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A Method of Prototype Construction for the Active Creation of IoT Application Ideas and Its Evaluations

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Abstract In recent years, various applications are expected to arise for IoT systems that incorporate sensor technology, network technology, and information processing technology. With IoT systems, several technologies must be combined systematically. Design and construction of IoT systems require great amounts of knowledge, time, and funds. In this paper, we propose a method of prototype construction for the active creation of IoT application ideas. This method clearly presents contents and procedures for prototyping for students of non-IT courses and non-science/non-engineering courses in their own specialized fields. This method has an IoT device implementation framework. Application of the framework facilitates ease of connection of versatile sensors and actuators. After the prototype is constructed according to this construction method, those who constructed it (constructors) can perform problem solving, idea creation, and needs assessment related to their own specialized fields. This construction method was applied practically by science and engineering students in non-IT courses and non-science/non-engineering students, for whom its effects were evaluated.

Keywords IoT system, M2M system, Prototype, Gateway, Cloud, Sensor, Actuator

1. Introduction

Internet of Things (IoT) and Machine to Machine (M2M) systems can perform automatic processing using various sensors, networks, and information processing technologies, fused together in a cross-sectional manner. Actually, IoT/M2M systems are applicable to fields of industry, public infrastructure, and medical care and welfare, and to life areas of human society. In many fields, IoT technology has been applied extensively [1-5]. This rapid extension of applications is attributable to rapid advances in sensor technology for detecting the status of object devices and network technology for collecting data from many locations. Moreover, cloud computing has evolved quickly.

Future IoT/M2M systems are expected to extend the range of applications further. For that to occur, both idea creation for practical applications and human resource development are crucially important. However much knowledge must be acquired to design and construct IoT systems, frequently entailing longer time periods and higher costs. If prototype construction methods using open hardware and software were available, then the constructor could produce IoT prototype systems rapidly. They could understand IoT systems through prototyping. Using IoT prototyping, a constructor could solve problems of their own fields and create ideas to meet specific needs.

In this paper, we propose a method of prototype construction for the active creation of IoT application ideas. The method includes basic configuration of the IoT prototype and procedure. Basic configuration elements are selected from open hardware and software. Then the prototype constructor can produce an IoT system prototype from this basic configuration. The contents of prototyping and procedures of construction are defined by every specialized field. Particularly, sensors and actuators of numerous types are involved in the construction. The proposed construction method has an implementation framework of the IoT device to enable ease of handling of these elements. A prototype system was constructed according to the construction method and implementation framework. Based on the prototype construction experience, the constructor can expand the prototype, create ideas, and ascertain needs for problem-solving of their own

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specialized field.

The construction method proposed herein was applied to the education of science and engineering students of non-IT course and non-science/non-engineering course students. Then its features and efficacy were evaluated.

2. Outline of IoT and Prototyping

(1) Outline of IoT system

Attention has been given recently to IoT systems using sensors and equipment connected to the internet to provide diverse services without human intervention [1-4]. Results of these studies have clarified the IoT system architecture.

Figure 1 presents an IoT system outline. The figure shows sensors and actuators of various types mounted on the device shown at the left. Data from the device are transmitted to the server or cloud via the area network, gateway, and access network. Data collected by the information system on the server and cloud are processed for visualization and analysis, with feedback to the device to control it.

(2) Problems related to IoT system construction

The IoT system consists of many configuration elements, as presented in Figure 1. The element technology of each component should be acquired. Then the whole system should be designed before construction. These are handled primarily by IT engineers in the science and engineering field. However, application of IoT is sought in multidisciplinary fields. Therefore, ideas presented by people in various fields other than IT fields are valuable. To encourage students to understand the basic technology of IoT and to create ideas for IoT application system, it is important for students to construct an IoT prototype system by themselves.

In the IoT research field, most studies address problem -solving in the respective technical fields of sensors, area networks, gateways, server interfaces, and services on the server. However, for easier construction of the prototype of the whole IoT system, configurations and procedures have not been made available yet. As a study of specific IoT system building or prototype construction, for example, a system exists to perform control and monitoring in the home using a smartphone [6]. Furthermore, studies have examined detection of human hand movement using a camera as an IoT system [7]. In this way, studies have assessed particular IoT systems applying IoT technology. Researchers have explained construction, evaluation and verification. Results of these studies, have resolved various problems and produced solutions for IoT systems and prototyping. However, few reports of the literature describe studies of methods of construction, their application to education in universities, or their evaluation.

