Front-end Device Technology for Human Centric IoT

● Naoyuki Sawasaki ● Teruo Ishihara ● Makoto Mouri ● Yuichi Murase
● Shoichi Masui ● Hiroyuki Nakamoto

We are now in the age of the Internet of Things (IoT), in which all information about humans, things, and the environment is digitized and connected to networks. Front-end devices in the IoT, which are provided in places where people carry out activities, play the role of acquiring data from various things in the real world, in real time, and offering the necessary services to users in a timely manner. The trends in front-end devices show that portable devices are beginning to be used for continuously acquiring information about personal health and behavior and efficiently acquiring data useful for personalized services. Meanwhile, devices placed in the environment are beginning to be used to continuously acquire environmental information at unmanned locations and times and observe the behavior of people. In response to these trends, we are developing user interface technology that uses information and communications technology (ICT) through wearable devices and technology that controls devices without requiring maintenance. This paper presents examples of our development of a glove-style wearable device, ring-type wearable devices, and a maintenance-free beacon. They have been developed with the aim of constantly supporting people's fields of activities. This paper also describes our approach to future technologies such as a boost converter for energy harvesting.

1. Introduction

We are now in the age of the Internet of Things (IoT), in which all information about humans, things, and the environment is digitized and connected to networks. Fujitsu aims to achieve "Human Centric IoT" to build a better society by grasping the "things" that consumers, companies, and societies want to achieve, and the "things" that must be done from a human-centered perspective, and creating delivered value together with customers. The role of front-end devices in the IoT is to acquire real-time data of the real world and provide services to users.

This paper presents examples of Fujitsu's development of various front-end devices and describes our approach to future technologies.

2. Functions expected from front-end devices

Front-end devices can be broadly divided into "devices that people carry" and "devices placed in the environment" (**Figure 1**). As the IoT evolves, technologies are being actively to enable front-end devices to continuously acquire fine-grained real-world information. Portable devices are evolving from smart terminals that are taken out for use whenever necessary, to wearable devices that are used worn on the body at all times. Wearable devices are expected to allow the continuous acquisition of data on the health and behavior of individuals through sensing functions that automatically detect biometric information and highly responsive user interface functions, efficiently acquiring useful data for personalized services.

On the other hand, devices placed in the environment are evolving from network-connected devices and tools to small environmental sensors distributed over an area. Environmental sensors are expected to be highly useful for the continuous acquisition of environmental information at unmanned locations and times, and for multifaceted monitoring of human behavior with spatially distributed sensors.

In this way, front-end device technologies for the detection of the activities of people in the real world and changes in the environment, and the provision of optimal services for each occasion are required.

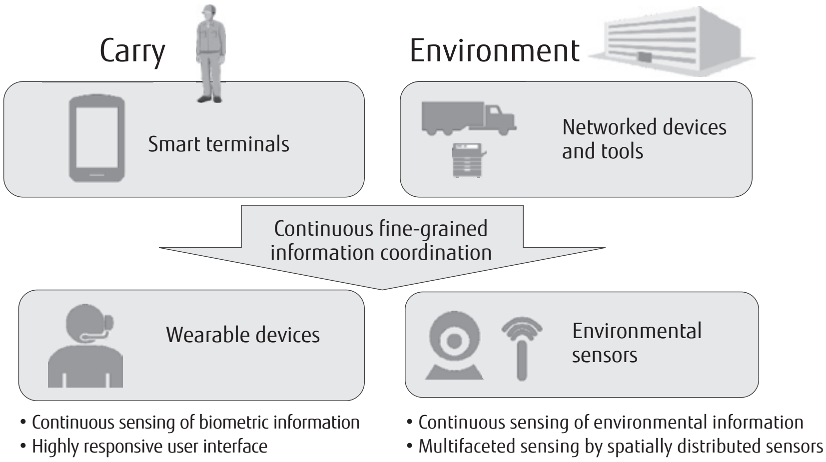


Figure 1
IoT evolution and front-end devices.

For example, in terms of human interface, instead of the conventional user-terminal interface, a user interface for the use of information and communications technology (ICT) in everyday activities through the use of the five senses, and technologies that allow front-end devices to be adapted to individual differences and installed in all kinds of locations, are required. Furthermore, power-saving technologies and energy harvesting (environmental power generation) technologies that take into account operation and maintenance aspects to allow the continuous use of huge numbers of devices in a coordinated fashion are also needed.

