Investigating Emerging Technologies Role in Smart Cities' Solutions

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Abstract. A smart city is defined as a one that provides solutions to rapid urbanization, exploding population, scarce resources, congested traffic, and energy management through the effective and integrated use of information and communication technology. The conceptualization, integration, and implementation of smart cities have been recognized and seen as a means to optimize the limited resources and improve the quality of human lives. The smart cities planning, designing, and development have been affected due to big data storage, big data governance, Internet of Things (IoT), and artificial intelligence (AI) techniques. The smart cities' solutions cover different themes of varying importance such as smart health, smart education, intelligent transportation, smart energy, smart governance, etc. The emerging technologies are the one which are presently under development or might be developed in the future, and which can have a wide impact on research, business, and social lives. The emerging technologies are the groups of technologies that have been partially explored, continuously evolving, and under development such as, IoT, big data, machine learning (ML), social network, and cloud computing. The emerging technologies have created renewed interest in smart cities' solutions. The smart cities' progress and advancement are the results of the successful exploitation of emerging technologies.

This paper aims to investigate and discuss the success stories of emerging technologies in smart cities' solutions. The emerging technologies included in the study are the IoT, big data, and AI. The paper further summarizes a process of applying tools and techniques for the successful initiative of transforming a traditional city into a smart one using emerging technologies.

Keywords: Smart cities · Smart energy · Smart education · Internet of Things · Big data · Machine learning · Artificial intelligence

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1 Introduction

A smart city aims to optimize resources, minimize wastage, and improves the quality of life. The smart cities implementation is not the one-step solution instead, it incorporates many phases and sub phases such as infrastructure development, stakeholder engagements, cloud computing, edge computing, AI, and collaboration with big companies.

The European Union took the smart cities initiative in 2011, since then several countries have designed their blueprints such as, SMART (China), u-City Smart City (South Korea), i-Japan Smart City, Multimedia Super Corridor-Malaysia, Intelligent Nation iN2015-Singapore, and Intelligent Taiwan- Taiwan. The South Korean government has targeted smart grid/energy solutions [1]. The prominent private companies actively participating in smart cities solutions are Cisco, Hitachi, and IBM. There are a number of smart technologies available for smart cities design, development, and implementation. The fast-evolving emerging technologies are the IoT, big data, and AI. According to McKinsey (2015), the revenue from IoT will increase from $3.9 in 2015 to $11.1 trillion by 2025 [2]. The sensors and actuators are major components of the IoT. A sensor converts the physical parameters into human understandable electronic signals while an actuator gives a mechanical response based on an input. The IoT has applications in waste management, disaster management (earthquake (vibration and deformation sensors), floods), understanding crime patterns, and enhancing the security of cities. The smart renewable and non-renewable energy management systems use big data technologies for operational efficiency, cost control, system stability, and reliability. The social networks/media analytics helps in monitoring crime, natural calamity (fires, floods) reporting, and public complaints disposal. Moreover, drones (unmanned aerial vehicles) have applications delivering healthcare and emergency services to remote areas [3]. In the COVID-19 pandemic, countries such as China, Spain, Italy, and Oman among others have used drones for healthcare delivery and crowd control. The study investigates and explores the role of emerging technologies in smart cities solutions. The emerging technologies considered in this study are the IoT, big data, and AI.

This paper includes the following parts: Sect. 2, describes the research method and motivation. Section 3, presents the emerging technologies in smart cities. Section 4, illustrates the smart cities solutions. Section 5, highlights the smart cities initiatives in the Sultanate of Oman. Section 6, discusses the findings. The last section draws the conclusion.

2 Research Method and Research Gap

The study investigates and explores contents on smart cities solutions extracted from academic manuscripts, scientific reports, government reports, and IT companies reports. The "UN Urbanization Perspective 2011 Revision" report says that by 2050, 6.3 Billion people will move to major Metropolitan Cities. This enhanced urbanization will put unimaginable pressure on the already fast depleting earth resources, unless the

solutions in the form of smart cities are implemented. The inherent goal of smart cities is to solve the citizens' problems and ease the government in public administration.