Sensors and actuators are becoming smaller and cheaper by virtue of recent progress in the technologies which play important roles in the application of IoT system. Even in the prototype, various sensors and actuators should be handled in the engine for controlling IoT devices. However, this mechanism and method of construction have not been clarified yet.

For prototype construction, it is possible to simplify the construction if the architecture is defined in advance and if several elements are black boxed. The constructor can then understand the IoT system, understand roles of the components and obtain basic knowledge to devise applications.

3. Proposal of IoT Prototype Construction Method

We propose a method of constructing a prototype aiming at creation of ideas for IoT application system. Using this method, the constructor produces a prototype according to the contents and procedures of a specialized field along with the basic configuration of the IoT prototype. The constructor can then understand the IoT system, create ideas, and ascertain needs for problem solving for one's own specialized field.

3.1. Configuration and Construction of IoT System

Figure 2 presents the basic configuration of the IoT prototype system and objectives. In the figure, the lower area shows options of the components, the middle area shows the basic configuration of IoT prototype system, and the upper area presents objectives of prototype construction. The components include open hardware, software, and cloud services. Based on this configuration, the constructor selects each component and combines them appropriately to realize the construction simply and less expensively. Configuration of the IoT prototype in the middle area in the figure is constituted such that one can experience a series of flow. A series of flow means that data are acquired from various sensors and accumulated in the server/cloud via gateway. The data are then fed back and output to actuators. Application of the gateway performs communication with IoT devices, data format conversion, and internet communication processing with the server/cloud. Because the data go through the gateway, communication tools with the server/cloud are unnecessary for every IoT device. Processing loads of the IoT device and power consumption can therefore be reduced. Cloud services and application on the server/cloud execute processing such as accumulation, conversion, and analysis of the data. When the data are fed back to the IoT device side depending on the results of processing by server/cloud, the application of the server/cloud transmits an instruction to the IoT device via the gateway. The IoT device which received this instruction issues an instruction to the actuator.

Features of the method of constructing prototype proposed in this paper are that parts are selected from open hardware, software and cloud services and that selected parts are combined appropriately to construct a prototype system. Consequently, people with no knowledge of IT systems are able to construct the prototype. The constructor can then create new ideas from actual construction experience.

3.2. Prototyping Contents for Special Fields

Constructors were divided into two categories depending on their specialized fields. One category is science and engineering students such as electric/electronic course as well as mechanical courses. The other category is non-science /non-engineering students specialized in, for example, nursing care, childcare, welfare and housekeeping. The prototype configuration conforms to the basic configuration to elucidate the whole picture of the IoT system. Constructors are divided into two so that they can select components according to their specialized fields and so that they can perform prototyping easily.

Science and engineering students such as those of electrical/electronic and mechanical courses construct a prototype using sensors and actuators related to own specialized field and use board computers as the gateway. The prototype thus constructed is practical. It can be developed easily for use in one's own specialized field. For example, the constructor will experience prototyping to control LED brightness by illuminance to control the growth of vegetation.