3. Examples of development of front-end devices

This section presents examples of the development of front-end devices carried out by Fujitsu Laboratories. Examples of wearable devices we have developed a glove-style wearable device and ring-type wearable devices for use in conjunction with smartphones, and maintenance-free beacons for deployment in the environment.

3.1 Glove-style wearable device

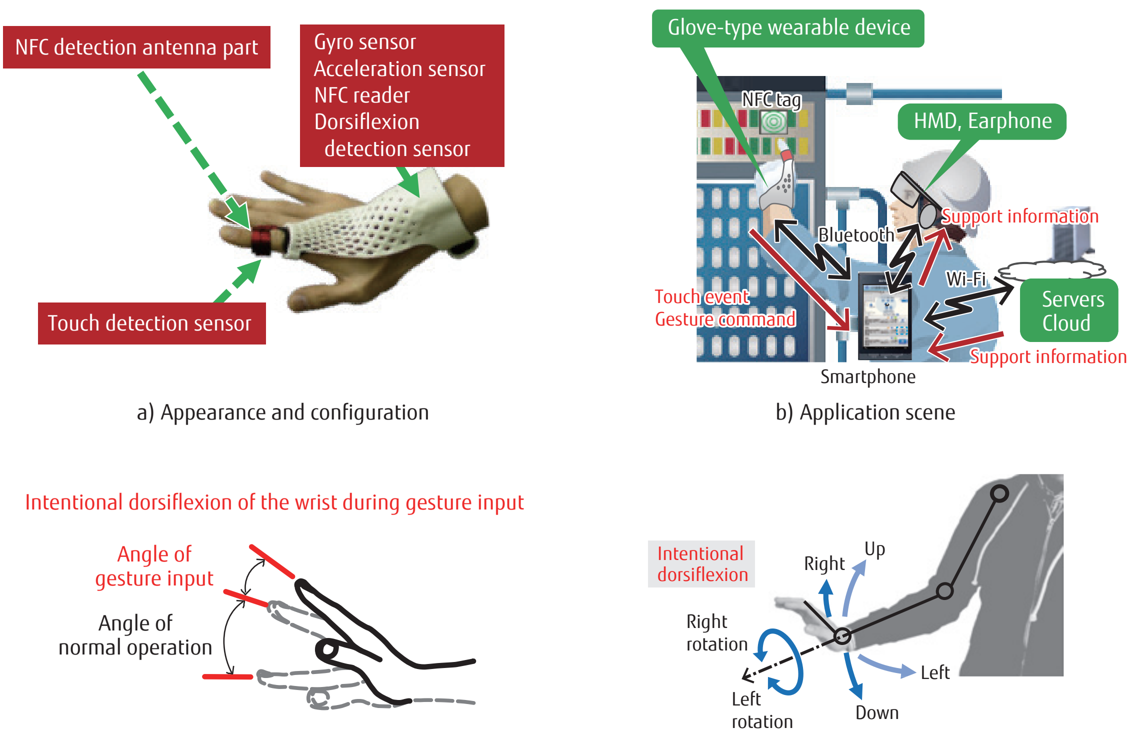
Work is currently being done on initiatives for workplace support through the digitization of work records and the improvement of work efficiency through the use of smart devices such as smartphones and tablets. Further, in workplaces where manual tasks such as plant and facility inspections are frequently required, head-mounted displays (hereafter, HMD) are also starting to be used for information viewing. However, HMDs do not allow users to touch the screen directly, a new input interface that allows users to manipulate information while working is needed.

To this end, the authors have developed a glove-style wearable device as an input device that uses ICT as the starting point for work actions.[1] The appearance and configuration are shown in **Figure 2 a)**, and a facility inspection scene in **Figure 2 b)**. This device, which is connected to the smartphone serving as the information gateway via Bluetooth, is equipped with a gesture input function that uses a finger-tip near-field communication (NFC) reader and the motions of one of the user's hands. The NFC reader is used to narrow down the information by the simple action of touching work objects and work locations to which an NFC tag has been attached. On the other hand, hand gestures are used for the selection of menu items and so on narrowed down by tags. The usefulness of gesture input depends on the ability of the system to tell apart everyday work motions and actual gestures.