There are many articles on smart cities that bring to notice the different aspects. They mostly cover advantages and challenges, but pay little attention to highlight and analyze the role of emerging technologies. The existing emerging technologies in smart cities solutions are the IoT, big data, and AI. The integrated approach of the IoT, big data, and AI are paving the way for personalized services in smart cities. The emerging technologies are the source of successful stories in the design, development, and implementation of smart cities solutions. Therefore, this research article lays down the role of emerging technologies in smart cities solutions.

3 Emerging Technologies in Smart Cities

The present study covers the emerging technologies mainly, IoT, big data, and AI. Each of them has its role and contributions to the smart cities solutions, which are described as follows.

3.1 Internet of Things

IoT is a platform for global connection and integration of sensors, actuators, RFID, Bluetooth, and other digital devices. The IoT consists of integrated components of services, data networks, and sensors. In the IoT, "Things" represent different devices (sensors, actuators, RFID, NFC). The IoT is the key driver of smart cities, facilitating communication and connection of a large number of devices. The IoT through connectivity and interoperability helps in the realization of smart cities around the world [4]. The IoT and its advanced form Industrial IoT integrate smart homes, wearable devices, smart grids, automobiles, smart farming, smart traffic, health applications, retail, security, energy, water management, waste management systems, smart factories, and smart industries [5]. The communication mechanisms between IoT devices can be device-to-device, device-to-cloud, device-to gateway, and backend data sharing. The main concerns of the IoT are security, privacy, confidentiality, and integrity. The cloud server, RFID, Wireless Sensor Network, Bluetooth, ZigBee etc., are the base of smart cities solutions.

In cloud computing, many computers are connected/clustered via real-time communication network for processing the data. The cloud computing has Platform as a Service (PaaS), Software as a Service (SaaS), and Infrastructure as a Service (IaaS) to the IoT devices. The smart cities computing model could be cloud, fog, and edge computing [6]. Radio Frequency Infrared Detection (RFID) is a tag attached to objects for tracking and uniquely identifying them. They are used in hospitals, libraries, and supply chains. The smart reading devices such as smart meters have RFID embedded. Wireless Sensor Network (WSN) are miniature devices attached to the sensors, for communication between different types of sensors (connect various distributed and independent devices). The applications include, smart homes and smart healthcare for monitoring temperature, light, humidity, pressure, etc. Wi-Fi is a wireless protocol that allows users to access the internet when connected to an access point. The Ultra-

wideband is oriented to high bandwidth is indoor short-range wireless networks over multimedia links. ZigBee is a wireless communication technology designed for short-range communication between devices. Longer battery life is an advantage of ZigBee. In smart cities, it is widely used in a smart home for connecting smart lighting devices. The Bluetooth uses a wireless radio system for short-range communication. It has replaced cable for keyboards, mouse, printer, joysticks, and so on, due to lower power consumption and cost.

The LTE technology describes the 4G wireless network (extension of 3G). The 4G shifts the paradigm from hybrid data and voice networks to a data-only IP network. The 4G uses multiple-input multiple-output (MIMO) and orthogonal frequency division multiplex (OFDM) to acquire more data throughput than 3G. The 5G networks will result in fast and resilient access to the Internet and support for smart cities realization. Many useful applications can be derived for smart cities using Near Field Communication (NFC), mobile communication technology, and cloud architecture. The manufacturer can directly interact with customers when the NFC tag is scanned and data is stored in the cloud.

3.2 Big Data

The healthcare, education, transportation, e-governance, etc. generate a huge volume of heterogeneous data through the sensor devices. The produced data are structured, semi-structured, and unstructured. The big data governance is concerned with managing and identifying meaningful patterns in large data sets (big data) [7]. The big data analysis faces a lot of challenges, such as data compatibility and inconsistency [8]. The big data management, storage, and analysis form the backbone of a smart city design, development, and implementation.