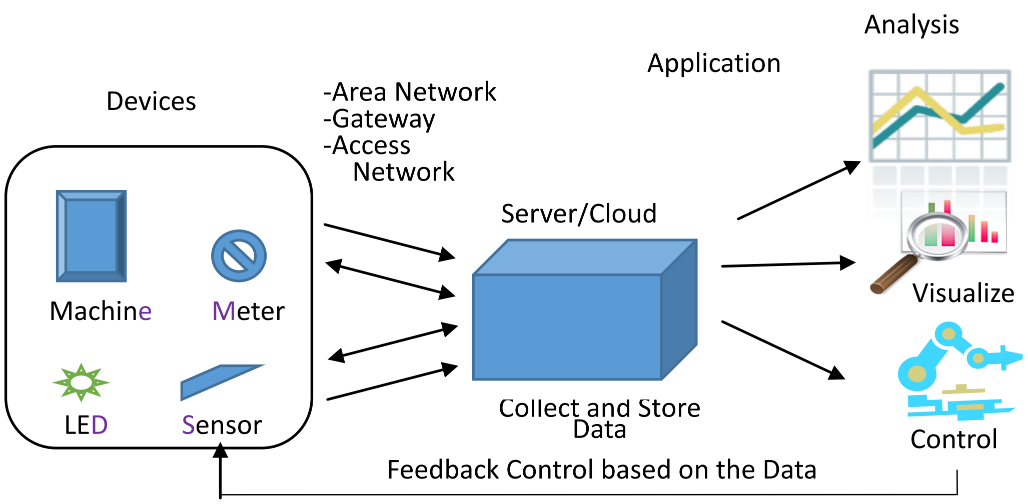

Figure 1. IoT System overview

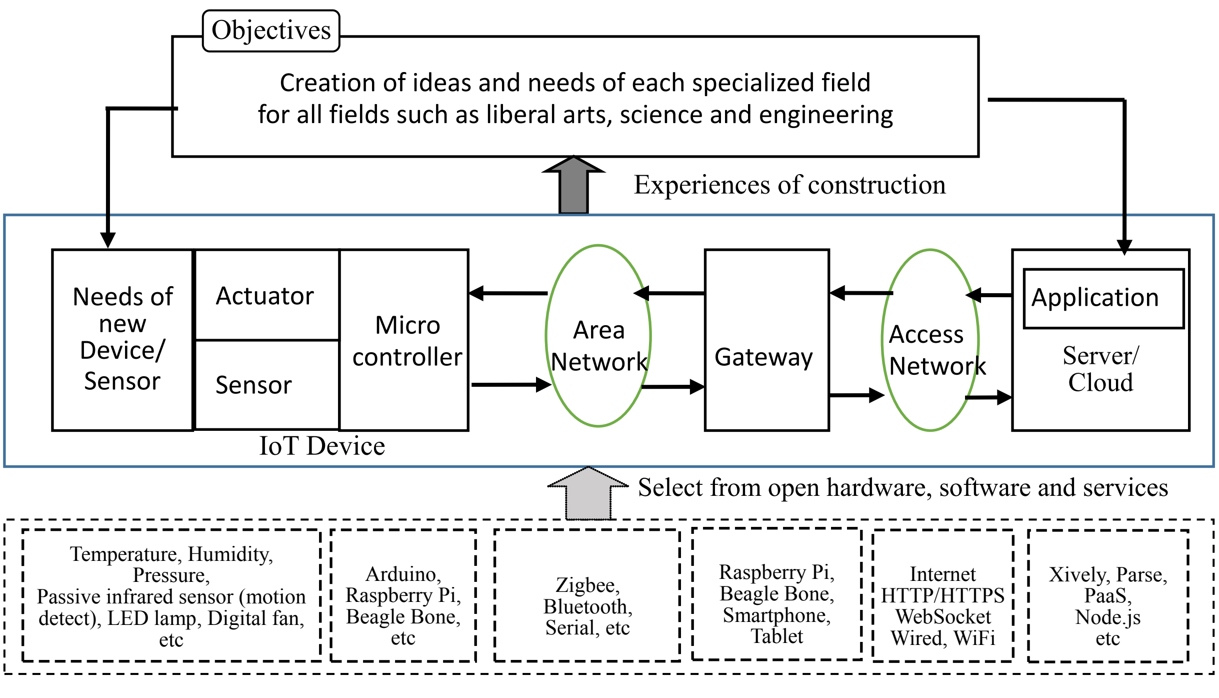

Figure 2. Basic Configuration of IoT Prototype System and its Objectives

The objective of prototyping for non-science/ non-engineering students is comprehension of the mechanisms of the IoT system. To realize a prototype system, the constructor uses sensors and actuators that yield easy-to-understand results, with personal computers as the gateway. The constructor uses services that allow data accumulation and an easy-to-view display as the cloud service. The program is black boxed and supplied in the form of a sample program so that the constructor might not create a new program.