Thus, the glove-style wearable device is provided with an operation interface that allows the direct gesture input mode to be entered by assuming a variety of hand positions during work. Specifically, as shown in **Figure 2 c)**, the technology recognizes when the wrist is dorsiflexed, upon which input can be done by moving the arm while maintaining that wrist posture. Such a dorsiflexed position almost never occurs in the course of daily behavior, and since it can be assumed with one hand, it allows gesture input with high reliability and ease. The trajectory of the hand is estimated by the motion sensor mounted on the wrist, and a very high recognition rate of 98% is achieved for the six gestures shown in **Figure 2 d)**. Next, we will study the integration of the NFC antenna part of the hand with the work glove and the applicability of the resulting device for inspection and assembly work where the use of gloves is mandatory.

3.2 Ring-type wearable devices

This section introduces ring-type wearable devices that benefit from more compact device size and sophisticated sensor processing while maintaining the merits of glove-style wearable devices that allow one-handed information manipulation. We have developed two models that, as their common feature, allow handwriting of numbers and characters by tracing them in the air with the fingertips—the type equipped with an NFC reader function shown in **Figure 3 a)**, and the type equipped with a QR Code (2D barcodes) reader function that employs a camera, shown in **Figure 3 b)**. Both ring-type wearable devices are equipped with a motion sensor, a sensor processing microcontroller, Bluetooth Low Energy (BLE) module, and a rechargeable secondary battery. The NFC reader function equipped ring has a tag reader at the tip of the fingertip, allowing tag detection when the fingertip is bent, brought in proximity of a tag, and an operation button is pressed. Reading of the QR Code by the camera is done through processing by an image processing extension microcontroller selected for its fast response. Reading of the QR Code is processed by approaching the ring-type input device to the targeted QR Code followed by pressing the operation button with the thumb. The device is also equipped with a function that allows targeting with an LED light, so that when reading a QR Code, the camera mounted on the ring is able to determine whether it faces the QR Code that is the target. Moreover, a function to transfer camera images to smart terminals to allow saving of images of trouble spots in confined areas in the course of inspection work and the like is



a) Appearance and configuration

b) Application scene

c) Identification of gesture input and normal operation

d) Six types of hand gestures

Figure 2
Glove-style wearable device.

also provided.

With regard to the function for inputting characters handwritten in the air, character recognition is carried out by a wireless-connected smart terminal. The processing flow for characters written in the air is shown in **Figure 3 c)**. Character input is started by pressing the operation button on the side of the ring with the thumb, and it is stopped by releasing the operation button once a single character has been traced with a single stroke, thereby distinguishing normal finger movement from character input operation. The correction command used in case of erroneous input is also recognized by the fingertip motion during the input interval. Since it is not necessary to physically remove the thumb from the button at the end of character input, and the user does not have to mind character size and input position, continuous input operation with little fatigue is possible. The tracing trajectory of the character is compared with the swinging movement of the user's body, based on the data of the motion sensor mounted on the ring-type wearable device, and the dominant motion components of the handwriting motion are extracted and interpreted. The character recognition processing is performed following trajectory correction processing, such as removing parts of the trajectory that are estimated to be superfluous for each character written in one stroke. If the writing is limited to numbers and uppercase alphabet letters, the recognition rate is at least 95%, and once one becomes used to the operation, numeric input can be done without even looking at the tracing trajectory. The high numeric recognition rate makes this application of practical use for numerical recording tasks during work such as the selection of menu numbers in HMDs, meter inspections, and picking [**Figure 3 d)**].

