Agents and Operators	Core Issues for IoT Technologies
Energy and electricity	Automation of transmission and distribution	Companies providing automatic electricity services, and combined Internet and smart grid services	• Various communication standards • Essential part of smart grid systems • One of the biggest potential markets in IoT technologies
	Optimization, management, and reduction of accommodated energy	Companies providing electricity grid services and utility grid	
Architecture and building	Building management	Companies providing telecommunication services and construction	• Different building preferences: Construction company with existing building (IoT technologies with wireless infrastructure), IT solution or telecommunication service providers with newly built building (IoT technologies with wired infrastructure)
	Building automation	Companies providing telecommunication and office management	
	Home automation	Companies providing telecommunication services and construction	
Automation and transportation	Remote parking management	Companies providing parking control facilities, Internet and Intranet services	• Rapidly increased demand of autonomous or remote control services: utilizing wireless IoT sensing technologies or devices
	Business fleet management	Companies providing telecommunication, system integration, and Internet services	• Generalization of management systems using IoT technologies for transportation vehicles
	Vehicle telematics	Companies providing telecommunication and vehicle component manufacturing	• Utilizing individual mobile devices and distributing connected automobiles with IoT technologies
Security	Home security	Companies providing telecommunication and security services	• Utilizing various IoT technologies and devices that support video and voice telecommunication models
	Protection of children and elderly	Companies providing telecommunication and social safety net services	
Healthcare and monitoring	Smart healthcare	Companies providing telecommunication, system integration, and healthcare services	• Rapidly expanded markets using healthcare IoT technologies in advanced countries
	Smart hospital	Companies providing telecommunication, system integration, and hospital services	• Necessity in tracking medical teams and facilities located in hospitals • Requiring healthcare-IT convergence services based on electronic medical records and order communication systems

Table 3. Summary of technology roadmaps (TRMs) for smart city (Classifications A and B).

Classification	Core Product Category	Core Technologies (Examples)	Description
A. Smart home platform	A.1. Smart home control platform	A.1.1. Energy load management technology [14,15]	• Energy usage monitoring, energy supply, load control, and optimization technology for a smart home environment
		A.1.2. Smart home cloud server technology [16,17]	• Background server technology integrating smart home environment and cloud computing services
	A.2. Smart home user interaction platform	A.2.1. User natural language recognition technology [18,19]	• Technology for providing words or sentences by recognizing speech and images
		A.2.2. User interface technology [20,21]	• User interface technology for supporting communication among objects, systems, machines, and humans
		A.2.3. User emotion recognition technology [22]	• Biometric information recognizing technology
	A.3. Home context awareness framework	A.3.1. Context awareness technology [23,24]	• Technology for providing appropriate services by recognizing the current situation based on the collected data of sensors, machines, and user interaction in a smart home environment
		A.3.2. User-customized service operation technology [25]	• Technology for providing appropriate services based on user preferences and demographic information
	A.4. Open architecture home service framework	A.4.1. Compatible technology for controlling devices in smart home environment [26]	• Technology for a particular service in a single platform on multiple devices
		A.4.2. Smart home service framework [17,27]	• Technology for providing appropriate services based on user preferences and demographic information • Technology for accepting and supporting solutions of other service providers
B. Wired and wireless home network interworking technology	B.1. Home network connection components	B.1.1. Wired and wireless connection gateway technology [28,29]	• Home gateway technology for providing interface services between various network environments (Ethernet, WiFi, 3G/LTE, Zigbee, and so on) and smart home cloud server
		B.1.2. Home network device technology for various service domains [30]	• Smart home device technology for providing various services (automation, security, safety, energy, healthcare, and so on) through smart home gateway interface
	B.2. Home network service cloud technology	B.2.1. Connection supporting technology between gateway and cloud [31]	• Interworking technology between smart home gateway (REST-oriented) and cloud servers for smart home services through cloud servers
		B.2.2. Home network service cloud server construction [32,33]	• Construction technology of cloud server and database for smart home services with enhanced security
	B.3. Market vitalization technology	B.3.1. Development of home network service DIY tools [34,35]	• DIY tool-technology for various scenario-oriented services utilizing home network resources through smart home cloud servers
		B.3.2. Development of home network device SDK based on multiple sensors for universal services [36,37]	• Home network device technology for supporting multiple sensors and services through an integrated single platform

Table 4. Summary of TRMs for smart city (Classifications C and D).

