Roles and Challenges of Network Sensors in Smart Cities

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Abstract. The study in this paper is in response to an increasingly technological and connected world. Scientific discoveries, engineering achievements, and social dynamics have led to the evolution of human societies. In the last two decades, ways in which people interact and live have changed, mainly because of the new technologies. In this paper, we explore the roles and challenges of network sensors as elements of a smart city and propose solutions and implications to address the challenges.

1. Introduction
Technological advancements in computing and telecommunication have drastically transformed the world. In particular, the growth of Internet of Things and cloud computing have been used to enhance the quality of services in cities [31]. Information technology has become an indispensable instrument for both private and public stakeholders due to the rise in microprocessors, online technologies, and powerful data networks. To exemplify, the growing importance of economic and social aspects of cities in strategic plans has led to the exploitation of emerging technologies [2]. The integration of information, communication, and advanced sensors to manage city assets leads to the concept of smart cities. In particular, the sensor networks play a significant role in the collection of important information regarding the urban environment [7]. Through a combination of camera computers, and a data network, it is possible to transmit real-time information, which almost appears as an extension of the ability to see.

The rise in population is the major contributing factor towards the need of smarter infrastructures. Smart Cities improve sustainability and efficiency of various urban dynamics such as health, water, land, and energy [17]. From a closer examination, application of smart technology is effective when applied within urban zones and then extended to other areas, before forming a continental and even global network. The concept of the Internet of Things (IoT), has become central to the conceptualisation and implementation of Smart Cities due to the required connectivity between the sensor nodes [6]. Although a contested term, a Smart City refers to a proper use of resources through the application of real-time technologies that automate some tasks [1]. In fact, sensor technologies are essential for cities because they present a quintessential and operational feasible environment. Therefore, owing to the indisputability of the power of sensor technologies, it is necessary to explore ways in which urban authorities can implement these innovations in developing smart cities.
2. Motivation
In this paper we aim to investigate and identify the roles and challenges of network sensors (referred to as smart sensors in this work) in smart cities, using an exploratory approach based on literature review. The study also aims to propose solutions and future tasks to address the challenges.

3. Literature Review and Analysis

3.1 Overview
The rise of smart device and sensors as emergent technologies have revolutionised public service in cities [23]. In particular, governments around the world have undertaken digitalisation programs, a foundation of smart cities. Digitalisation entails the development of policy and infrastructural framework aimed at supporting the smart city applications [18]. However, some scholars have noted that municipalities must eliminate accessibility challenges that arise due to limited infrastructure to attain a smart city [21]. It is only when the citizens can access gadgets that it is possible to construct a virtual network of smart devices and sensors. In this regard, an evaluation of the behavioural aspect in the adoption of IoT technologies explains the technological gaps that exist across the world [3]. It is crucial to improve consumer trust to increase the use of IoT technologies in Smart Cities. The capacity of smart technologies to exponentially improve quality in public service extends to principles of welfare state. Smart cities are, in essence, advanced forms of welfare states.

3.2 Smart Network Accessibility and Application
Many cities, especially in the Global North, continue to exploit advantages of sensor technologies in realising smart cities. The increasing complexity of integrating citizen participation, IoT, and the varied domains of smart city applications requires an understanding of generated data to realize efficient city planning [29]. To exemplify, smart city planning, infrastructure management, and citizen participation have different requirements based on the data sources. As a result, each application takes a distinct approach in the development of its smart network. For instance, the smart city concept has been developed to address the issue of security among its users. The development of an Internet of People from IoT is a crucial smart network required for the development of Smart Cities [11]. Crowd sensing requires an internet of people to provide security to Smart Cities. In particular, crowd sensing is used to detect and control individuals in a crowds or busy roads. The crowd sensing system is a smart network that requires trustworthy crowd sensed data which can be achieved through the use of auction based approaches [27]. Non-technical concepts required to facilitate availability of crowd sensing data entail the reward of users. By a different token, the application of smart networks is accompanied with a major concern linked to the privacy of citizens in the smart city [8]. Privacy is a crucial part of security whose violation poses a major threat in the development of efficient smart cities.