The big data is stored either at the dedicated server of the company or the data centers provided by vendors such as Amazon, Google, Microsoft, and Cloudera. The traditional relational databases such as MySQL, Oracle, etc. are unsuitable since the smart cities data are mostly unstructured, so the NoSQL database management system is used. The NoSQL databases are of three types, Key-Value, Column-Oriented, and Document-Oriented. The different platforms supporting each of them are Redis (KeyValue), Hbase (Column-oriented), and MongoDB (Document-Oriented). The InfluxDB, handles the time-series database. In Hbase the data is stored in tables, which can expand vertically and horizontally as opposed to the traditional SQL databases. The columns are like variables assigned for each row. The Hbase provides real-time read-write access to files stored in the Hadoop Distributed File System (HDFS). The big data analytics help in faster decisions on data. The big data analytic platforms are HDFS, HPCC, and Stratosphere. Big data analytics approaches include YARN (Yet Another Resource Negotiator), Map Reduce, Spark, HBase, Hive, and Kafka. The Hadoop vendors are Cloudera, Hortonworks, IBM, and MapR.

Hadoop (High availability distributed object-oriented platform) is an Open Source platform for data processing on cloud/clusters. There are two primary components:

HDFS and Map Reduce. MapReduce is a batch-based programming model for parallel and distributed processing of data on clusters. The MapReduce breaks tasks into smaller, dispatching to different servers, and then accommodating the results.

The HDFS has two nodes Namenode/Masternode and Datanode/Slavenode. The Datanode executes operations requested by the Namenode. The Apache Hive enables SQL processing and analytical capabilities on the data stored in HDFS. The Apache Spark has replaced the Map Reduce jobs for batch and stream processing. The platforms such as Amazon EC2 and HDFS manage smart cities data from multiple sources. The HDFS provides scalability and fault-tolerance. The analytic part is the key to decision making in smart cities solutions [9]. The backend distributed processing is due to Hadoop and Microsoft Azure. The big data analytic helps in getting valuable insight into big data.

3.3 Artificial Intelligence

The AI uses various algorithms and models to extract useful information from big data. The smart cities have a huge volume of data generated through data sources such as shopping centers, traffic sensors, transit points, police records, etc. AI has applications in counting vehicles, license plate reading, and objects recognition in image and video files [10]. The big data needs advanced algorithms to handle the volume, variety, velocity, and veracity of data. In Changsha (China - smart transportation), AI has been used for processing information generated through surveillance cameras [11]. In Taipei (Taiwan- smart governance, smart transportation, smart health, smart security, smart energy, and smart finance) AI has been used for processing information generated through the IoT [8]. The relationships between the IoT, big data, and AI are shown in Fig. 1.

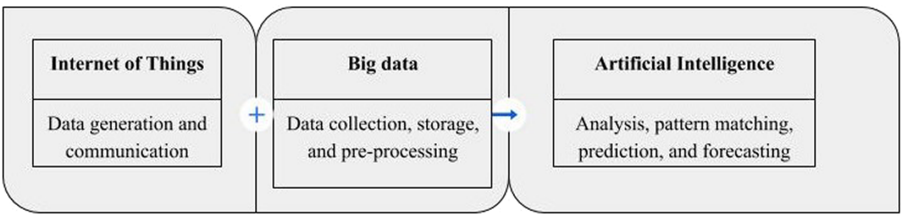

Fig. 1. Relationship between emerging technologies in smart cities solutions

The most common method of performing big data analytics is ML. AI is the superset of ML and deep learning. The ML is supervised, unsupervised, semisupervised, and reinforcement learning. ML has a number of applications in smart cities solutions [12, 13]. The traditional ML approaches are Support Vector Machines (SVM), Decision Tree, and Nearest Neighbor classifier. For example, [14] used Bayesian approach to residential property valuation, [15] used SVM for forecasting of photovoltaic (PV) output for efficient renewable energy systems. Deep learning is a subset of ML. It includes Deep Neural Network (DNN), Convolutional Neural Network (CNN), Recurrent Neural Network (RNN), Long Short Term Memory (LSTM), Auto encoders (AEs), Generative Adversarial Networks (GANs), and Deep Belief Network

(DBNs). They have been studied for smart cities solutions including mobility, safety, energy, healthcare, education, and governance.