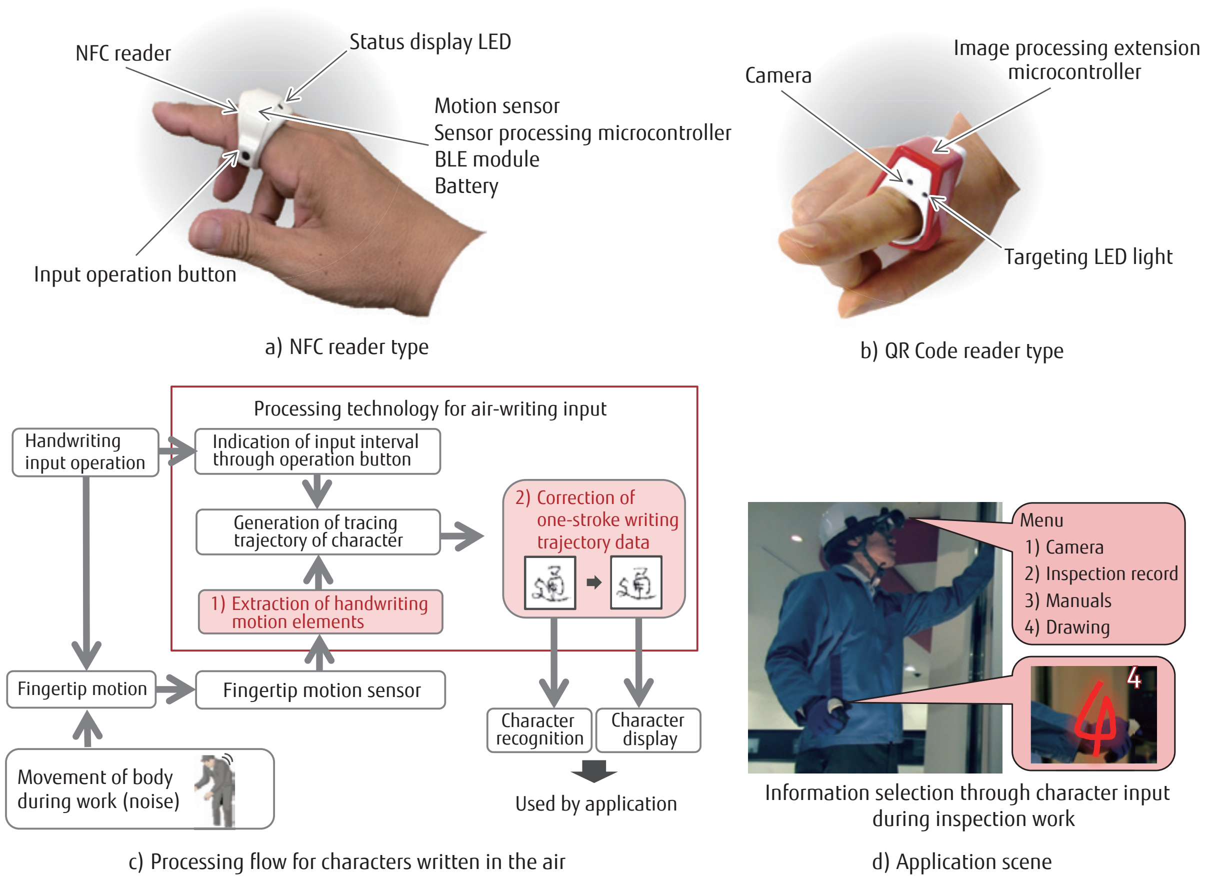


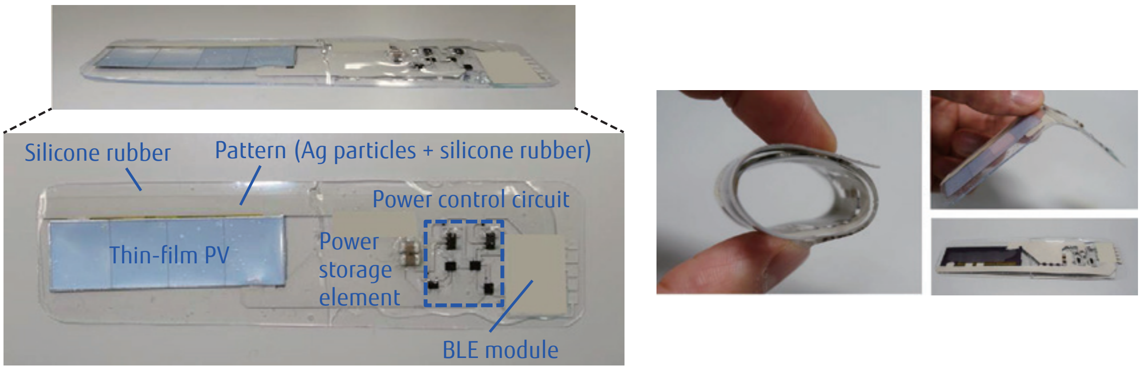
Figure 3
Ring-type wearable device.