3.3. Construction of IoT Device Program

The program run by the IoT device engine is operated on Arduino [8] equipped with various sensors and actuators. The program performs processing such as sensor reading, outputting to actuators and sending and receiving to and from the gateway. We define a framework as a mechanism to connect various sensors and actuators and to cope with changes of communication methods of sending and receiving to and from the gateway. The method is depicted in Figure 3. In the figure, the event table at the center is a table for control of the input–output of various sensors and actuators and timing of sending and receiving to and from the gateway according to the priority order. Each of the processes is implemented as the library and is called from the framework of event control. Even if types or combinations of sensors or actuators or types of area network differ, construction of the program is patterned. Therefore, the program can be understood easily and reused easily. Furthermore, a common class for IoT is implemented at the upper level of the sensor/actuator/ communication library shown at the center of the figure. Using this configuration, the person who created the application program can create a program with ease even if the data delivery method, types of sensor/actuator, or types of communication differ.

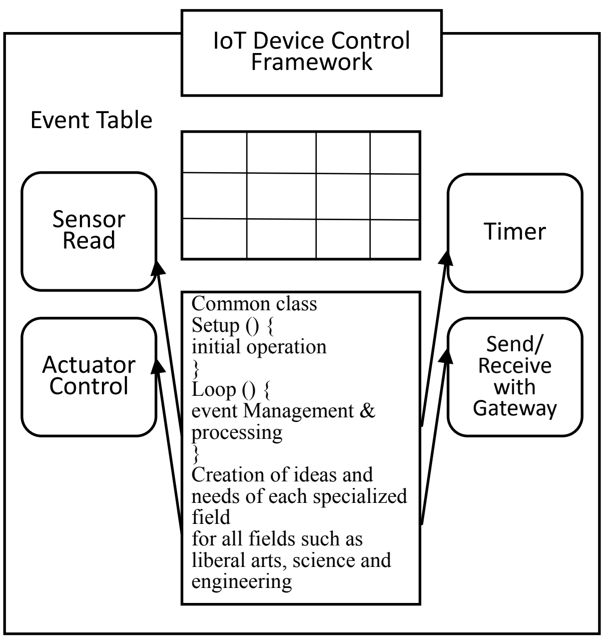

Figure 3. IoT Device Control Framework

4. Application of IoT Prototype Construction Method and Its Evaluations

This chapter explains results of application of IoT prototype construction method and its evaluations.

4.1. Application and Evaluations

We defined prototype configuration of two types by the specialized field shown in Chapter 3, prepared specifications and procedure manual and created a program to construct the prototype. Contents of the practice and evaluations by students and teaching staff are presented here.

4.1.1. Application to Science and Engineering Students in Mechanical and Electric/Electronic Courses

(1) Application to mechanical and electronic engineering courses

For students of Mechanical & Electronic Engineering Department of Salesian Polytechnic [9], we gave lectures and practiced engineering skills as research. Figure 4 presents the configuration constructed, with data flow and processing of the application of concrete IoT prototype system. First, data from temperature, humidity and color sensors are sent to Raspberry Pi [10], acting as the gateway in the form of a ZigBee [11] wireless interface.

Next, the gateway displays the data on the screen in the form of graphs and executes Parse [12] transmission of the cloud service. The cloud service registers those data to the database. The gateway takes out the data registered to the cloud service and sends an instruction to the IoT device according to the condition of the value concerned. Upon receiving it, the IoT device changes the LED lamp color. According to such processing flow, the constructor can experience a series of processing flow as the IoT system.

The idea which the student created from their experiences was applicable to remote control of the hydroponic culture [13]. The hydroponic culture is plant cultivation using color of light and water. Remote control and monitoring are made possible if IoT is applied to it. Figure 5(a) shows one aspect of the hydroponic culture. In the photograph, the upper area is an IoT device which senses temperature and illuminance and controls the light color. Figure 5(b) presents an example of monitoring in the form of graphs.

Evaluations by the teaching staff was conducted as follows. The student who practices prototype construction is normally in the mechanical and electronic engineering course and is not in an IT field. However, this student does know that "Convenience of the student's specialized field will be improved by application of IoT technology."

If the student did not know IoT, the student was unable to devise an idea related to remote monitoring. However, the student who came to know IoT technology was able to create added value by a combination of knowledge.