Classification	Core Product Category	Core Technologies	Description
C. Intelligent information home appliances	C.1. Home appliance-security technology	C.1.1. Digital trespassing recognition technology [38]	• Technology for packet filtering of potential invalidated users for internal home network and firewalls
		C.1.2. Compatible security service technology for multiple devices [39]	• Technology for security services on the crowding of devices
	C.2. Smart care appliance technology	C.2.1. Customized user interface technology [40]	• Technology for information exchange between users and objects with various forms such as screen touch and speech or gesture recognition
		C.2.2. Technology for unconsciousness information collection of users [41]	• Technology for determining life patterns of user based on the investigation and collection of various types of sensing information
		C.2.3. Emotion recognition technology [42]	• Technology for recognizing user emotions based on biometric data such as voice, facial expressions, EEG, EMG, skin electrical resistance, or behavior
	C.3. Home sensor-network technology	C.3.1. Wireless sensing technology for home environment [17,43]	• Sensing technology and measurement device for monitoring home environment using wireless networks (WiFi, cellular, or Bluetooth)
		C.3.2. Technology for providing services based on the collaboration of devices [44]	• Technology for supporting the collaboration of devices providing diverse services using device functions
D. Home sensor technology	D.1. Sensor communication technology	D.1.1. Sensor communication technology for wireless network [45]	• Wired and wireless interworking and pairing technology among servers and sensors
		D.1.2. Complementary sensor management technology [46]	• Technology for providing user-customized services and recognizing context awareness
	D.2. Element development technology for commercialization	D.2.1. Implementation technology for the functions of low-power sensors [47]	• Optimization technology for reducing power consumption of sensors
		D.2.2. Technology for SoC sensor control-module [48]	• Technology for controlling and operating sensors using SoC
	D.3. Sensor fusion and converging technology	D.3.1. Optimized sensor design technology [49]	• Sensor technology for collecting environment and personal information
		D.3.2. Technology for designing and manufacturing multi-functional sensors [50]	• Technology for converging more than two sensor functions

Table 5. Summary of technology roadmaps for smart city (Classification E and F).

Classification	Core Product Category	Core Technologies	Description
E. Security technology for smart home and building	E.1. Intelligent IP imaging devices	E.1.1. Object detection technology [51]	• Technology for recognizing the transformation of an object
		E.1.2. Intelligent human recognition technology [52]	• Technology for detecting and recognizing users and objects through image analysis algorithms and deep-learning process
		E.1.3. Intelligent human tracing technology [53]	• Technology for tracing the subject of users
	E.2. Analytical technology	E.2.1. Movement detection and sensing technology [54]	• Analyzing technology for risk prevention by categorizing natural and unnatural situations based on metadata and object data records
	E.3. Information security technology using IoT	E.3.1. Technology for information security and multimedia management [55,56]	• Technology for managing information by avoiding false operations of IoT actuators based on data pattern analysis
F. Smart building automation and system	F.1. Smart building automation technology	F.1.1. Development and scenarios for automated services [57]	• Smart building automation device and service based on service scenarios of user needs
		F.1.2. Cloud-based control and management technology [58]	• Control and remote management solution technology for smart buildings and cloud servers
	F.2. Smart building energy management technology	F.2.1. Smart building energy monitoring technology [59]	• Complex energy monitoring solution technology of the inflow, consumption and generation of various energy resources utilized in smart building
		F.2.2. Technology for predicting energy consumption and efficiency of smart building [15,17]	• Technology for predicting energy consumption and efficiency based on smart building profiles
		F.2.3. BIM-based smart building energy management and analytical technology [60]	• Analytical and visualization technology for real-time monitoring, control, and management based on BIM
	F.3. Smart building optimization technology for control and management	F.3.1. Cloud-based smart building optimization control and energy management technology [61]	• Technology for energy optimization of smart buildings based on cloud servers and solutions
		F.3.2. Analytical technology based on big data collected on cloud server [62]	• Various analytical and visualization technologies for the performance, prediction, modeling, and improvement of smart building based on big data

3.2. Procedure

A total of 198 professors and experts who responded that they have outstanding knowledge and insight into IoT technologies took part in the survey. Based on the extracted core technologies presented in Table 3, they were required to answer the following questions.

- (1. Importance): How do you rate the importance and significance of IoT in successfully developing this core technology (0–100 points)?
- (2. Essentiality): Is IoT essential and indispensable for this core technology (7 Point-Likert scale: 1, Extremely unnecessary; 4, Neutral; 7, Strongly necessary)?