3.3 Maintenance-free beacon

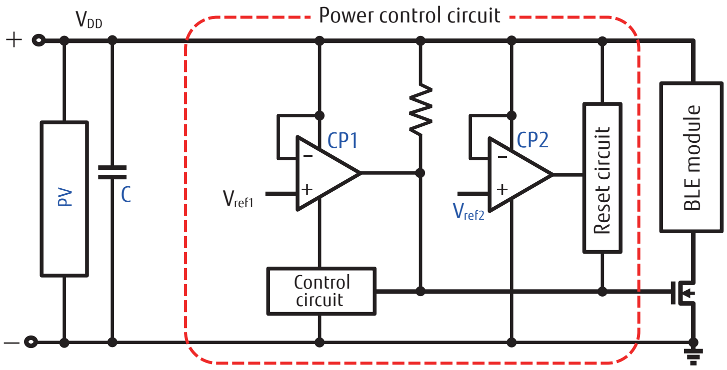
In the area of GPS for underground areas and inside buildings, to achieve difficult-to-realize path guidance and information provision during approach, we have developed a flexible beacon that does not require battery replacement, does not require maintenance of the sensor node, and can be installed practically anywhere.[2] **Figure 4 a)** shows the appearance of the beacon that was developed. This beacon uses flexible photovoltaic cells (PV) as the power source, and eschews a voluminous and costly power supply IC or secondary battery to store their output, instead using only a small power storage element for power stabilization, which is itself connected directly to a BLE wireless module (hereafter, BLE module) that can transmit a beacon signal three times per second.

Power control is performed in this maintenance-free beacon, as shown in **Figure 4 b)**. If after the power is switched on, power supply voltage V_{dd} is smaller than V_{ref1}, the BLE module is in the OFF state and the electrical charge from the PV is stored in power storage element C. When V_{dd} becomes greater than V_{ref1}, the BLE module switched ON, and unnecessary power consumption is reduced by stopping the power supply to power monitoring comparator CP1 at the same time. Even as V_{dd} drops owing to the power consumption of the BLE module, the values of V_{ref1}, V_{ref2}, and power storage element C are adjusted to enable the BLE module to continue communicating until V_{dd} falls below the level of V_{ref2} ($V_{ref2}<V_{ref1}$).

V_{ref1} and V_{ref2} are generated inside CP1 and CP2. The execution of power control without the use of a voluminous power supply IC allowed the realization of a compact beacon just 2.5 mm thick and weighing just 3 g. Further, this beacon being thin and flexible, it can be installed in the gaps of ceiling lights, an advantageous location for the transmission of radio waves owing to the lack of obstructions.



a) Configuration



b) Power circuit

Figure 4
Maintenance-free beacon.

4. Future Human Centric IoT technologies

Obstacles in the way of realizing IoT services that use a large number of sensor nodes include the labor cost required for the replacement and charging of the batteries used in devices. The use of energy harvesting technologies as a means of eliminating the need for battery replacement is drawing attention. Energy harvesting technology is a technology that uses devices called energy harvesters to convert environmental energy such as light, vibrations, and temperature differences, into electricity. As the output voltage of energy harvesters varies greatly with the operating environment, energy harvesters can be said to be unstable power supplies compared for example with primary batteries.

A boost converter is required in order to compensate for the output fluctuations of energy harvesters due to changes in the environment and boost their output voltage to the operating voltage of the load. The authors have developed a boost converter with a function to charge a secondary battery that is highly efficient and supports a wide range of input voltages compared with conventional boost converters.[3)]

The configuration of the developed boost converter is shown in **Figure 5**. A switched inductor boost converter (hereafter, SIBC) that boosts the voltage by inductor charging/discharging is used in the main circuit. The start-up circuit, which is composed of a transformer-based oscillator and a rectifier, starts operating with input voltage V_{IN} from the energy harvester, and the succeeding stage SIBC is driven by a voltage higher than V_{IN}.

