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Methodology and Technology for Internet of Things

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1. Introduction

Initially known as a buzzword, the "Internet of Things (IoT)" is expected to begin full-scale operation and develop into a large market. The International Data Corporation (IDC) predicts that in 2025, 41.6 billion devices will generate 80 ZB of data [1], where 1 ZB is global data volume in 2018. Better operations and new business models cannot be created by only blindly collecting vast amounts of data. The characteristics of IoT is that the information collected in the physical world is taken into the cyber-space and used. To bring out the real value of IoT, methodologies, and technologies based on this feature are necessary.

In this chapter, we will explain methodologies and technologies for IoT. First, in Section 2, we trace the history of the IoT, which has grown at an amazing speed since its birth. Next, Section 3 explains the methodology for the IoT. The important thing we need to keep in mind is "What to do with IoT", not "How to do IoT". Next, we formalize the IoT system as a data processing process, detailing the tasks of each step and related technologies. Section 4 and Section 5 describe IoT technology. Section 4 introduces the "IoT architecture", which is the basis for "how to make an IoT system." In Section 5, we will introduce the "IoT platform" that offers a combination of optimal technologies to build an IoT system speedily. Finally, Section 6 provides a summary and future work.

2. Birth and Growth

In 1999, Kevin Ashton coined the term IoT [2]. He is co-founder of the MIT Auto-ID Lab in the United States. He named the system that connects the physical world through the ubiquitous sensor as the Internet of Things. In 1999, human beings were the main users of the Internet. Ashton thought that a service that would be useful to humans would be realized by eventually connecting the devices directly to the Internet and exchanging various information between them without human intervention.

Unfortunately, in 1999, this idea and the term IoT were not widely recognized. There were two main causes. The first is that the cost of computer terminals that are required to take physical information

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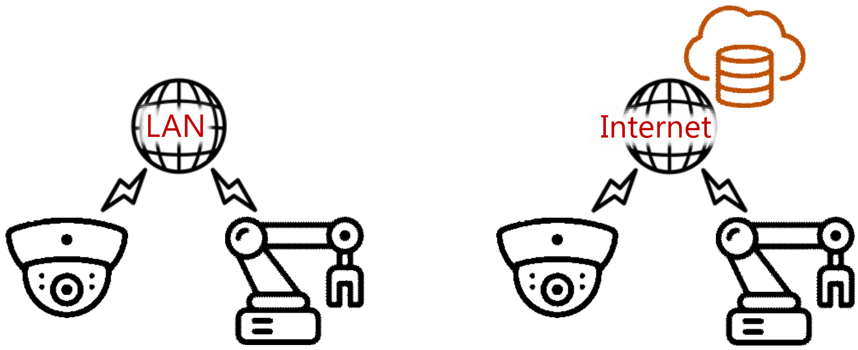
into cyberspace was high. The second reason is that the network or communication environment at that time was not ready to realize IoT.

The word Machine-to-Machine (M2M) has been widely used since around the year 2000. M2M refers to the exchange of information between machines in a physical space. M2M is a concept similar to IoT. However, M2M does not include the use of that information in cyberspace. Figure 1 shows the difference between M2M and IoT. The IoT uses the Internet instead of a closed network such as LAN. The IoT is intended not only for sucking up physical space data but also for utilizing it.



(a) M2M (b) IoT

Figure 1: M2M and IoT

The turning point for IoT came around in the year 2008. In 2011, Cisco System's Dave Evans reported that "More devices than the world's population were connected to the Internet between 2008 and 2009" [3]. He thought that not only merely increasing the number of things, but also connecting things in a "one-to-many" relationship via the net will bring great value. For example, connecting a car to other cars, roads, sensors installed in homes, and smartphones will enhance the user's experience. He also stated that it will be the driving force in the IoT.

In 2012, Germany announced "Industrie 4.0" [4] as a national strategy. Initially, it was an effort to protect the manufacturing industry in Germany. However, it became a big boom, and it developed into the fourth industrial revolution that will change all industries. In 2014, the United States established the Industrial Internet Consortium (IIC) to utilize IoT in the industrial field. Then, "Digital Twin" [5] that reproduces the same environment similar to the real world in cyberspace by using real-time data such as factory equipment acquired by IoT was proposed.