3.3 Other Applications
Other than security, the concept of smart cities has been used to timely manage and optimize municipal resources. As a result, the infrastructural and social needs of citizens are met [9]. Smart sensors are utilized in traffic control, lighting, pollution control, garbage collection, health, air quality, and food and water tracking [20]. These are some of the fundamental requirements for an operational city. In traditional systems, these utilities are operated through schedules. However, in smart cities, there are sensors in place that detect in the change in environmental conditions. The significance of sensor technologies, as elements of smart cities, is that they not only extend human sensibilities but also make cities habitable. Service innovation in smart cities is realized through resource liquefaction, density, and integration [19]. Even so, the gap which this study aims to explore, is the application of sensor technologies in further refining the ethical demands, capabilities of the smart sensor technologies, and service delivery structure within smart cities. Figure 1 gives a snapshot of key areas of social application for smart sensors.
4. Types of Network Sensors and Their Roles in Smart Cities

Needless to say, a smart city is infeasible without the deployment of sensors. In the smart city, a sensor is used to measure the physical properties of any object, or situation. The main sensors used include the biosensors, electronic sensors, chemical sensors, and smart grid sensors. The types and roles of these sensors are explored in the following subsections.

4.1 Electronic Sensors

The main function of electronic sensors is to detect different energy forms through the use of electroscope, magnetic anomalies and voltage detectors among others. Examples of electronic sensors include the environmental surveillance sensors, parking sensors, and speedometer sensors among others. The wireless feature of the sensors results in limitations such as high energy consumption, low flexibility, and high complexity [32]. Monitoring power and current levels ensures faults are timely detected; as a result, the efficiency of electronic signals transmission is guaranteed. Additionally, the infrared sensors are used in technological advancements aimed at generating unbiased data crucial in rapid decision making procedures in unfriendly environments. Contrary, the radar sensors utilize complex computer data to perform its functionalities. The smart sensor has the ability to learn and interpret videos from numerous sensors, such as security street cameras and mobile phones. Its high level accuracy in generation and transmission of data obtained from actions such as gesture motions results in its provision of smart services in human-computer interactions [12]. In a smart city, the sensors in conjunction with neural networks is used to develop and analyse data from speech recognition, video, image, and natural language processing. The analysed data is used to make important decisions and monitor environments to guarantee citizens of security [10].

4.2 Chemical Sensors

The chemical sensor currently includes sensors such as carbon dioxide sensors, oxygen sensors, electronic nose and catalytic bead sensors among others. When dealing with chemicals, they are very sufficient in identifying all problems that may be linked to chemicals. That is; they are beneficial in detecting chemical reactions and the physical properties of a system or environment. Chemical sensors have been used to generate and transmit important information regarding the practicability of electronic noses in the diagnosis of allergies in patients [28]. The main chemical sensor alternative is the environmental monitoring sensor whose usability is not limited. The sensor can detect oxygen, or carbon monoxide among other components in an environment or substance effectively.

4.3 Biosensors
The current function of the biosensors is detecting the anolytes in biomedicine. The current biosensors include the sensors used for ionising and subatomic sensors such as neutron and MEMS sensors among many other biosensor devices. The limitation of the biosensors is that they are only able to work in the biomedicine’s field.

The biosensors can only operate through signal transduction. For instance, odorant binding proteins are used in biosensors to provide highly sensitive information where the signals are detected by an electronic system [26]. The use of optical techniques in biosensor is advantageous due to factors such as high level accuracy and timely results. These merits describe the generative, transmissive, and distributive roles of biosensors. On a different note, the electrochemical biosensor applies the basics of the electric and chemical sensors in its processes of anomalies detection. The electrochemical sensor uses the electrical properties of various ions and chemical properties to show the concentration of the anolyte. As a result, it could be effective in measuring non-polar molecules [30][25].

