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A Review of Data Management in Internet of Things

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Abstract

Internet of Things (IoT) has emerged to provide convenience and better lifestyle for users. IoT incorporates many underlying technologies such as man-to-machine and machine-to-machine communication, networking, and sensors. One of the keys in the success of IoT is the data that flows underneath these technologies. This article discusses the challenges and issues in data management in the context of IoT. Different aspects of data in IoT including the sources of data, data gathering, data processing, and the transmission devices are identified and discussed. The challenges brought by the needs to manage vast quantities of heterogeneous data across heterogeneous systems are also discussed in terms of the logical and physical data management and communication network. The data models used in IoT along with the techniques for data control, cleaning, and indexing are discussed based on the characteristics of IoT data. Lastly, a discussion on the benefits and limitations related to data management in IoT is presented along with examples of real-world applications.

Keywords: *communication network, data management, sensors, Internet of Things*

1. Introduction

One billion of devices such as PCs, tablets, smartphones, televisions, automobiles and wearable devices will be connected to the Internet in 2015 [1]. Within a few years, over two billions of devices are projected to always connect to the Internet. The idea that these things are recognized and controlled via the Internet generating prodigious amount of data introduces the regime of the "Internet of Things (IoT)". Cisco Internet Business Solutions Group (IBSG) quoted that "Internet of Things" is the state that we are reaching the point of time where "things or objects are connected to the Internet more than people" [2]. This implies that the surrounding environment of humans will change from the state where computers and the Internet depend almost entirely on humans to the phenomenon where objects and people are equipped with identifiers connected to the Internet. Definitely, the more devices connect to the Internet, the more reality befalls for Internet of Things.

In nature, large volume of data will be enormously generated by things automatically. Its volume will be incremented with high velocity and multitudinously.

By the year 2020, more than 50 billion devices are predicted to be connected to the Internet. The way people, businesses and societies interact will be enhanced by mobile broadband, connectivity and networking [3]. Main enablers of the internet access are the reduction on price of communication modules, sensors and technology devices. Data both animate and inanimate from various sensors attached to all kinds of devices will be generated in demand. Such data blasting from queries of Internet-search to stream of data captured by sensors are what contributes to 'Big Data'.

What makes data big is not only technology but is also components of the innovation value chain. More and more raw data is combined with data from other sources, classified and stored in data repository. Algorithms and analytics are applied by an intelligence engine to interpret and determine necessity from the aggregated data. Its output can be converted to tangible values, insights or recommendations[4]. In terms of business facets, healthcare, automotive, manufacturing, wholesale and retail industries are the precursors of "big data". The analytics of traffic routes[5] or health records[6] are major generators of continuously massive data. With these emerging technologies, enterprises can reduce their costs, improve customer satisfaction, and create new business models based on the inherent value of information. This trend forces organizations to do more than collecting massive amount of sensory data but to take advantage of the massively scalable big data for the business processes.

To create an awareness on technical scheme for the intricacy in processing large volume of data in IoT. This paper emphasizes technologies available to manage data derived from applications such as healthcare, safety, business and environment. Section 2 describes types of data in IoT, data characteristics and its primary sources. Section 3 presents the mechanisms to quickly extract information from such data. The innovation in database technology in collaboration with the realization of real world applications is demonstrated. The needs of users in data storage solutions based on SQL and NoSQL, and efficient index framework are highlighted. Section 4 explains the complexity of processing events of large database, the privacy of big data, and the common challenges of data's transmission in IoT as well as the recommendation on how to tackle those issues. Section 5 presents challenges, opportunity and gaps for data management. The paper is then concluded in Section 6.

2. Data in the Internet of things

Data related to customers, daily transactions and operations of organizations is generally produced in trillion of bytes. This data is definitely generated from various sources such as mobile phones, smart sensors, vehicles, and smart equipments. The recapitulation on how large pools of data can be captured, communicated, aggregated, stored, and analyzed is described below.

2.1 Type of data

From the aspect of data semantics, data in IoT can be low-level raw data and high-level generalized data. Different formats of data introduce the basis of data polymorphism and data heterogeneity. As example, data in a "*name*" field can be an abbreviation, full name, or name and last name. This is obviously inconsistent.

The ambiguity of semantics, the error of measurement, and the dynamic change of data further lead to data uncertainty**.** A few definitions and examples of data types in IoT are given below:

1) Polymorphism & heterogeneity

Applications in IoT often involve diverse types of data from different applications. Data can be physical data, biological data and chemical data. As the complexity of applications is increasing, various data from different sources can be correlated. For example, Logistics and Supply Chain Management[7] and transportation control and monitor systems [8,9] generate physical data such as orientation, positioning, and route map of objects from GPS, accelerometer, and GIS. Health monitoring systems[10,11] evaluate patient status by taking biological data such as blood pressure, heart rate, facial expression and sound. Disaster and ecological monitoring environment systems [12] consume chemical data on humidity, luminance and oxygen consumption as input. Evidently, data from various sources mentioned can be, but not limit to numerical, text, and XML. The structure of data can be combination of structured data (such as standard records), semi-structured and non-structured data (such as video, audio and other multimedia data).

2) Massive scale

A huge amount of intelligent equipments connected to the Internet can establish not only billions but trillions of real-time data. Such data needs a large storing space and a powerful system to process. Imagine a scenario in a retail store where millions of merchandizes are available daily. If these objects need to be tracked per day, and each tracking generate 100 bytes data. The total of constantly produced data may reach 100 GB and 36.5 TB in a year to support object tracing and discovery.

3) Rich semantic

Data in IoT is generally spatial with space-time information such as personal expression data and GIS data. The former is widely used in healthcare applications such as in-home healthcare station (IHHS)[13] and non-contact health monitoring system (NCHMS)[6]. The latter is used in a road monitoring system[5] and special material transportation vehicles [14]. These applications generate various raw sensory data that are deployed on highly distributed, heterogeneous, and resource -constrained devices interconnected and communicated in different scenarios autonomously. Hence, reliable integration and fusion techniques are required to manipulate data in such complex semantics.