3.3. Results

Table 6 and Figures 1 and 2 show a summary of the main survey results.

Table 6. Summary of evaluations of importance and essentiality of IoT technologies.

Core Technologies	1. Importance (Mean (Standard Deviation))	2. Essentiality (Mean (Standard Deviation))
A.1.1. Energy load management technology	73.10 (12.21)	5.44 (1.21)
A.1.2. Smart home cloud server technology	77.31 (14.92)	5.29 (1.19)
A.2.1. Recognition technology of user's natural language	17.43 (17.01)	4.15 (1.01)
A.2.2. User interface technology	25.13 (13.82)	4.22 (1.09)
A.2.3. User emotion recognition technology	23.08 (13.74)	4.01 (0.98)
A.3.1. Context awareness technology	28.55 (16.21)	3.11 (1.11)
A.3.2. User-customized service operation technology	22.25 (12.19)	2.98 (1.29)
A.4.1. Compatible technology for controlling devices in smart home environment	24.51 (15.09)	3.11 (0.95)
A.4.2. Smart home service framework	19.48 (11.49)	3.25 (0.99)
B.1.1. Wires and wireless connection gateway technology	30.34 (19.41)	2.81 (0.94)
B.1.2. Home network device technology for various service domains	51.02 (29.93)	2.79 (1.02)
B.2.1. Connection supporting technology between gateway and cloud	72.29 (14.78)	4.29 (1.02)
B.2.2. Home network service cloud server construction	76.28 (19.74)	4.31 (0.98)
B.3.1. Development of home network service DIY tools	27.35 (12.22)	2.74 (1.02)
B.3.2. Development of home network device SDK based on multiple sensors for universal services	27.08 (12.20)	2.51 (0.91)
C.1.1. Digital trespassing recognition technology	18.08 (16.45)	2.54 (0.91)
C.1.2. Compatible security service technology for multiple devices	42.17 (15.86)	2.41 (1.23)
C.2.1. Customized UI technology	48.91 (13.86)	2.49 (0.95)
C.2.2. Technology for unconsciousness information collection of users	39.24 (11.40)	2.65 (1.01)
C.2.3. Emotion recognition technology	28.75 (9.45)	2.99 (0.91)
C.3.1. Wireless sensing technology for home environment	82.60 (10.41)	5.15 (0.91)
C.3.2. Technology for providing services based on the collaboration of devices	72.20 (12.24)	5.21 (0.99)
D.1.1. Sensor communication technology for wireless network	86.74 (7.83)	5.12 (0.91)
D.1.2. Complementary sensor management technology	75.62 (13.80)	5.04 (0.95)
D.2.1. Implementation technology for the functions of low-power sensors	27.13 (12.99)	3.91 (1.04)
D.2.2. Technology for SoC sensor control-module	20.62 (12.48)	3.33 (0.91)
D.3.1. Optimized sensor design technology	79.54 (12.37)	4.98 (0.85)
D.3.2. Technology for designing and manufacturing multi-functional sensors	81.98 (10.72)	4.81 (1.20)
E.1.1. Object detection technology	78.07 (12.06)	5.11 (0.97)
E.1.2. Intelligent human recognition technology	61.15 (17.03)	5.05 (1.01)
E.1.3. Intelligent human tracing technology	64.93 (11.81)	4.96 (1.22)
E.2.1. Movement detection and sensing technology	50.46 (12.33)	5.22 (0.99)
E.3.1. Technology for information security and multimedia management	45.13 (16.22)	5.31 (0.98)
F.1.1. Development and scenarios for automated services	34.11 (13.22)	3.91 (1.11)
F.1.2. Cloud-based control and management technology	23.59 (12.60)	3.96 (0.97)
F.2.1. Smart building energy monitoring technology	66.75 (11.29)	4.98 (1.23)
F.2.2. Technology for predicting energy consumption and efficiency of smart building	30.18 (14.29)	5.02 (0.99)
F.2.3. BIM-based smart building energy management and analytical technology	68.66 (11.82)	5.13 (1.22)
F.3.1. Cloud-based smart building optimization control and energy management technology	69.45 (19.88)	2.32 (0.94)
F.3.2. Analytical technology based on big data collected on cloud server	20.44 (9.44)	2.96 (1.13)