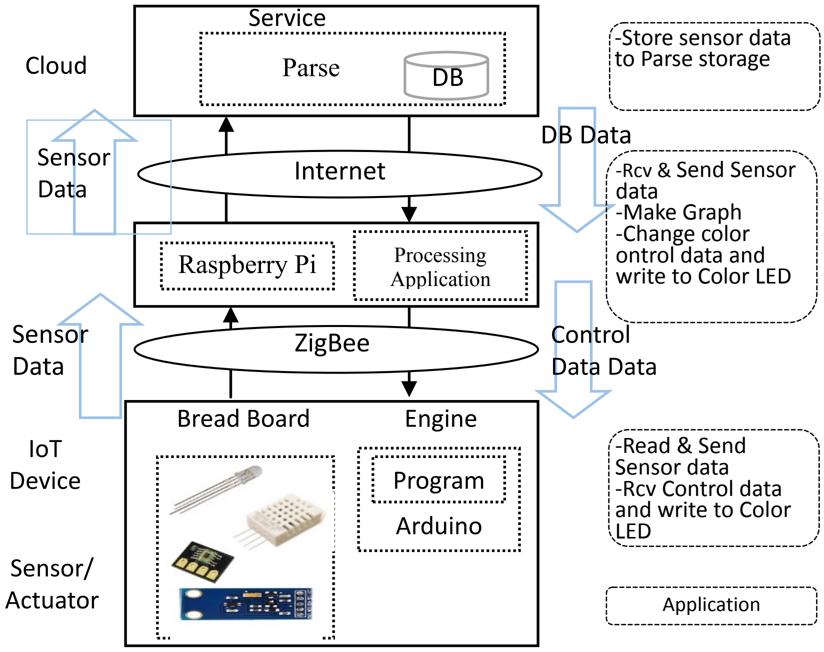

Figure 4. IoT Prototype Example

Figure 5(a). Application to hydroponic culture

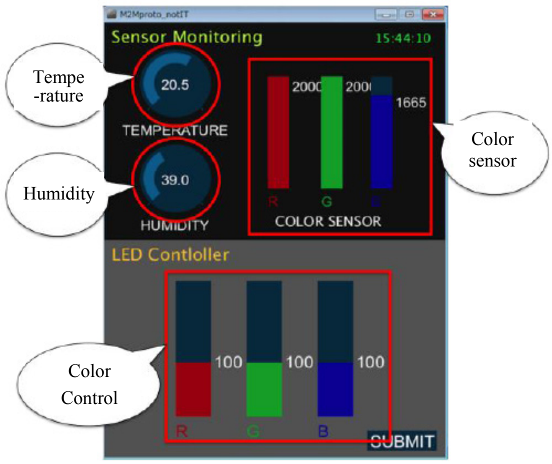

Figure 5(b). Graph Sample on Gateway Monitor

(2) Application in System science and engineering course

Department of Electronic Information Systems, Faculty of Science and Technology of the Shibaura Institute of Technology [14], has been implementing the Project Based Learning (PBL). Its features is that the students of the undergraduate and graduate school traverses the field. As its outcome, they have done the research about a design and the implementation of international PBL by the graduate student of the fields such as machine, electronic information, environment, mathematics science and life sciences [15]. In addition, they have done the research about the assessment of outcome of systematic PBL [16] and the education on systems architecture related to the plan and the design of embedded system for graduate school master students [17]. This time, the students completed an IoT prototype system based on IoT prototype configuration, which monitors potted plant cultivation using temperature, humidity and soil moisture sensors. State monitoring using a smartphone from a remote location was made possible while the data are sent to the cloud. The constructor was able to know benefits of the IoT system through processing of these data series. The student was able to understand operations of the whole system in which each of the elements cooperates with others as the IoT system and was able to understand the roles of each element of the IoT system.

One idea which students created was that environmental data such as temperature and humidity and image data would be collected using smartphones, accumulated in the cloud and be applied to monitoring of agricultural plastic greenhouses and safety monitoring of elderly people. It must be acknowledged that such original ideas were created through prototype construction.