A principal of automated information communications and interactions in IoT is to make data descriptions trustful so that machines and software agents can process and interpret data precisely[15]. As an example, when a physician justifies a symptom of a patient, several vital signs such as blood pressure, and heart signal are usually monitored. The implication drawn is the interoperability among the "things" is one of the utter fundamental requirements for object addressing, tracking, and discovery.

4) Timeliness

The state of things is mostly sensed from their changes. Therefore IoT data is apparently required to be sent to the server swiftly and regularly. Although historical data is essential but the timely data can describe the status of object in real-time in a more clear-cut point of view. Therefore, tightly coupled physical systems with reliability and availability of databases that exhibit high level of integrated intelligence are essential. These systems are a part of the enabling technologies for IoT to operate with or without the humans in the loop. Otherwise, the conclusion drawn out from IoT may be astray.

2.2 Sources of data

In the environment of IoT, data is accumulated from different kinds of sensors. Primary sources of data are 'things' or 'interaction with other things'. These things can be autonomous, semi-autonomous or not autonomous[16]. In consideration to the dependency on variety of data sources, data in IoT can be categorized into eight following facets[17] as depicted in Figure 1.

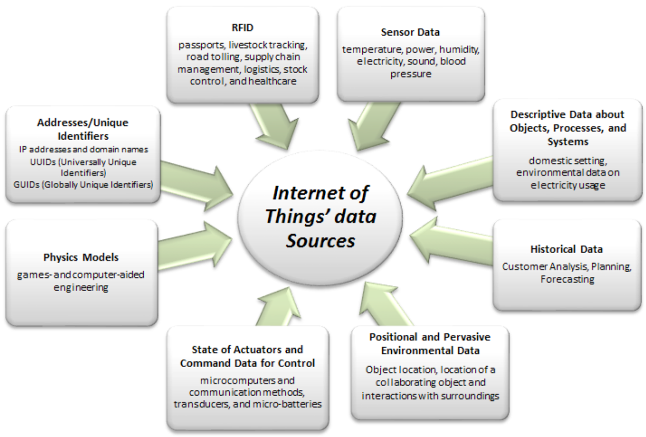

Figure 1. Sources of data and applications

1) *RFIDs*: RFID tags are uniquely identifiable and can be attached to everyday objects. These tags can store information internally, which can be transmitted as radio waves to an RFID reader through an antenna[18].

2) *Addresses/Unique Identifiers*: The objects in IoT are uniquely identified by IP addresses. As the number of objects grows, the number of IPs will also grow. At present, this barrier can be moderately handled from the availability of IPv6, which can accommodate the explosion growth of the Internet through the 128-bit addressing.

3) *Descriptive Data about Objects, Processes, and Systems*: The data and metadata recorded in objects is the driving force of IoT. The objects producing this multitudinous data are not only concrete objects but also include processes and systems which are considered as special types of objects.

4) *Positional Data and Pervasive Environmental Data*: Positional data is generally obtained from a global positioning system (GPS), a local positioning system or a position of tagged object. These devices include satellites, Wi-Fi access points, or cellular base stations. The collaboration of these architectures provides transparent tracking of static and moving components. For pervasive location, the information on environment is modestly available to flourish the interactions with surroundings so called "Internet of Places"[17].

5) Sensor Data: The current technology of power grids and sensors provides a great possibility to capture an extensive amount of data faster and with higher precision. In disastrous scenarios, sensory data such as temperature, humidity, light, and pressure which is usually multidimensional time series is frequently transmitted through Wireless Sensor Networks (WSN).

6) Historical Data: As the time goes by, data is accumulated as history. Although it is not current, this growing volume of data remains indispensable for decision making or business planning. The appropriate management for this static data per requested is significant.

7) Physics Models: Reduced -power microcomputers and communication methods, energy-harvesting transducers, and improved micro-batteries are defined as physics models. Their characteristics such as instance gravity, force, light, sound, and magnetism represent templates for reality where their widespread use is manifested in games and computer-aided engineering.

8) State of Actuators and Command Data for Control: Miniaturization technologies and energy-efficient electronics can often be noticed in the remote control devices. For example, a user in a smart home wants to switch on the air condition before arriving home. Such activity can be initiated by issuing a command interfaced through the Internet.

2.3 Characteristics of 'Big Data'

The explanation of the 'Internet of Things' as "...sensors and actuators embedded in physical objects... linked through wired and wireless networks, often used the same Internet Protocol (IP) that connected the Internet" is presented in[19]. Its notion generally refers to the situation where many different 'things' are connected to the Internet and thus can be connected to each other[16]. Vice versa, the definitions of 'Big Data' [4,16,20,21] remain intricate. The high volume, high variety, and high velocity are the basic essential characteristics of big data. Albeit, other characteristics are equally important, especially when big data is applied to operational processes. The key features of 'Big Data' as *classic Vs* is illustrated in Figure 2 whereas its characteristics are explained in Table 1.