4 Smart Cities Solutions and Emerging Technologies

Smart solutions to cities problems are needed for overcoming population growth, and sustainable utilization of natural resources. The realization of a smart city is successful, when it has smart healthcare, smart education, smart home, intelligent transportation, and smart energy. The important smart cities solutions and technologies used are described below.

4.1 Smart Healthcare

In smart healthcare, the IoT (sensors, wearable devices, smart devices) connect health centers, hospitals, patients, doctors, and pharmacists. This eases online appointments, digital record storage, remote home services, and remote patient monitoring. Smart healthcare includes wearable technologies, patient's electronic records, hospitals electronic records, and remote monitoring systems. The big healthcare data upon analysis is useful in monitoring patients' health, epidemics prediction, disease diagnosis, personalized medicine, and maintenance of health records. The patients' data could be used by insurance agencies for managing their businesses.

4.2 Smart Education

The smart education environment uses big educational data for learning analytics. The learning analytics helps in delivering personalized learning content, monitoring the learners' progress, and improving teaching quality. The AI along with the big educational data identifies the learning patterns and generates personalized learning contents [16]. The IoT has been enabling data generation and collection in the educational sector. Adaptive learning content is delivered to learners via web applications and mobile apps [17].

4.3 Intelligent Transportation

An intelligent transportation system monitors vehicle movements, minimizes accidents (understanding accident cause), optimizes supply chain, and enables smart parking. The sensors and actuators record the vehicle movements. AI is implemented on the big data for vehicle route optimization and fleet movement. The traffic is monitored by applying adaptive signal control technology, integrating sensors data, vehicle tracking devices, and cameras for traffic analysis.

4.4 Smart Governance

The smart governance entails integration, collaboration, communication, and data processing. The government and organization can devise policies and implement

schemes based on the analyzed results from health, educational, transportation, energy, and social network data. Using ML algorithms entities with a common interest can be identified for smooth governance. The smart governance leads to judicious utilization of natural resources and urban planning. IoT and big data analytics process real-time user data thereby the government can make efficient and accurate decisions. This improves citizens' quality of life.

4.5 Smart Home

The sensors and actuators based smart devices are interconnected inside homes. The smart homes have smart meters, smart light, smart heating, and smart waste management systems. These devices are controlled by applications running on smartphones and tablets. The smart home has benefits of monitoring and controlling home devices at any time and from anywhere [18].

4.6 Smart Energy

Smart energy regulates energy demand and supply. It consists of power grids, solar energy, and wind energy. The smart grids and smart meters in conjunction with communication network records the energy consumptions and power utilization habits of customers, which help in understanding the future demand and developing pricing plans. For instance, on-demand energy supply in passive buildings (i.e., not all the building and houses need power supply/water supply all the times of the day) [19].

4.7 Smart Tourism

Smart tourism uses the IoT and big data for providing optimized packages and information on touristic destinations for attracting the visitors. The data recorded in smart tourism consists of money transactions, capturing photographs/videos, using social networks (Facebook/Twitter/Flicker).

4.8 Smart Environment

The smart environment solution uses IoT, big data, and ML for waste management, water management, air pollution monitoring, and control. The waste management employs smart techniques of waste collection, smart bins, and recycling. Sensors attached to smart bins send messages about the level of waste in the bin for the waste truck collector to come and collect the waste.

4.9 Smart Parking

The smart parking uses sensors and application data (i.e., parking requests through app) for sensing, understanding, and monitoring the available parking space. The smart parking has two parts; sensors that send information about the parking status and mobile application which displays the nearest free parking space. The sensors record

the incoming vehicles, outgoing vehicles, free parking slots, and then propagate the information among the citizens via website or mobile application.

4.10 Smart Advertisement

In smart cities, the mobile network-based solutions such as GPS sensors or the Call Detail Record (CDR) data can be effectively used for the position and location-based advertisement. As soon as a consumer passes through a shop, he will get a message about the latest discount and offers.

4.11 Smart Weather Forecasting

Instant and real-time weather information is very useful for travelers. Weather conditions such as humidity, high winds, sandstorms, thunderstorms etc. could help people to visit the areas. They might get warning and advisory messages.