4.1.2. Application to Non-science/Non-engineering Students

At Hosen College of Childhood Education [18], where students specialize in training childcare workers in subjects such as early childhood education and childcare, we gave lectures including IoT prototyping practice. Table 1 presents a summary of the curriculum of the lectures. According to this curriculum, to perform practical training of IoT prototyping, a prototype is constructed step by step while deepening understanding by the students. Lecture contents are similar to those given to science and engineering students. One difference is that Xively [19] was used as the cloud service and PC was used as the gateway. Regarding the IoT device, Arduino microcontrollers were used to control sensors and actuators. Serial interfaces using USB were used for connection with the gateway. Figure 6 shows the configuration used. The prototype system used atmospheric pressure, temperature, and illuminance sensors and as actuators, LED lamp and electronic buzzer were used. During Steps 1–4 shown in Table 1, operations were confirmed step by step and in the subsequent "Idea Creation," every student was encouraged to present various ideas based on the construction experience and to discuss their ideas. Non-science/non-engineering students are not familiar with programming. For that reason, the teaching staff provided programs run on Arduino and on personal computers. Figure 7 presents an example of a graphic display of sensor measurements of PC in Step 2.

For the lecture preparation, prior explanation was given to the teaching staff in charge and rehearsal took place. The lecture and practice were given to teams consisting of several students. As a result, non-science/non-engineering students were able to attain prototype construction and to create ideas for IoT systems.

The degree of attainment of application of IoT prototype construction method by the lecture and practice was measured as follows: Evaluations of the degree of attainment performed according to the procedure manual was performed from 0%–100% at 20% intervals. Results show that trainees gave an average of 77.6%. The teaching staff also gave an average of 75%. These results demonstrate that if a prototype is constructed according to the procedure manual, students were able to understand the IoT system to a certain degree. Upon construction of the prototype, lecturers and student held discussions based on ideas presented by each student. Consequently, ideas unique to students' learning of childhood education were collected. In addition to ideas related to nursing environments and play equipment, the following comments were presented (major comments only): (1) Age and grade restriction are set to the play equipment, and a warning is given when a child under the age limit attempts to play on it. (2) A camera is provided at the gate which would not open for unregistered person other than a child, infant, or staff member. If one attempts to break in forcibly, a buzzer sounds. (3) If a child wanders into a forbidden area, a buzzer sounds. (4) It is dangerous if an infant lies on its stomach during sleeping. An appropriate warning is sent to the childcare provider.

Table 1. Summary of Curriculum of an Education for a IoT Prototyping

Lesson step		Contents
Get Knowledge		Basic knowledge of an IoT system
Prototyping Practice	1st step	Produce IoT device comprising sensors, actuators and a microcontroller. Check movement on Serial monitor.
	2nd step	Transmit sensor data to IoT gateway. Draw graph on the Gateway.
	3rd step	Transmit sensor data to Cloud service Store data on the Cloud service storage.
	4th step	Feedback to IoT device by judgment of data on the Cloud services.
Idea Creation		IoT application idea creation after the IoT prototype systems construction practice

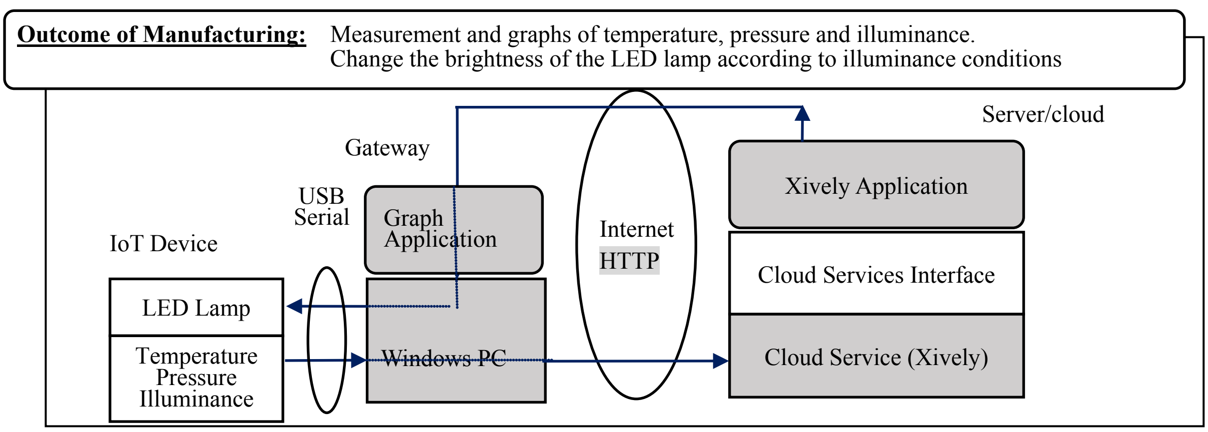

Figure 6. Outcome of Manufacturing by Prototyping for Non-science/non-engineering course