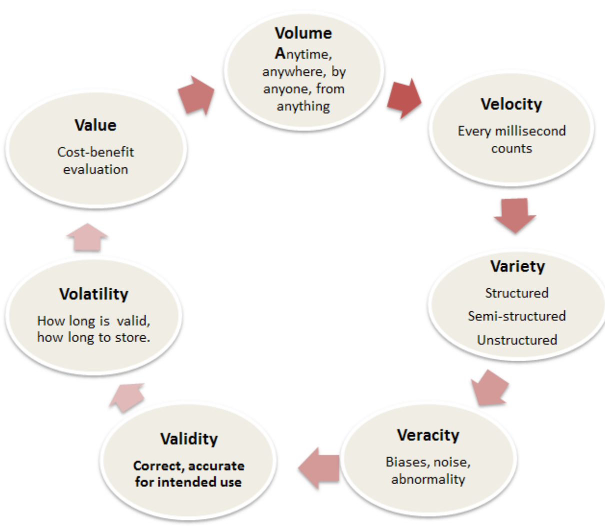

Figure 2. Definition of Big data as classic Vs

Table 1. Characteristics of data in IoT mapped to the definition of 7Vs

Characteristics	Description	Example
Volume	Rather than capturing business transactions, moving samples and aggregating to another database, applications now capture all possible data for analysis. The application reads the consumption data on so many sensors tied to so many appliances and devices. The reading is roughly occurred 100,000 times per day per residence.	anytime, anywhere, by anyone and anything
Velocity	Current applications are capturing data streaming from other systems or sensors which data is generated continuously.	Every millisecond counts
Variety	The format of data could be structured, semi-structured, and unstructured. 1. Structured - data with semantic meaning, easy for computer to understand.	Database data
	2. Semi-structured - data is a form of structured data that does not conform to the formal structure of data models associated with relational databases.	XML, other mark-up languages
	3. Unstructured - no latent meaning attached to the data in a way that a computer can understand what it represents.	e-mails, text messages, audio and video streams
Veracity	Referred to the biases, noise and abnormality in data which is the biggest challenge when compares to volume and velocity. Data cleaning and processes to protect 'dirty data' are crucial.	dirty data
Validity	If that part of data is important or is determined to be important, data must be validated.	correct and accurate data
Volatility	In some situations, understanding what data is out there and how long it can be stored can help analysts define retention requirements and policies for big data. This is not the case if data is always available for analysis.	Period of data validity and period of data stored.
Value	This 'value' provides the key cost-beneficial criteria in terms of determining whether or not 'Big Data' should be used because the development requires infrastructure for data gathering, storing and processing.	cost-benefit evaluation

3. Data Management & Applications

The basic logical and physical structure of data management for IoT can be identified in various perspectives. For simplification, Figure 3 addresses the main facets of IoT data management[22] which can be inferred as four primary modules stated as data collection, data transmission through communication channel available, data administration, as well as data processing.

The data collection module focuses on the identification of "things" to feed data to IoT data stores. This data may be stored for a certain time interval before reporting to governing components. Data is then filtered and processed, and possibly fused into compact forms for efficient transmission from the lower layer of "things" to the upper application layer. The transmission to collection points can be carried out through wireless communication technologies such as Zigbee, Wi-Fi and cellular. The analysis of data is enabled by the middleware and database architecture with substantive factors, such as; access management, query optimization and data aggregation. In what follows, different stages that demonstrate the importance of well-established data management of IoT are reviewed. Related work in IoT data management in terms of the data collection devices and database technologies are summarized in Table 2.

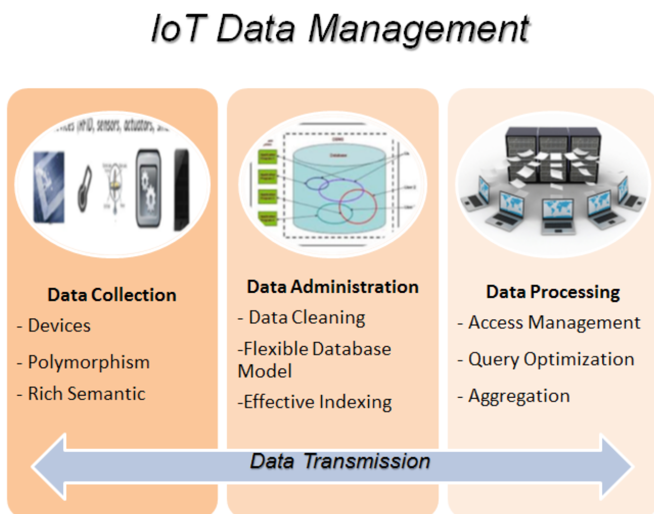

Figure 3. Basic Concept of IoT Data Management

Table 2. the applicable of data sources, data types and databases in IoT

Ref	System	Data Source							Database		Application Area
		RFID	Smartphone	Sensor	GPS	NFC/WSN	PDA	Actuator	SQL	NoSQL	
34	Efficient index framework based on key-value store (UQE-Index)				P					P	HBase
23	OLAP DBMS for inventory and sales processing (parallel database)	P							P		MySQL SQL Server
30	IoTMDB system (NoSQL)			P						P	MongoDB
25	Mobility First's identity based routing			P	P			P	P		SQLite
31	document-oriented for heterogeneous and multimedia data				P					P	CouchDB
32	General Statistical Database Cluster (IoT-StatisticDB)			P	P				P		PostgreSQL
61	NoSQL for WSN community			P						P	Redis
62	XML Database Based Resource Directory					P			P		MySQL, Sedna
33	Discovery Service (DS)					P				P	Hbase

3.1 Data Collection

A discovery mechanism of data source is an important part of IoT applications where the application services can be announced only when responses have been forwarded from sources. Technology devices that can empower the ability to tap into diverse sources of data are RFIDs, GPS, NFC, smart phones, actuators and variety of sensors.

RFIDs[13,23,24] seem to be the forefront device in application arenas of healthcare, hospitalization, and disaster management. For example, a RFID tag is attached to a regular medical box embedded with healthcare application[13] to seamlessly integrate patient daily consumption to the hospital's prescription system and forward to physicians. In oil depots, RFID tags are equipped in all area of the worksites to function as a smart environment monitoring system. The unpredictable situations are captured and forwarded by PDAs which act as RFID readers[24].

Smart phones[5,13,25] are also gaining popularity in a paradigm of social sensing. The capabilities of the substantial sensors generally equipped on these smart phones can form the M2M (Machine to Machine) or V2V (Vehicle to Vehicle) network to monitor road conditions [5]. They also have the ability to serve as context -awareness device. An example is illustrated in MobilityFirst[25] where a user can use a smartphone to locate the location of available cabs within the nearby area. Also, the locating of objects can be continuously traced as long as the phone battery is alive.

Diversity of sensors such as wearable sensors, digital cameras and microphones can assist the grasping of dynamic data generated from humans. A hospital application, NCHMS[6] deploys cameras, microphones and other sensors to monitor facial expression or voice changes of users for remote physicians to delineate the symptoms of user.

3.2 Data Administration

Classic approach for IoT data administration is a relational database, a document oriented database or a knowledge base solutions. The deployment of these technologies as the middleware storage solutions depends on specific needs of the implementation. An overview of processes to analyze large data repositories is described as follows.

1) *Cleaning*

Data cleaning is a process to detect and remove errors and inconsistencies from data to improve the quality of data. In the case of IoT, real time data is constantly generated from many different distributed sources such as; smart objects, people and variety of services[26]. Effective data cleaning is needed to the quality of data from multiple data sources.