In 2015, the Ministry of Economy, Trade and Industry and the Ministry of Internal Affairs and Communications of Japan established the "IoT Acceleration Consortium" [6] to promote technological development and new business creation related to IoT through industry-government-academia collaboration. In addition, the "IoT Acceleration Lab" was created to encourage the creation of new business models using IoT. However, at the time of establishment, many participating companies were in a state of "they do not know what to do actually". The year 2016 is said to be the first year of IoT in Japan. In January, the Japanese government clarified its stance of promoting IoT with "Society 5.0". Finally, Japanese companies started to consider full-scale utilization for IoT business. Companies have started to come out with the proof of concept (PoC) stage and have entered the operational stage from the proof experiment. Moreover, in 2016, the "Local IoT Acceleration Lab" was started to expand the activity of the "IoT Acceleration Lab" into every corner of Japan (See Figure 2). 29 regions were selected as the first batch in July 2016, 24 regions as the second batch in March 2017, 21 regions as the third batch in August 2017, 19 regions as the fourth batch in September 2018, and 8 regions as the fifth batch in September 2019. 101 regions were selected in total. See Table 1 for details.

Figure 2: 101 regions selected as Local IoT Acceleration Lab

Table 1: List of Local IoT Acceleration Lab

Batch	Regions
First (Jul. 2016) 29 regions	Sapporo City, Hokkaido Pref. / Kushiro City, Hokkaido Pref. / Shihoro Town, Hokkaido Pref. / Miyagi Pref. / Aizuwakamatsu City, Fukushima Pref. / Ibaraki Pref. / Toyama Pref. / Ishikawa Pref. / Kaga City, Ishikawa Pref. / Fukui Pref. / Ina City, Nagano Pref. / Gifu Pref. / Shizuoka Pref. / Aichi Pref. / Mie Pref. / Kyoto City, Kyoto Pref. / Osaka City, Osaka Pref. / Kobe City, Hyogo Pref. / Nara Pref. / Wakayama Pref. / Shimane Pref. / Hiroshima Pref. / Kochi Pref. / Fukuoka Pref. / Kitakyushu City, Fukuoka Pref. / Fukuoka City, Fukuoka Pref. / Kumamoto Pref. / Kagoshima Pref. / Okinawa Pref.
Second (Mar. 2017) 24 regions	Hakodate City, Hokkaido Pref. / Sendai City, Miyagi Pref. / Semboku City, Akita Pref. / Saitama Pref. / Chiba Pref. / Kanagawa Pref. / Yokohama City, Kanagawa Pref. / Sagamihara City, Kanagawa Pref. / Yokosuka City, Kanagawa Pref. / Shonan Area (Fujisawa City, Chigasaki City, and Samukawa Town), Kanagawa Pref. / Niigata Pref. / Hakusan City, Ishikawa Pref. / Sabae City, Fukui Pref. / Nagoya City, Aichi Pref. / Toyota City, Aichi Pref. / Shiga Pref. / Osaka Pref. / Yamaguchi Pref. / Kahankei Area (Iizuka City, Kama City, and Keisen Town), Fukuoka Pref. / Saga Pref. / Nagasaki Pref. / Nagasaki City, Nagasaki Pref. / Oita Pref. / Miyazaki Pref.

Batch	Regions
Third (Aug. 2017) 21 regions	Sarufutsu Village, Hokkaido Pref. / Akita Yokorenkei（Yokote City, Daisen City, Gojyome Town, and Higashinaruse Village） / Yamagata Pref. / Nagaoka City, Nigata Pref. / Gunma Pref. / Yamanashi Pref. / Ota Ward, Tokyo / Kawakami Village, Nagano Pref. / Fujieda City, Shizuoka Pref. / Kahoku City, Ishikawa Pref. /Gujo City, Gifu Pref. / Kakamigahara City, Gifu Pref. / Kota Town, Aichi Pref. / Eiheiji Town, Fukui Pref. / Asuka Village, Nara Pref. / Awaji City, Hyogo Pref. / Okayama Pref. / Setouchi City, Okayama Pref. / Tottori Pref. / Minami Town, Tokushima Pref. / Minamishimabara City, Nagasaki Pref.
Fourth (Sep. 2018) 19 regions:	Muroran City, Hokkaido Pref. / Kitami City, Hokkaido Pref. / Wakkanai City, Hokkaido Pref. / Naganuma Town, Hokkaido Pref. / Higashikawa Town, Hokkaido Pref. / Aomori Pref. / Iwate Pref. / Takizawa City, Iwate Pref. / Akita Pref. / Tochigi Pref. / Nomi City, Ishikawa Pref. / Maibara City, Shiga Pref. / Yao City, Osaka Pref. / Tokushima Pref. / Kamiyama Town, Tokushima Pref. / Takamatsu City. Kagawa Pref. / Shimabara City, Nagasaki Pref. / Okinawa City, Okinawa Pref.
Fifth (Sep. 2019) 8 regions:	Mori Town, Hokkaido Pref.; Tsubame City, Niigata Pref.; Nagano Pref.; Kisosaki Town, Mie Pref.; Ehime Pref.; Ube City, Yamaguchi Pref.; Nogata City, Fukuoka Pref.; and Onna Village, Okinawa Pref.