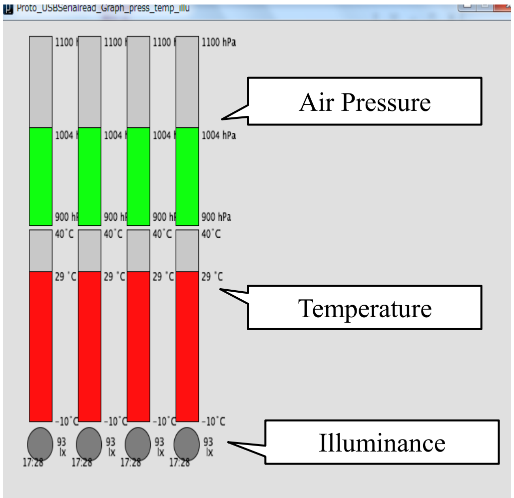

Figure 7. Graph Display Sample of Sensor data

4.2. Application of IoT Device Program and Framework and Evaluations

The framework for IoT device program creation was applied to the construction of the prototype of two types. There were differences of sensors and actuators between the two types, and differences between the ZigBee connection and serial connection. Basic processing of IoT device was performed by the framework and sending/receiving to/from the gateway, and differences of type of sensors and of data sampling method among manufacturers were handled by the library. From results, it was verified that addition of new sensors and actuators is possible by a similar method. It was evaluated that, using this method, expansion of the prototype such as addition of sensors is easy and that construction of a prototype for realization of the idea is simplified.

5. Discussion

(1) Discussion related to understanding of IoT by IoT prototype construction method

This construction method covers IoT device fabrication, which connected sensors and actuators to gateway and cloud, and IoT system prototype construction via a network. It is characteristic that this method covers a broader range.

This prototype construction method is not a mere fabrication of an electronic circuit of IoT device, but a prototype system construction method including the gateway and cloud service. Through experiences of constructing the prototype, the constructor was able to understand the IoT technology consisting of sensor technology, network technology, and information processing technology and to create ideas for the prototype application.

The prototype construction method proposed here is not restricted to specialized fields. The constructor can conceive of applications from the viewpoints of how the constructor learns independently of some problem for the IoT system, and how the IoT system resolves it. Furthermore, the constructor had continually deepened understanding of how to construct an IoT system, and how to facilitate collaboration and cooperation with users of different specialized fields where necessary.

(2) Discussion of idea creation

One student of the science and engineering course involved in this study was engaged in hydroponic culture using sensors and actuators related to agriculture. They were able to create an idea of remote control of the hydroponic culture easily by application of the IoT technology. With conventional hydroponic culture, colors were controlled by manual operation, but the use of IoT enabled program control and remote monitoring and control of the hydroponic culture.

Although students of non-science/non-engineering courses have sufficient knowledge to manipulate personal computers and smartphones, chances for learning the IoT system are scarce. Using the prototype construction method, students constructed it step-by-step according to the procedure manual and observed data transition detected by temperature and illuminance sensors, lighting of LED lamps, and buzzer sounding. They were able to understand an outline of the IoT system in the daily life. This triggered idea creation in the field in which they were involved.

6. Summary

We proposed a method of prototype construction for the active creation of IoT application ideas, applied it in practice, evaluated it, and discussed it. The proposal defined the basic configuration of the IoT prototype system. The contents and procedures of the prototyping of two types were specified for use for students of science and engineering courses such as mechanical, electrical/electronic courses, and students of non-science/non-engineering course specialized in different fields. By applying this prototype system construction method, the constructor deepened understanding of IoT and became able to create various ideas incorporating systematic modes of thinking and IoT application.

Furthermore, this paper proposed a framework for IoT device construction and stated an IoT device construction method using this framework. Now, the constructor can connect various sensors and actuators with ease. Prototype construction of ideas using sensors and actuators has been simplified.

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