2) Flexible Database Model

Data storages in the context of IoT have to deal with a huge amount of data both at rest and constantly generated. Data storage of IoT can be identified as SQL (Structured Query Language) and NoSQL (Not only SQL)[19]. SQL is a query language used in relational model where data is organized into *relations* such that each record of data is represented by a table consisting of *rows* and *columns*. Obvious difference between SQL and NoSQL databases is that NoSQL databases do not divide data into relations, nor do they use SQL to communicate with the database.

NoSQL has been used as the underlying database abstraction for ad-hoc networks because its queries outperform that of SQL. Particularly, when there is a requirement to support a large data size over long periods. The evaluation on query performance of NoSQL with regard to time complexity of different data structures shows significant predominant in performance. Relational databases, in contrast, are neither designed to handle the large volume of heterogeneous data of modern applications, nor styled to take an advantage of the cheap storage and processing power available. However, query optimization of NoSQL may not be as good as that of SQL. User is required to possess significant programming expertise, even though he wants to perform a simple query because only few facilities for ad-hoc query and analysis are available.

Both models have been widely used in many of the research. However, recent research in IoT data storage tends to focus on NoSQL databases[27]. NoSQL underlying benefit is being a schema-free database that can accommodate flexible schemas of IoT data. Their availability have illustrated in various forms of databases, such as; document based, graph based, key-value based, and column family[28,29].

One of the solutions for storing IoT data as a public service platform (RNS) is IoTMDB[30]. IoTMDB is a storage management solution based on NoSQL with data abstraction to reduce the complexity of data query based on ontology. The form of key-value as well as a data preprocessing and sharing mechanism for a common IoT data expression is deployed. The other solution designed to effectively handle data sharing and collaboration[31] is based on CouchDB, a document-based NoSQL. For documents uploading, RESTful APIs and optimized schemes are used. Its main strength is the abilities to support multimedia data formats such as image and audio (video) encodings, load balancing and distributed query processing. Another interesting data storage bundled with numerous statistical functions is IoT-StatisticDB[32]. This solution focuses on expressing complicated statistical queries in the standard SQL format based on statistical operators inside the DBMS kernel. For a better performance, it runs in a distributed and parallel manner over multiple servers. The master server is designed to globally execute the query by coordinating multiple servers for parallel execution before forwarding data.

3) Effective Indexing

Queries are the most frequent transactions issued to the databases. The trade-offs between efficient retrieval and scalable index storage are needed when developing indexing techniques to facilitate the retrieval of massive volume of streaming sensors data. The building and storing of indexes are prohibitively expensive both in terms of storage and processing. However dynamic spatiotemporal indexing has been recognized as an essential step. Some of the technologies in indexing proposed are the Discovery Service (DS)[33] and the "update and query efficient index" (UQE-Index)[34]. Both are implemented as parallel processing using HBase as a data storage. DS is intended to optimize the discovery efficiency of objects in logistics supply chain. Its storage schema uses object ID as row key, event timestamp as column identifier and event index content as cell value. The central-indexing relies on a distributed NoSQL database. As for UQE-Index, it is aimed at capabilities on high insert throughput and efficient multi-dimensional query.

3.3 Data Processing

Data processing and analysis such as sorting and mining require heavy computations. These tasks are considered the most expensive energy consumption process. Different technologies and components involved in data processing mostly use proprietary ad-hoc protocols to exchange data among different systems, which are very complex. To get a clear picture of the main functions performed at this stage[35], the following section describes essential techniques to handle data representation, interfaces, and interoperability.

1) Access Management

Applications on IoT rely on 'Big Data' where SQL has been the de facto standard for data access. SQL is usually the core process to perform standard selection/projection/join/aggregation operations or nested operations for complex queries[36]. The former mainly refers to queries issued to either request real-time data to be collected for temporal monitoring purposes or to retrieve a certain view of the data stored within the system. The latter obviously provides more globalized views of data and in-depth analysis of trends and patterns.

TinySQL and TrikiDB [27] are examples of the constructs to accommodate new forms of data accessing. Both query processing systems represent sensors as a table where users can insert queries at the base station. These queries are then converted into sensor node understandable format and sent to nodes to get the results. Both are in flavor for applications in WSN. The other interesting technique is the optimization query based on parallel DBMS [23]. This solution is aimed to optimize the single-node servers whereas the construction is determined as a series of sibling servers.

2) Query Optimization

A large volume of message exchanges that are translated into communication overhead has been primary concerns for IoT environment because IoT devices are mostly geographically distributed. The data-fetching plan that costs the least is a normal targeted for query processing. Therefore, the query processing to locate the best plan to fetch data from various collection devices and return aggregate readings as results is not simple.

Some extensive solutions trying to optimize the query processing had existed. One of those traditional techniques used in the past decade was an energy-efficient data dissemination and query processing based on two scheduling mechanisms, a wave scheduling and a tree scheduling[37]. The first was a class of simple activation schedules and associated routing protocols that achieved scalability and energy-efficient with modest delay penalty. The latter applied the structure of tree to route message from sensor nodes to a specific server.

Currently, there exists a new paradigm for large-scale data analysis called MapReduce. MapReduce is bundled with rich features, high scalability, fine-grained fault tolerance and easy programming.

3) Data Aggregation

Data Aggregation has been put forward as a main paradigm for wireless routing in sensor network. The idea is to combine the data coming from different sources by eliminating redundancy and minimizing the number of transmissions. It also saves energy and fuses information into the base station. It is considered an essential mechanism for lowering the communication overhead expected for transmitting raw streaming data. Its main objective is to collect the most critical data from the sensors and make the data available in an energy efficient manner with minimum latency. Other important measurements of the aggregation algorithms include network lifetime, data accuracy and latency. Through a process of aggregation, potential loss of accuracy may occur because underlying detailed data may be discarded. However, data aggregation and fusion are still required for some certain applications[38].

3.4 Communication

Wireless protocols coming into attention of IoT are Wi-Fi, Bluetooth and ZigBee. Cloud technologies are also of interest because they can consistently improve the communication throughput and latency[35]. In addition, several low power communication technologies which can boost up the efficacy of IoT include Bluetooth, RFID and NFC. For example, the hospital application, IHHS[13] uses a mobile network as the main communication and employs smart phones, NFC, and PDA as transmitters between patient and physician. The others extend their communication capabilities through NFC and WSN connections for security and efficiency in oil depot monitoring system[24] and road monitoring system[5].