Figure 3 shows 330 IoT devices that can be purchased in Japan as of 2018. The "IoT Device Map 2018" [7] was released by Robot Start Inc., Japan. The devices are categorized by use and location such as the bathroom, living room, health/fitness, garage, wearable/personal, theater room, private room, kitchen, entrance, office and others. These classifications help us to imagine how to use those devices at a typical Japanese house.

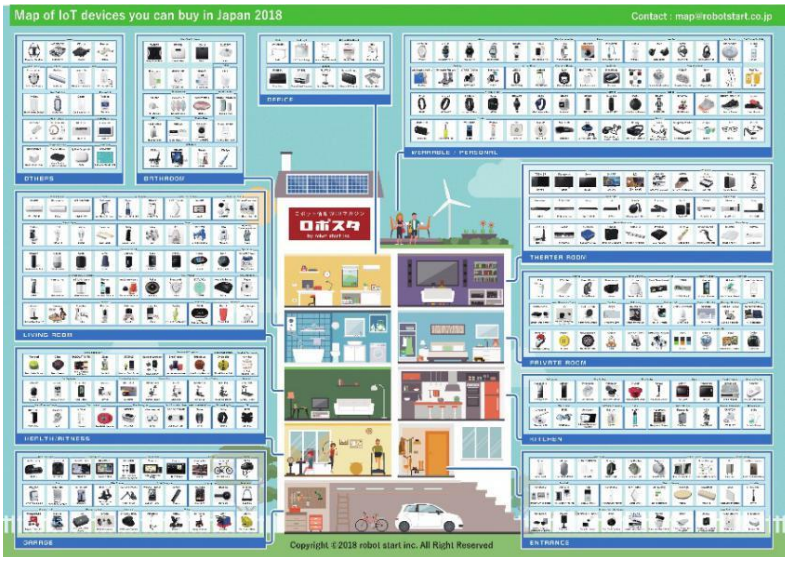


Figure 3: IoT Device Map 2018 [7]: 330 devices available in Japan

3. Methodology

The most important thing we need to keep in mind is that "What to do with IoT," not "How to do IoT." Better operation and new business models cannot be created by only blindly collecting data with IoT. First, we need to know the characteristics of data handled by IoT.

The data handled by IoT has the following characteristics:

1) Large Volume: A large number of devices repeatedly generate data.
2) Heterogeneous: There are products with various standards and various formats. The formats of input, output and protocols are different.
3) Noisy: A missing value or an outlier occurs due to the installation location, communication environment, and battery consumption.
4) Time Sensitive: Due to network delay and time difference of each device, time delays, and error in values occur.
5) Dynamic: Applications of data change rapidly due to changes in the environment.

A data processing process based on the above characteristics is required. Yako et al. [8] gave the process (See Figure 4) as follows:

1) Collection
2) Accumulation
3) Cleansing
4) Aggregation
5) Analysis
6) Utilization

Figure 4: Process of data processing

The six steps of the data processing are described as follows:

Step 1) Collection: Collect the data generated by the device through the network. Consider the size and cost of the network, and decide on what format to collect them. Then, decide whether to send the collected data to the cloud or to a device or gateway.

Step 2) Accumulation: Store the collected data on the cloud side. It is recommended not to discard the data collected for future use. It is important to store a large amount of data in a form that is easy to retrieve. NoSQL (Not only SQL) is widely used because it is strong against large amounts of data and high-speed processing and easy to scale up.

Step 3) Cleansing: Cleanse the data into a usable form. This is because the data sent from the device may have different formats or may contain noise (missing values or outliers). However, noise also represents information about what is being done in the field. Therefore, it must not be removed blindly and its source must be identified.

Step 4) Aggregation: Gather the data needed for analysis to achieve the goal. Not only IoT device data, but also core system data, open data, and commercial data should be used. It is better not to physically combine them into one database, but to link the data using API according to its purpose.