5 Smart City Initiatives in the Sultanate of Oman

The Ministry of Transport, Communication, and Information Technology (MTC) (-formerly, Ministry of Technology and Communication/Information Technology Authority) conducted a workshop on smart cities solutions in 2015. The workshop was focused on smart cities transformation. The Gartner's Research Vice President for Environmental Sustainability, Bettina Tratz-Ryan, discussed different smart cities solutions to logistics, health, and energy [20]. In July 2018, the South Korean Government Authorities and Omani Government signed an agreement for the development of a smart city at Duqm port. A memorandum of understanding was signed between Oman and South Korea for establishing futuristic smart cities in the Sultanate [21]. They plan to replicate success of Duqm in other parts of Oman.

The Sultanate of Oman has set two important initiatives: Oman vision 2040 and eOman 2030 strategy to meet the present and future needs by rapid technology adoption, smart infrastructure development, and creating a competitive economy. The MTC in cooperation with the Public Establishment for Industrial Estate (Madayn) has implemented Smart City Pilot in Knowledge Oasis Muscat (KOM). The project covers 1-Environment dimension (air quality, smart energy management, smart water management, and smart waste management), 2-Quality of life dimension (public transportation, and safety and security), 3-Infrastructure dimension (urban mobility) [22]. In Oman, urbanization, digitization, and adoption of Industry 4.0 technologies are taking place at fast speed, giving rise to realization of smart city solutions.

6 Results and Discussions of the Study

The applicable domain of smart cities includes smart transportation, smart environment (pollution monitoring and control), smart energy, and smart government. The smart cities design, development, and implementation are based on layered structure in the

form of 1) data generation layer, 2) data transmission/network layer, 3) data collection layer, 4) data analysis/computing layer, and 5) presentation layer. In the data generation layer, the end-users interact with the digital devices, sensors, and actuators. The data transmission serves as a sender of data generated at the data generation layer. In the data collection layer, cloud and servers store the collected data. The data analysis layer is the place where big data analytics, ML computation is applied on the data. The last layer is presentation, which shows the output in an understandable format such as graphs, charts etc.

The integrated approach of IoT, big data, and AI, help in optimized and orchestrated use of natural and manmade resources. Likewise they are needed in identifying the crime pattern, video surveillance, drones, and cybersecurity. The IoT, big data, and AI must work together to ensure the uniformity, accuracy, consistency and accountability of informed decisions. The heterogeneous data sources are smart sensors, smart meters, social networking platforms, crowdsourcing mobile applications, ERP systems, facility management systems, transportation management, and building management systems. The smart cities services include smart energy, smart management, smart transportation etc. AI and IoT are used in contextdependent recommendations and support systems [23]. The first-wave smart cities relied on smart transportation and security services. The second-wave smart cities have provided comprehensive urban services such as smart energy. The smart cities solutions are mainly in the area of intelligent transportation, smart grid, and smart energy as shown in Fig. 2. The obtained value is the result of quantifying the explored study on emerging technologies and smart cities solutions. The data has been derived from the explored study on emerging technologies and smart cities solutions.

Fig. 2. Smart cities solutions as identified from different studies

The intelligent transportation for real-time traffic patterns analysis and management using GPS navigation, and installed sensors have been implemented in Amsterdam, Barcelona, Taipei, London, Copenhagen, New York, Stockholm, Rio de Janeiro, and Changsha (China). The smart governance for monitoring crimes, sewage treatments, and emergency calls using installed surveillance cameras, sensors, social networks, and web dashboards have been implemented in Amsterdam, Santa Cruz, Songdo City, Paris, London, and New York. The smart energy for energy saving, real-time water requirements using smart meters, installed sensors, have been implemented in Amsterdam, Barcelona, Songdo City, and Taipei. Figure 3 shows successful implementation of smart

cities solutions in some of the major cities of the world. The values have been extracted from the multiple studies on emerging technologies and smart cities solutions found in the literature.