3.5 IoT Applications

IoT gains acceptance in businesses and communities is gained from its state-of -the-art applications. Table 3 reveals some of the existing applications in IoT. These applications are closer to our daily lives than we can imagine.

Table 3. the applications in IoT

Ref	System	Data Source							Application Area
		RFID	Smartphone	Sensor	GPS	NFC/WSN	PDA	Actuator	
5	Road Condition Monitoring and Alert Application		P		P	P			Safety
6	Non-contact Health Monitoring System (NCHMS)	P	P	P					Health
13	In Home Healthcare Services (IHHS)	P	P	P		P	P		Health
40	Rural Healthcare Monitoring and Control	P	P	P		P	P		Health
39	Monitoring Health of Elderly People			P		P			Health
24	Oil Depot Safety Management System	P	P				P		Safety
43	Robot navigation and object manipulation	P	P				P		Logistics
44	A Logistic Mobile Application (ALMA)	P	P		P				Logistics
45	A Logistic Geographical Information Detection UIS	P				P			Logistics
52	Remote performance monitoring system and simulation testing of battery	P			P	P		P	Safety
51	License plate Identification	P		P	P	P			Safety
12	Health Monitoring and Risk Evaluation of Earthen Sites			P			P		Safety
41	Ambulance Route Search	P							Hospital
46	Food Quality Supervision	P				P			Manufacturing
47	Apparel Network	P				P			Manufacturing
48	Material and Production Tracking in Toy Manufacturing	P			P	P			Manufacturing
42	Hospital Wireless Sensor Network	P				P			Hospital
49	Monitoring of Discrete Manufacturing Process	P				P			Manufacturing
50	Shop-floor Production Performance Analysis	P		P					Manufacturing

1) Healthcare

People have started to pay more attention to personal health problems where IoT can be intelligently applied. A non-contact health monitoring system (NCHMS) monitors the user's facial expressions, postures and sounds without interfering with daily life of the user[6]. This application introduces the concept of emotional space detection of the human emotion in combination with other human factors. Therefore user can be diagnosed without body contact. Through the analysis, user's current information on health can be justified whether a user requires medical care. Another is a Home Health Hub Internet of Things (H^3IoT), a 5–layered framework architecture developed for home based monitoring for elderly residing at home[39]. The system uses biosensors such as Electrocardiogram (ECG), Electroencephalogram (EEG), and Electromyogram (EMG) to sense physiological activities. Blood pressure, blood glucose, temperature of the body and related parameters are forwarded through 3G or Wi-Fi. This information can also be used as detail health history of the elderly.

The accessibility to healthcare of people living in the rural may not be easy. The rural healthcare center (RHC) requests any person who registers with the system to wear one active RFID sensor[40]. Any changes in the normal parameters will then be alert to patient and RHC doctor. The RHC staff can access to medical facilities to provide emergency healthcare if needed. Another solution is iMedBox, an intelligent medicine box attached with RFIDs[13]. It is a specific in-home monitoring applications based on open source operating system such as Andriod. It can simultaneously work as in-home medicine container and a "medication inspector" in daily healthcare monitoring. Patient vital signs are transmitted to medical center via USB, NFC, RFID, and WSN.

2) Hospitalization

Common issues patients face when using hospital services are how soon can ambulances deliver emergent services to patients, and how can doctors keep continuous monitoring of patients' vital signs while the patients are on the move.

When there is an emergency, the ambulance driver will traditionally choose the best route to reach the scene by relying on his own experiences. In big cities, sometimes traffic jam cannot be effectively escaped. One of the solutions proposes an ambulance equipped with RFID tags. These tags serve as portable data capture systems and positioning systems[41]. Thus, the real-time traffic conditions from wireless sensor nodes located on the roads can be sent to the dispatch control center in the hospital by the multi-hop method. The control center can then forecast the optimal path to provide the fastest route for the ambulances.

The proper mobility management to connect between patient nodes and the hospital network is essential to monitor the exact locations. This is where IPv6 mobility protocols are distinctive. Real-time monitoring of vital signs such as ECG (electrocardiogram), heart rate, SPo2, blood pressure, weight and breathing rate is sensitive for patient under treatment, and should be monitored both in the hospital and at the scene. A new mobility protocol for mobile patient nodes is proposed[42]. The system comprises a set of sensor nodes formed into a single unit, called mobile patient node in HWSN6. In this scheme, Mobile Routers (MR) acts as a coordinator to manage the mobility scenario and the Personal Area Network (PAN) functions. This mobility solution can decrease the number of messages and overhead, and prolong the lifetime of a patient. PAN is valuable to guarantee patient signal stability.

3) Logistics

Logistics processes have become more complex and dynamic driven by internationalization of supply chains and global competition, shorter product life-cycles, mass customization, and quality requirements. New technologies like IoT can alleviate these challenges.

One of the logistics solution applied the idea of using robot to replace human in the furniture assembly process. Both the robot and the objects are attached with RFID tags to synchronize the robot navigation to the objects [43]. To enable robots to navigate towards an object of interest and manipulate it, RF-Compass is deployed as a RFID-based system for robot navigation and object manipulation. This process can be done without complex machine learning algorithms based object shape and color. High accuracy on orientation and position of object can be plausibly achieved.

ALMA is a logistic application designed to solve the problems on truck loading and vehicle routing[44]. This system deploys High Performance Computing (HPC) infrastructure to deliver logistic services with high quality service. On delivering goods, the transporter scans the RFID tags and transmits product information to logistic center via a smartphone connected through 3G. At the same time, real-time information on traffic incidents is forwarded to the transporter for evaluation.

A Logistic Geographical Information Detecting Unified Information System [45] using a smartphone as a device for user to detect the location of object is another option. A communication of information is formed on multiple general technologies such as PDA, mobile phone, PC and other devices. The UIS works in a way that when a user sends positioning command to a mobile terminal, a mobile terminal will launch geographical position detecting information back. This location can be either detected from Geolocation API embedded in browser or GPS sensor.