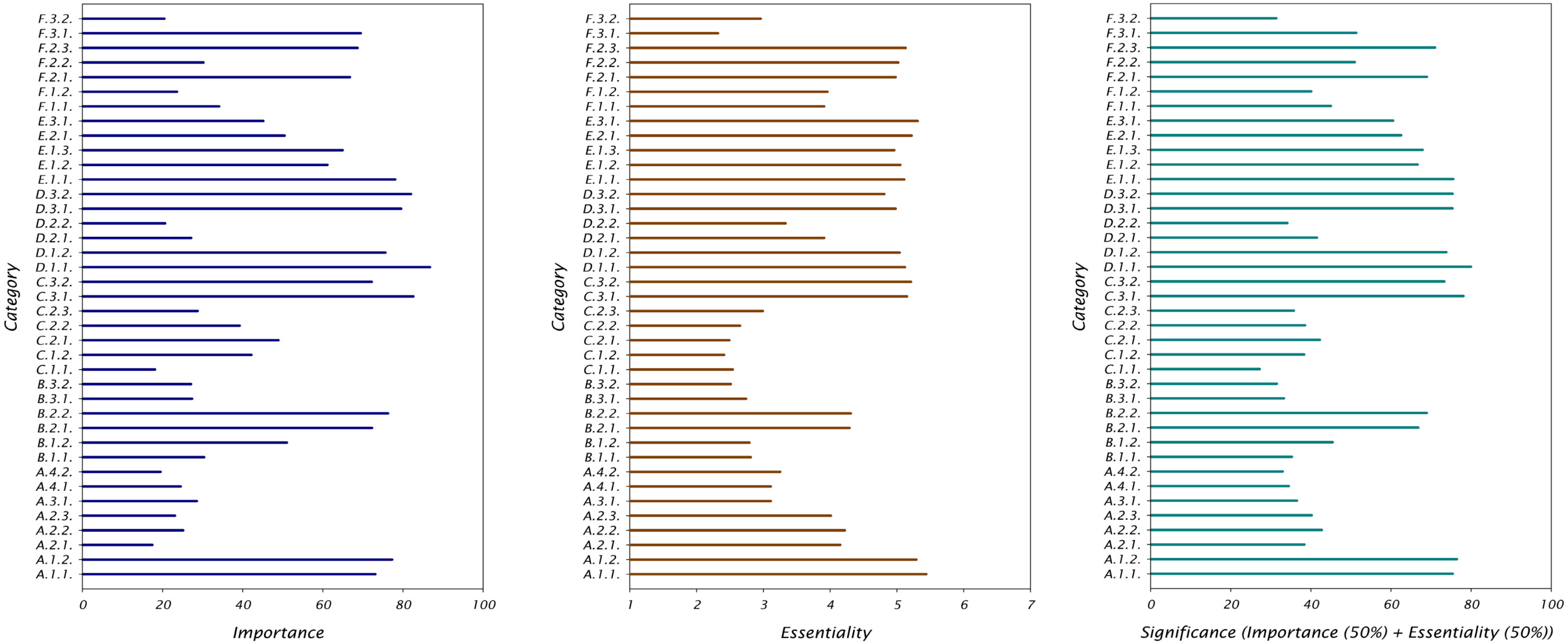

Figure 1. Summary of the survey results (items).

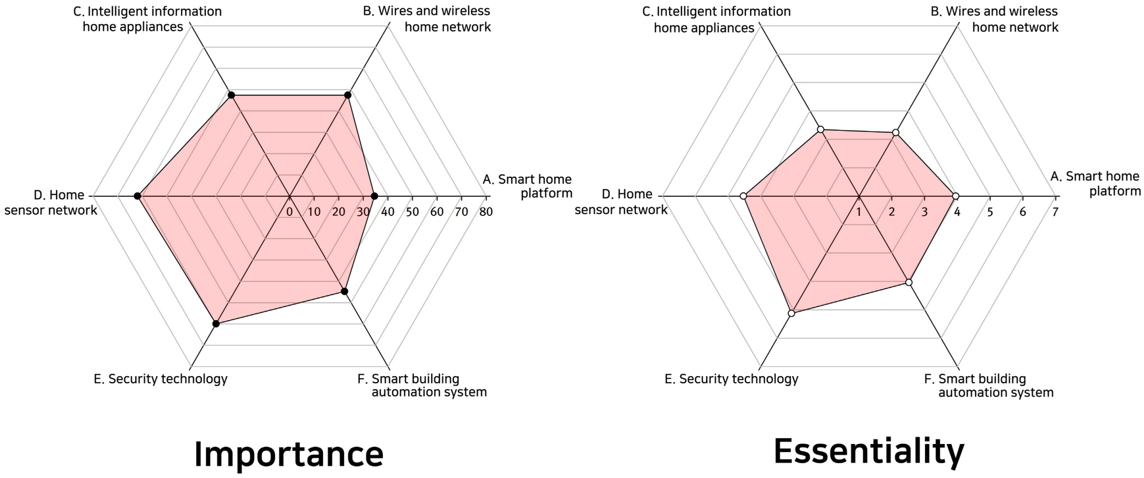

Figure 2. Summary of the survey results (category).