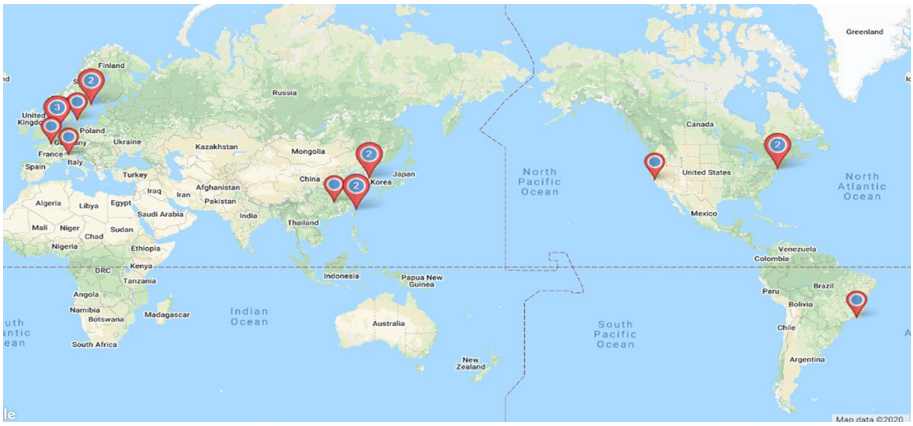

Fig. 3. Smart cities solutions in major world cities

The process used to implement smart cities solutions is shown in Fig. 4. The sensors/connected devices generate data. The JSON/RESTAPI/MQTT converts the generated data into an understandable format. The Cassandra/Apache HBASE stores the data. Apache Spark/Hadoop Map Reduce along with ML model processes the data. The decision makers get outputs in the form of graphs and charts.

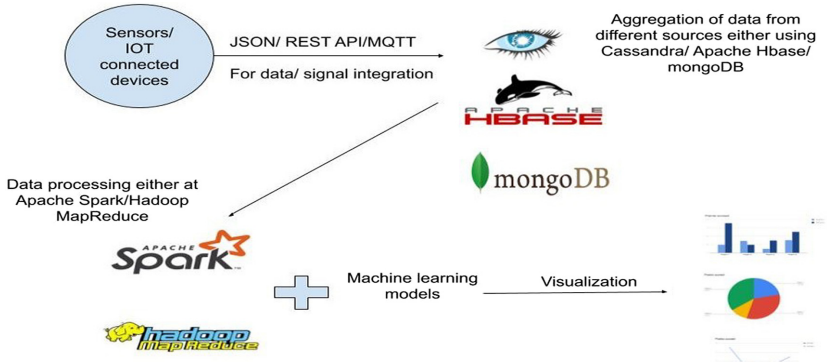

Fig. 4. Tools, technologies, and smart cities solutions process

The AI provides a strong processing capability. ML implementation can help smart cities in computation of thousands of variables. There are a number of challenges that hinder successful integration, such as different data sources and their formats,

uncleaned data, security and privacy issues, cost, and speed of data generation. The challenges associated with the IoT are power efficiency, security, data privacy, and interoperability. The challenges with big data are heterogeneity and privacy of data. The data quality in terms of inconsistency, inaccuracy, incompleteness, and irrelevance has been major obstacles affecting the efficiency and effectiveness of smart cities solutions. The successful governance of a smart city requires publicprivate partnerships in co-designing, data collection, and decision-making.

7 Conclusion

The smart cities in emerging technologies environments are not only improving the lifestyle of people but also making the society stronger and cohesive. A smart city has a well-defined ecosystem such as intelligent transportation, smart health, smart education, home automation, smart energy, and remote management of resources. The IoT enables a wide range of intelligent services in smart cities. The IoT is a potential data generator to capture events and activities. The surveillance camera generates a huge volume of image and video data. In smart cities connecting big data analytics, physical infrastructure, the IT infrastructure, the social infrastructure, and the business infrastructure leverages in investigating the residents' behaviors, lifestyles, and opinions. The issues with big data are data security risks, data inconsistency, and data traceability. The study has analyzed and assessed the role of emerging technologies in smart cities solutions. Additionally, the tools, technologies, process, and future prospects have been discussed concerning smart cities solutions. The study concludes that emerging technologies have applications in smart cities for intelligent transportation, smart governance, and smart energy solutions. The future research needs to pay attention towards solutions such as epidemiology, telemedicine, in smart city settings using emerging technologies.

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