4) Manufacturing

New safety directive, environmental protection, process monitoring and relations with both clients and partners are survival factors for many manufacturers today. Despite these companies may have been implementing sensors and computerized automation for decades. These sensors and actuators are generally organized in hierarchical fashion within individual devices and often lack of connections to internal systems. Therefore, the development and adoption of IoT is a critical element of smarter manufacturing.

A method on constructing the quality supervision platform of the whole process of food production is unfettered in current food industry. Main processes often involved with raw material selection, food production, shipment, storage and distribution, and food sale. (PFQC-IoT)[46] was proposed. This system deploys two dimension barcode, RFID tags and sensors to collect the information and data affecting the quality of food. In data integration layer, WSN and cables are used for data transmission. For food enterprise, the intelligent management can support the enterprise decision-making. For users, the visualized tracing and inquiring of the food can be noticed. For supervision department of food quality, the automatic report of food quality, consuming alarm, recall and other functions can be realized.

Toy and garment manufacturing are facing hurdles; such as wastes, inefficiencies, relationships with customers and partners as well as aftersales services. A garment network customization systems is one of the solutions[47]. It was designed to support features of online shopping, virtual fitting, and individualized clothing. RFIDs are used to keep track through each step of production. Customers can visualize relevant information in terms of virtual design, 3D clothing fitting, and tracking the shipment status. As of toy factory, a collaborative architecture of toy material and production tracking system is implemented[48]. The system used barcode to identify raw material such as paint, plastic and electronics devices, and RFIDs to track semi-finished and finished products. Customers can get accurate and detailed data while enterprises can optimize the production management through the combination of material and production tracking information. Similar context is also applied to a discrete manufacturing monitoring system[49] and a critical event based manufacturing information process[50].

5) Safety

Safety of human lives can be increased by utilizing surrounding information. Locations, speed of the vehicles, traffic lights, weather condition, and changes of environment are considered crucial. Through IoT technologies, things can learn from the experiences of others and thus adapt to real-time situations.

A system to eliminate the unsafe acts of employees is installed in oil depots in China[24]. Many states of operations can pander unsafe acts of workers; such as when accepting oil and distributing oil, skipping of the instruction, or ignore to perform safety audit of standard operations. Each sensitive item in worksite is installed with RFID tags whereas RFIDs and PDAs are used as worksite audition tools. When audition, a supervisor must carry PDA to sense the unsafe state of the facilities and report directly to supervisor through 3G communication channel.

Not only the leakage of oil can cause disaster but also the poor stability of environmental control can induce a sudden partial collapse or even destruction of the earthen sites. A Health Monitoring and Risk Evaluation of Earthen Sites (HMRE2S) based on human immune theory[12] is one of the solutions. The system uses nodes to monitor the earthen site conditions. Environment information such as temperature, humidity, light, vibration, and rainfall is captured via sensors and forward to data center to evaluate the immune system of the sites. Therefore, people in the surrounding area shall get warning before the disaster occurs.

Insufficient parking space, congested traffic, and unsecured of individual life are always dismal situations for people living in a big city. A Road Condition Monitoring and alert system is an option for people who want to get away of overcrowded traffic[5]. The application uses GPS signal or smartphone to detect vehicle’s current location and generate alerts for pothole to driver which can facilitate user life as well recommend safety routes.

The license plate recognition [51] is another application that can facilitate users in locating parking spaces as well as save time for stopping at the toll system. RFID tag is attached to the car license plate where that plate can be recognized by computer vision and pattern recognition. Therefore, when a car passing through the highway toll, the toll system can perform automatic charging. With this license plate tag, parking guidance information is automatically released to the driver so that driver is not forced to drive around to find parking place. Besides, it is also convenient for rescue services and security monitoring of vehicle in case of emergency.

The solutions in this area are not only available for people who own vehicles but also to passengers. The simulation on performance of power battery for electrical vehicle is another example [52]. To protect the electrical vehicle to run out of battery while it is on duty, the electric load simulation system will calculate the power consumption according to the road condition captured from the control system. Not only passengers can be assure on the security but also the cost of maintenance services shall be reduced.

4. Discussion and suggestion

Multitudinous benefits have been gained from incorporating IoT into lives and businesses. For daily life, it can be seen in the forms of health, disaster alert, traffic control and home utility. For businesses, the interweaving of logistics, smart factory and customer management are remunerated. The integration of IoT into these systems have been proven to be of real benefits to our society.

The vision of the future IoT may pose new challenges and opportunities for data management and analysis technology. However, vulnerable facets in handling and processing of data in IoT remain as follows:

4.1 Data Collection

Three main barriers of data collection in IoT comprise the quality and efficacy of data collection devices, the massive volume of data as well as security. These issues raised are highlighted as follows:

1) Blind spots of IoT devices:

One challenging issue of IoT data collection devices is the dead spots of data transmission. For example, the present of RFID tags is typically between 5 to 20 meters from the readers to effectively assure the reading process. The signal is rather cramped if the distance is over such limit, causing significant dropped in number of reading. Massive noise, incomplete and redundancy of data can as well occur from repeatedly scanned of EPC tags from the same location.

For smart phone, its practical usage is often seen in the context of user-centric applications or working with other smart devices in smart infrastructure. The embedded of various sensors such as GPS, accelerometers, microphones, or video-cameras can allow direct human input into the sensor process. For microphones and video-cameras, the main limitation is the quality of data, for example capturing data in noisy area or capturing human face in the dusky zone. One noticeable drawback of GPS is the ability to detect location is not precise if signal is acquired only from GPS satellite. For accuracy, GPS and cellular network shall be collaborated to supply an approximate location to simplify and speed up the necessary GPS calculations[26]. For other sensors, they do have a number of limitations on not being able to collect arbitrarily kinds of environment data such as pressure and humidity.

2) Massive and heterogeneity of data:

From the aspect of IoT data format, data can be numerical/text, video and audio. These kinds of data contribute to data polymorphism and result in data heterogeneity. On the other hand, data is not consistent with dynamic nature since a collection of devices in wireless networks can be added or removed from the network which induces continuous changes. The ambiguity of semantics, the error of measurement, and the dynamic change of data can further lead to data uncertainty.