4. Future Directions of IoT Technologies in Smart Cities

As shown in Table 4, IoT technologies contribute significantly to the majority of the detailed aspects of smart city technologies and infrastructure. Because the fundamental concepts and ideas of IoT technologies are shared with those of smart city technologies and infrastructure, a large number of business opportunities and extensive growth potential exist. Moreover, for the efficient and successful development of future IoT technologies in smart cities, the following points require focus.

- Importance and essentiality: Sensor-oriented technologies for wireless networking are considered the top priority of IoT technologies for a smart city infrastructure (D.1.1. Sensor communication technology for wireless network; C.3.1. Wireless sensing technology for environment; D.3.2. Technology for designing and manufacturing multi-functional sensors; D.3.1. Optimized sensor design technology)
- Importance: In addition to sensor-oriented technologies, technologies for network services are considered the most important IoT technologies for a smart city infrastructure (A.1.2. Smart home cloud server technology; B.2.2. Home network service cloud server construction)
- Essentiality: Compared to other technologies, energy-related technologies are considered the most essential IoT technologies for the smart city infrastructure (A.1.1. Energy load management technology, F.2.3. BIM-based smart building energy management and analytical technology). Because the technologies applied in a smart home environment are fundamental aspects of a smart city, the technologies and infrastructure for a smart home network should be swiftly developed and prepared (A.1.2. Smart home cloud server technology).

In addition to these points, there are some challenging aspects that should also be resolved. First, because IoT technologies should provide various operating systems, which includes low- to high-capacity processors, providing appropriately distributed resources is one of the most important tasks required in devices employing IoT technologies. Moreover, because the inclusion of more devices with IoT technologies in a smart city infrastructure leads to a significant number of additional computations and data transmissions, the technologies for intelligently optimizing, scheduling, and controlling such devices are essential.

Second, data management solutions are required for the massive amounts of data collected by various IoT technology devices because the majority of such data is unstructured or atypical. This means that technologies for data categorization and intelligent analysis should be developed and introduced.

Third, the current IoT technology services are provided through independent specialized solutions, which are oriented and operated within a specific environment. Therefore, compatible integrated applications for providing various IoT technology services should be developed and prepared by using appropriate network technologies.

Fourth, both appropriate solutions and plans for data security and privacy should be established. When users connect to an IoT technology service, reliable data processing and storage should be applied with confidentiality, integrity, and privacy. This means that reliable and safe communications and connections from each IoT technology device to the smart city infrastructure should be provided.

5. Conclusions

To realize the concept of a smart city, IoT technologies are one of the most essential elements in carrying forward detailed plans of a smart city. Regarding the various aspects of IoT technologies, the following points should be addressed.

Comprehensive demonstration sites for the testing of IoT technologies within a smart city infrastructure should be established. It is necessary to carry out government-led demonstrations of complex sites for promoting the smart city industry and markets. This will allow the participants within a smart city infrastructure to evaluate and verify the efficiency, economic feasibility, and influencing effects of developing IoT technologies and suggested services. Moreover, related technologies in the ICT industry for promoting IoT technologies should be investigated and developed in parallel.

In addition, to retain the sustainability of an urban environment with an ecosystem, a data-oriented smart city infrastructure should be developed and established. For example, globally advanced cities including Barcelona and London have opened to the public various types of data on their urban environments through verified online services. Such open data are employed to create new business models for startup companies utilizing IoT technologies in smart cities and to allow citizens to solve the current urban problems.

Based on the results of the current study, it is meaningful to present both necessary and priority issues regarding the aspects of IoT technologies for the successful establishment of a smart city infrastructure and its related services.

Although the current study evaluated the importance of IoT technologies with regard to the concept of a smart city, in-depth discussions and debates among experts and engineers in fields related to smart cities and IoT technologies should be continuously conducted for the provisioning of specific plans of action. Moreover, extensive professional panels of experts in diverse research fields including urban development, information and communication technologies, transportation, and environmental policies should be organized.

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