4.4 Smart Grid Sensors

The smart grid technologies are categorized into five important segments with regards to their role, the sensors, advanced components, communication, decision support systems, and other highly improved components [16]. Different sensors are utilized in smart grids to ensure efficient generation, transmission and distribution of power from the generating source to the end users.

The use of thermal sensors with respect to weather conditions plays a crucial role in accurate tracking of the transmission and distribution of energy [13]. In this regard, the smart personal sensors ensure power efficiency through management of the demand-side energy. By a different token, the wireless sensor networks give instantaneous information regarding the power transmission lines as a measure of improving energy efficiency [14]. Smart power meters are additional sensors used to monitor the transmission of power in the smart grids. An analysis of the monitored power metrics is based on IEEE standard 1459-2010 and facilitates real-time decision making processes [22]. The decisions are aimed at eliminating instances characterized by the delivery of low quality and interrupted energy to end users.

5. Challenges and Solutions of Network Sensors in Smart Cities

The social and economic impacts of digital migration are indisputable. It is, as such, necessary to identify some of the key challenges in the application of network sensors as integral components of smart cities. Due to the space constraint, we explore only seven challenges as follows.

5.1 Safety and Security Management

Although emergency services have drastically improved, cities continue to lose lives due to delays in report and response time. Therefore, it is important to not only focus on crime and risk prevention but also mitigation strategies. The police or the firefighters are sometimes informed of accidents or crimes only after occurrences. This delay can be eliminated by installing gunshot, accident and noise sensors around the city. Also, connecting smoke sensors to a central repository, which is based on an artificial intelligence system, can facilitate timely response by police, ambulance and firefighters.

The main challenge likely to be encountered in security management lies in the availability of voice telecommunication IoT supported device [24]. The telecommunication model is crucial in realizing the role of noise sensors. By a different token, the privacy and security of transmitted data in an IoT network is crucial in the development of a smart city. As a result, the use of Integrated Radio Frequency Identification sensors adequately addresses security issues in a cellular IoT system [15]. The utilization of a cellular network for the IoT devices addresses scalability and reliability risks.

5.2 Service Delivery and Optimisation

City authorities have faced challenges in provision of lighting and plumbing services to huge populations. Some cities depend on manual and rudimentary monitoring systems, an approach that is prone to error, and which can impede management optimisation. An integrated system in a smart city facilitated by the deployment of a higher number of sensor nodes than the population of the city has
the potential of streamlining service delivery [5]. When data from these sensors are consolidated, they can nourish daily operations and administration of smart cities. However, the presence of challenges such as scalability and energy limitation hinder the effective use of wireless network sensors in service delivery. The functionalities of the node radio facilitated by MAC protocols are the major cause of energy limitations. In this regard, the introduction of MAC protocols of different kinds dependent on the nature of the network’s structure prolongs the life of wireless sensor networks [4]. As a result, the efficiency of the different sensors, such as maintenance and wastage sensors, is improved.

5.3 Traffic Control and Parking
Cities lose millions of dollars because of traffic congestion. Owing to temporary immobility, quality time and fuel are lost on roads. Besides, these congestions diminish the quality of life within cities. Moreover, it is evident that the cause of the congestion is the difficulty in finding parking spaces. Additionally, transport management is crucial in an era of electric cars; as a result, the adoption of smart metering tools is efficient in addressing the challenge [29]. The facilities save on cost for all involved parties in the transport sector. Moreover, smart cities can use the potential of Global Positioning System (GPS) to direct traffic. The city can place a requirement for vehicles within the particular territory to have location smart sensors. Firstly, the sensors can process basic information on parking space – and which must be reserved – and use this information to ease congestion on particular streets. As such, by using smart network sensors, it is possible to solve parking problems, and, hence, mitigate traffic congestion.