As the data in IoT systems is multitudinous and each contains a clear description to express itself. The quantity and quality of data accumulated can ignite several problems such as transmission, storing, and processing. The first can occur during the transmission or from the stage of data inputting, the assurance on real time transmitted and quality of data may not be achieved due to the bottleneck of bandwidth and noise. The second can exist during data storing, backup, recovery, and data management. The last can be realized from the process of missing data handling, removal of redundancies, and the integration of data from different sources into a unified schema[53].

3) Security and privacy:

The security and privacy of data transmitted between IoT collection devices and data storage is frequently going through wireless medium. This data can be in danger from several attacks; the physical attacks: tapped into collection devices, or the wireless information attack: hack data from transmission medium. These are considered drastic because the collection devices have low self-defense, and no ability to accept security application for partial saving[54].

To guarantee the privacy of things, the personal information such as name of collector, means of data collection, and time of collection should be attached with each record for ease of tracing. Furthermore, the personal data collected should only be used by authorized person, stored in an authorized server, and accessed by authorized clients[53].

4.2 Data Administration

The issues related to data administration originated from two main cases; the schema related and data related. The first can be classified as naming conflicts which arise when the same name is used for different objects or different names for the same object. Meanwhile the structural conflicts may occur when there are different representations of the same object in different sources. Data may be formatted with different data type, and different integrity constraints. Major considerations to be focused are as follows:

1) Data Cleaning:

The cleaning process is often embedded in the middleware which interfaces with the sensor devices. The IoT data sources are typically developed, deployed and maintained independently for specific needs. Hence, this process is performed before loading the transformed data to overcome the problems of data misrepresented, overlapped or contradicted. Obvious problem found in case of overlapping data, is the mistake value representations or the error representations of the values[55]. Although variety of tools are available to support, a significant portion of the cleaning and transformation work has to be done manually or by low-level programs which are difficult to code and maintain.

As for RDBMS, the process of data cleaning shall not be performed in isolation. It should be performed together with schema-related data transformations based on comprehensive metadata otherwise the data cleaned will be useless. Data cleaning is one of the major issues in IoT data management but the research community only pays little attention to this stage.

2) SQL vs NoSQL Model:

SQL and relational model aimed to interact with the end user were designed long time ago. At present, the function for aggregated reporting information is very powerful. Features on explicitly control concurrency, integrity, consistency, or data type validity are as well very strong. As for NoSQL, the data modeling often starts from the application -specific queries as opposed to relational modeling. Thus, a deeper understanding of data structures and algorithms is required more than it does in relational database modeling. Besides, how to handle the data duplication and de-normalization in NoSQL which is a prime incident is rather complex[56].

3) Indexing:

The relational database management systems (RDBMS) are usually empowered with rich functionalities of indexing to support efficient multi-dimensional access based on K-d tree and R-tree indexes. However, those indexes cannot scale up well when dealing with massive volume data or millions of insert per minute. The more appropriate option is the Key-value (NoSQL) paradigm which can handle a large volume of updates per minute while providing fault tolerance and high availability. NoSQL does not equip with rich functionalities or natively multi-dimensional access. But it can proficiently support both point and range queries on rowkey and scanning the whole table for the queries on non-rowkeys. Hereby, SQL is less effective than NoSQL for IoT data management.

4.3 Data Processing

The data and events from IoT are enormous but their semantic information is very simple and cannot be directly utilized in applications. To aggregate these simple basic events into advanced events, data mining techniques have become a widespread technique where the complexity and energy consumption are their main characteristics. Some of the concerns on the processing of IoT data are stated below.

1) Query:

The traditional query processing is fading off due to extra investment in hardware. That is why MapReduce jobs are amenable to many traditional database query optimizations for selections, column-store-style techniques for projections, and etc. However existing systems do not apply them substantially because free-form user code obscures the true data operation being performed. For example, a selection in SQL can easily be detected. This selection is not easy to handle in a MapReduce program because Java code with lots of other program logic are embedded. Besides, the number of open-source MapReduce programs are relatively small and fairly strict adherence to its programming paradigm. The setup for data processing also creates several difficulties. Firstly, its model does not define the possibility of receiving the values sorted in some way in each call to the Reducer function. Secondly, a join function requires users to create two map functions instead of using standard SQL join. Thirdly, the creation of several output files required the utilization of the MultipleOutputs class which is not quite easy and does not perfectly fit[57].

2) Aggregation:

Data aggregation results in fewer transmissions with a tradeoff in greater delay. For example, data from nearer sources may have to be held back at an intermediate node in order to be aggregated with data coming from sources that are farther away. In the worst case, the latency dues to aggregation will be proportional to the number of hops between the sink and the farthest source[58].

4.4 Communication

The most popular protocol in IoT is the HyperText Transfer Protocol (HTTP). HTTP allows any types of computers to send files, images and videos across the web. However, in real scenario, the communication channel of IoT devices is normally via one or more "protocols". Thus, these devices have to handle many different tasks with less coincidence on which protocols to use. Also no guarantee on how these gadgets can talk to one another in the same language. To ease the communication of devices, many solutions offer the devices on IoT to communicate through centralized servers or a flock of sub-networks, but a failure in communication occurs easily. Imagine a case when a car's owner need a part replacement, he cannot order from other car companies. This infers that each device can only be controlled individually, making the forwarding of data among networks is impossible to be real time. Therefore, data transmission in IoT is still difficult to share because devices in the network cannot actually communicate with devices on other sub-networks. Data has to travel farther and may be subject to congestion at hubs, slowing down services as well as the centralization of data can raise security and privacy concerns[59].

As long as all communicating in IoT happens over some types of network. It must be admitted that some devices may be hardwired into an existing network but others may need to communicate wirelessly. Ideal implementation is to create mesh networks where nodes can relay information across the network. If devices and sensors can operate as nodes, the communication across the network will be robust. Especially if the network is self-organization, it can be confidence of optimization of network structure, traffic and load distribution. The other wish is if network can be self-healing and self-adapting then it can heal itself without interaction from users. Finally, another hefty obstacle to IoT is the lack of a common framework to communicate. This will continue to be so for some times. Without this ability, there is no way that real-time transparent communication can become real.