Step 5) Analysis: Analyze the accumulated data. Analysis methods are mainly divided into two types: statistical methods and machine learning-based methods. The former pursues interpretation, the latter pursues accuracy.

Step 6) Utilization: Utilize the analysis results to improve operations and to create new business models. This step still requires manpower. For ease in this step, Business Intelligence (BI) tools are widely used to visualize the analysis results. Visualization helps to find the true problem and to find clues to its solution.

Ideally, "What to do with IoT" should be clear from the beginning. However, it is not always possible to clarify the purpose from the beginning for systems that expand rapidly with IoT. The process shown in Figure 4 does not end once the process is completed. The important thing is to verify the results of utilization and execute them repeatedly to achieve the true purpose. In other words, the process must form a cycle including the verification step, as shown in Figure 5.

Figure 5: Cycle of data processing

4. IoT Architecture

IoT connects things and services that were not previously connected via networks. If a large number of individually developed products and services are connected ad hoc, it becomes difficult to operate and manage the entire system. To address this issue, IoT architecture has been proposed. IoT connects things and services that were not previously connected via networks. If a large number of individually developed products and services are connected in an ad hoc network, it becomes difficult to operate and manage the entire system. To address this issue, IoT architecture has been proposed. IoT architecture provides the basis of how to create an IoT system.

A typical IoT architecture is the IoT reference model [9] proposed by the IoT World Forum. The IoT World Forum is an international conference held every year, initiated by Cisco Systems. Figure 6 shows the IoT reference model of the IoT World Forum. This model consists of seven layers.

Figure 6: IoT Reference Model proposed by IoT World Forum

Layer 1 (Physical Devices & Controllers): This layer deals with technology related to objects in physical space. Currently, there are many considerations on the sensor side, but in the future, considerations on the accumulator side should be given more focus.

Layer 2 (Connectivity): This layer handles communication technology among devices, gateway, and cloud. In recent years, low-power, low-cost connection solutions specialized for IoT have appeared.

Layer 3 (Edge Computing): This layer handles edge computing technology. If an IoT system were a human, edge computing would be the "spinal reflex". In addition to prompt response, it enables cloud load balancing, communication cost reduction, and security assurance. Recently, fog computing has attracted attention. It can perform distributed processing in cooperation among interconnected edge computing nodes.

Layer 4 (Data Accumulation): This layer handles storage technology. Technology such as NoSQL is drawing attention in IoT systems. Also, in IoT systems that require immediate response, streaming processing is an important technology because it accumulates data and performs processing in real-time.

Layer 5 (Data Abstraction): This layer handles technology related to data aggregation and access. In addition to the data collected by themselves, external data should be actively utilized. The purchase and sale of data have already begun. It stimulates the utilization of external data.

Layer 6 (Application): This layer handles technology related to data analysis and visualization. Business Intelligence (BI) tools can assists us to prepare data for analysis and visualization. Furthermore, self-service BI tools have enabled end-users to understand trends and derive insights from their data.

Layer 7 (Collaborations & Processes): This layer contains the business model to be applied. It deals with the technology for connecting the analysis results to allow actions for improvement. However, analysis is not a goal. The real goal is to create better operations and new business models.

5. IoT Platform

There are a wide variety of IoT technologies, and each is evolving at a tremendous speed. In the development of IoT systems, we need to combine optimal technologies and to build them rapidly. An IoT platform has been proposed to meet this demand. The IoT platform is a packaged solution that combines multiple technologies. A platform corresponding to each layer of the IoT architecture is available. For example, there are secure communication packages for Layer 2 (Connectivity) and data linkage platforms for Layers 4 and 5 (Data Accumulation & Abstraction).

Some IoT platforms are cross-vertical. A representative example is PTC's ThingWorx [10]. ThingWorx provides a model-based development environment for IoT systems. You can build models and dashboards with mouse operations and confirm the behavior by simulation.

6. Conclusion

This chapter explained the methodology and technology for IoT. Section 2 introduced the history of growth from the birth of the IoT and clarified recent developments in Japan. Section 3 explained the data processing process based on the characteristics of IoT data. The process consists of the collection, storage, cleansing, aggregation, analysis, and utilization. This process must be repeated by including verification to achieve the true goal. In Sections 4 and 5, IoT technologies such as "IoT architecture" and "IoT platform" were introduced.

In the future, we can expect that the IoT system will evolve from "make" to "buy" and "sell". The authors have advocated the concept of "Design Once, Provide Anywhere" and are developing a platform called Elgar platform to realize the concept. For details, refer to References [11] and [12].

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