5.4 Smart Building
In the traditional systems, management of building is delegated to individual property managers. Not only is the cost of hiring and maintaining property managers high, but also efficiency of operation can be inconsistent. For example, it can take several days to report and react to a maintenance requirement by tenants. Also, the traditional systems demand the constant presence of a guard to monitor entry and exit of a building, and, therefore, enhance security. With smart buildings, it is possible to eliminate challenges posed by traditional systems. Smart cities can exploit the advantages presented by automation, and which is central to smart buildings. The automation in smart buildings can include an integrated system that is accessible through a decentralized system. From this system, it is possible to monitor the lighting, heating, security, and service systems. Here, service systems refer to repetitive operations of garbage collection and janitorial duties. Also, the security and surveillance sub-system can be integrated to the city’s security system.

The major issue in the integration of smart building systems into the city’s system is in the difference of IT infrastructure adopted by the buildings [24]. This issue arises from the initial stages of construction due to varied preferences. In this regard, a standard should be set for each city to govern the type of IoT infrastructure to be adopted.

5.5 Public Transport
Most public transport systems function by constantly stopping at bus stops. However, regular stops can lead to time wastage, as there might be no commuters. Also, there is the problem of time wasted as buses manoeuvre through locations that are out of the designated route, and also fail to find potential commuters. Therefore, it is possible to avoid these inconsistencies by developing a system that has terminals connected to both the bus stations and bus dashboards. This system can assist drivers in harvesting data that can be used in ensuring efficiency. Implementing this solution requires the development of an information system that is connected to remote terminals in smart cities. GPS can be indispensable in tracing the movement of the buses. Both the terminals are attached to input systems, and which are, in turn, sources of data for a public transport management system. It is the management system that functions as the decision support system, and which gives recommendation on whether it is advisable or not stop at every bus station.
However, the major challenge likely to be faced is on the generalization of the management systems [24]. The challenge limits the feasibility of the solution but can be addressed through strict adherence to policies regarding the established connections between the specific bus terminals and bus location.

5.6 Environment

Smart sensors have a potential to increase the environmental degradation. However, through the improvement and efficiency of energy generation and consumption, it is possible to address the climate change challenges faced by smart cities. The major challenge is in the control of the widely deployed sensors to obtain reliable information.

5.7 Ethical Implications

The major ethical issues that arise in the implementation of smart cities include privacy and security. Lack of security leads to intimidation and fraudulent acts among others. Figure 2 demonstrates the sources of ethical implications of smart networks and smart cities. All the stakeholders, including the government and policy makers play a crucial role in dealing with the ethical issues.

6. Implications of Smart Sensor Roles

Based on the results from the exploratory research conducted above, the following implications of smart sensor roles are proposed.

Firstly, there is a need to improve safety and security through elimination of incident reporting and response delays. Additionally, the connection of smoke and noise sensors with the help of IoT will address the safety and security issue.

Secondly, the sensors can be applied in improving service delivery, through consolidating data from waste and maintenance sensors.

Thirdly, the sensors can be used in directing traffic; as a result, eliminate congestions and manage parking areas.

Fourthly, smart networks can be useful in the development of smart buildings. These are buildings with automated systems that manage the utility and general services.

Fifthly, we explore the implication of smart city on environment and public transport.

Sixthly, we intend to explore the overarching ethical issues around smart sensors, including privacy and regulatory framework. Recommendations on these issues constantly emerge and will guide the implementation process.
Lastly, we intend to accomplish the objective on implementing strategies by highlighting methods of solving problems with the use of network sensors in smart cities.

7. Conclusion and Future Work

In this paper, we explore the roles of smart sensors within smart cities. Our study focuses on the benefits of smart sensors for cities, and also investigates the threats posed by these advancements. The roles are beneficial to both the public and private citizens. In households and businesses, smart sensors aid in control of resources and communication of information. In contrast, smart sensors are important within the public sector owing to their capacity to improve the service delivery method. Municipalities and cities can tap into the benefits of smart technologies, and which include optimization of services, such as parking, monitoring cultural sites, lighting, maintenance, and surveillance. In particular, sensor technologies can be used to detect gunshots, and which can trigger a timely response by law enforcement officers.

In exploring these factors, our study will adopt in the future a mixed research method – a combination of both qualitative and quantitative methods.

8. References

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