4.5 IoT Applications

IoT applications in this article refer to solutions using IoT technologies to improve processes, enable new and efficient ways to create services, offer an optimized infrastructure, reduce operational cost, or improve human safety. Potentialities offered by the IoT applications clearly improve the quality of our lives: at home, while traveling, when sick or at work. Some of their contributions include:

• Visibility identification, location tracking[43,47,51].

• Safety supported in hard environments[24,41].

• Right information providing or collecting[12,45].

• Reduced losses[39,44,46,52].

• Reduced energy consumption [5,49].

• New type of maintenance and lifetime approaches[6,42,50,60].

Even though their benefits are almost limitless in saving time and resources as well as opening new opportunities for growth. In order to fully utilize their capabilities, here are some of the issues to overcome:

• Incompatibility: each application is built on its proprietary ICT infrastructure and dedicated devices.

• Cost: similar applications cannot share related features for managing services and network, resulting in unnecessary redundancy and increase of costs.

• Vulnerability: handful of treats in the application like vehicle to vehicle communications concern standard codes such as the control of bus protocol. If hackers can figure out the codes for a c ompany, this can lead vulnerable because other companies' code will be quite similar.

• Data inconsistency: transmission of data between sources and processing units may contain noise or signal loss which will harm the application processing.

In the future, these applications will not only work in isolation, but they will share infrastructure, environment and network elements, and a common service platform. To reach such efficacy, they should be orchestrate these anticipation in the following ways:

• Creating algorithms and schemes to describe information created by sensors in different applications.

• Trust and ensure of data exchange among applications and infrastructure to prevent the introduction of false data.

• Design of cost-efficient application with confidence to consumers.

• Immediate identification of harmful circumstances.

• Standardization of interfaces from sensors and devices.

• Provide high degree of automation in processing of information.

5. Challenges, opportunities and existing gaps

The more challenges in data collection, data processing, data administration, communication and applications, the more development opportunities which can lead to a development of IoT in several domains. This section presents lessons learnt from the review.

1) Challenges: a few challenges facing in IOT data management are

• Technical aspects of devices: a set of technical features generally depend on application faucets such as sampling rate, communication, time synchronous of data in both single-hop and multi-hop networks. Heterogeneity frequency bands and sampling rate of networks or devices are difficult to manage.

• Lifetime: the lifetime of IoT devices is always less than normal. This mismatch needed shall be considered for the complete design and management.

• Energy: scarce of resources for active devices and the complexity of blended technologies have always been a major barrier of IoT due to the increasing in computational algorithms and knowledge requested from the systems.

• Data and information: as long as IoT data is from heterogeneous sources, adaptive data handling, data processing and data fusion methods must be reliable.

• Human and businesses: Easy to use and reuse of non-permanently attached devices for humans are often neglected.

2) Opportunities: data management in IoT will be of great opportunities in the future, if following capabilities are provided:

• Reliability: devices and systems shall allow a continuous operation of processes.

• Robustness: applications and devices shall be robust and adapted to the online task and hefty working conditions.

• Reasonable cost: the right balance between cost and benefit shall be justified. The impact of cost shall also be considered in both normal circumstances and in case of IoT devices or applications fail.

• Security and safety: the entire security strategy of the company shall cover cyber security threats. Whereas the safety is mainly derived from the device specifications, usability and the area of use.

• Ease of use: simple, and self-explaining are important for the overall IoT application acceptance. Context awareness and self-adaptation to the skills of user and location or environment are ideally expected.

• Less maintenance: the life cycle costs of IoT affected by high number of IoT devices in place. These devices are generally distributed over large areas which require high skills, advanced tools, and time for maintenance.

• Standardization: a set of standard IoT devices and interoperability of applications which introduces easy exchange and multivendor possibilities are always expected.

• Integration capabilities: easy integration in the IT, automation and landscape of the industrial plant are recommended.

• Sensing and data capabilities: complex sensing allowing distributed supervision and data collection are a big challenge in term of data processing.

3) Gaps: gaps for future exploration include:

• Low power wireless sensors: devices which do not need battery replacement over their lifetimes. Not only a low power-sensing unit is a dream solution, a design of low-power transmitter circuits shall also be considered.

• Stable connectivity: data transmission in IoT are in general an autonomous networking which connect large and dense data from stationary and moving devices. Consideration on cloud technology and clusters of machines shall be other possible options.

• Touchless environment: multidimensional and heterogeneous of data creates immense complexity in the analysis. Distinctive types of sensors with different in coming rate are also forcing data to by noisy and unreliable. A context aware-decentralized algorithms shall be designed. Autonomous data aggregation and correction at certain level of data transmission is another factor needed to escalate the computational capability from the backend server.

• Data security and privacy: the weakest links of IoT can be driven by the low-cost devices with low security and cryptography technologies. A development of low-cost and scalable cryptography algorithms and hardware accelerators shall provide a merit.

6. Conclusion

The potential of IoT is magnificent where its effect is already noticed in our daily life. Assisting the patients, managing the delivery of merchandises, and controlling the traffic systems are the development of changes. Despite that, several new challenges energized from data characteristics, transmission and technologies because IoT is a world of interconnected objects that are constantly exchanging all types of information. Futuristic volume of data generated causing data handling and performance issues. IoT devices are mainly connected to remote devices and systems where stability of connectivity with remote access and security have become vulnerable. To neutralize, solutions must be collaborated from both hardware and software technologies.

The incidences to overcome; such as design problems of diverse use cases, different resource constraints, and products and technologies available at many levels in the IoT environment can be accomplished only if standard methods of data processing and communication can be established. It seem to be an ideal case since different approaches may be suitable for different applications. As long as the complexity of data in IoT is something we cannot imagine of, we have to think hard whether our current methods of data management, querying and indexing work. At a high level, we need to establish a taxonomy of things from which general data processing can be built. At a low level we need to assess standard accessing and indexing approaches, to see how, and if they can be adapted.

In expectancy, the consolidation of recent technologies and weaknesses introduced can provide a predominate view for the integration of elements to escalate the efficacy of IoT data management. The sooner these issues can overcome, the more confidence we can trust on the quality and efficiency of IoT.

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