Either a high transconductance native type (threshold of about 0 V) or depletion type (threshold of 0 V or less) metal-oxide-semiconductor field-effect transistor (MOSFET) is used for main switch M_1 of the oscillator, enabling oscillation even at low input voltage. A 1:100 winding ratio is used for the transformer to ensure that the output oscillation amplitude of the start-up circuit is a large value. On the other hand, to protect the circuit from high input voltages, an amplitude limiting circuit is provided to automatically limiting the amplitude of the oscillator. Further, for higher efficiency, a power-down control circuit that automatically stops the oscillator after the SIBC started operating has been added. This circuit enables charging the secondary battery or operating the sensor with the small input voltage generated by the body temperature of the user.

The proposed circuit was implemented through the use of external commercial components and achieved an input voltage range of 60 mV to 3 V. High efficiency was also achieved with maximum efficiency of 92% and minimum efficiency of 45%.

Besides such power supply technologies, Fujitsu Laboratories develop also wireless technologies that are required for on-site installation and operation. In other words, for the realization of Human Centric IoT,

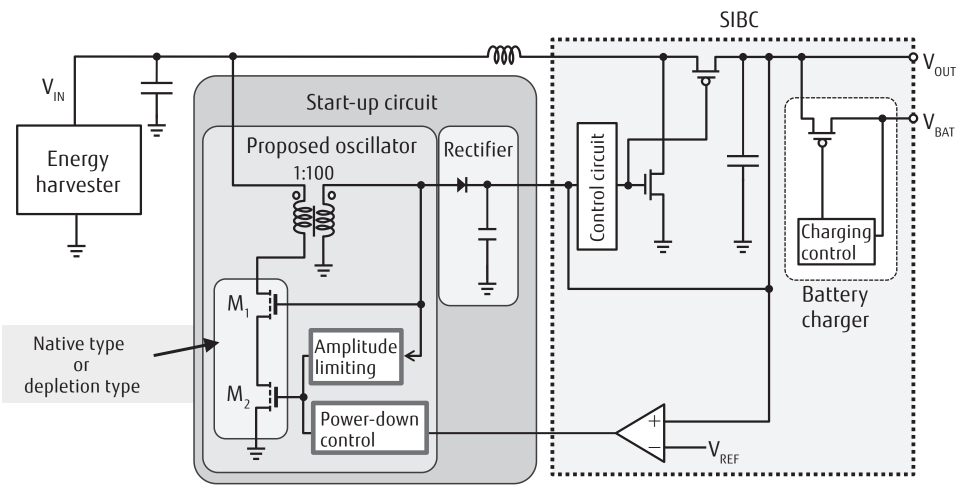


Figure 5
Wide input voltage and high-efficiency boost converter.

we develop various technologies such as ultra-low-power wireless body area networks (BAN) for medical applications, compact 300 GHz band receivers capable of achieving 10 Gbps or more for transmitting massive amounts of data, and various kinds of sensing technology.

5. Conclusion

As endeavors for the realization of Human Centric IoT, this paper has introduced two kinds of wearable devices, a glove-style wearable device for input through gestures, and building upon that through further advances, ring-type devices that enable character recognition and QR Code reading through fingertip motion, as well as a maintenance-free beacon for placement in the environment designed for applications such as path guidance that eliminates the need for battery replacement.

Next, we will further advance core front-end device technologies such as power supply technology for energy harvesting, technologies to make wireless transmission faster and less power hungry, and various sensing technologies for practical use with a view to realizing Human Centric IoT that delivers high value to our customers.

References

1) S. Jiang et al.: Developing a Wearable Wrist Glove for Fieldwork Support: A User Activity-Driven Approach. SICE International Symposium on Control Systems, pp. 22–27 (2015).
2) A. Muramatsu et al.: Thin and Flexible IoT-supporting beacon requiring no battery replacements. The 6th International Conference on Integrated Circuits, Design, and Verification (ICDV 2015), Session II, paper #15 (2015).
3) H. Gao et al.: A 60 mV-3 V input range boost converter with amplitude-regulated and intermittently operating oscillator for energy Harvesting. IEEE Applied Power Electronics Conference and Exposition (APEC), pp. 3283–3290 (2015).

Naoyuki Sawasaki
Fujitsu Laboratories Ltd.
Mr. Sawasaki is currently engaged in development of business application technologies for ubiquitous devices.

Teruo Ishihara
Fujitsu Laboratories Ltd.
Mr. Ishihara is currently engaged in the development of business applications for IoT sensor nodes.

Makoto Mouri
Fujitsu Laboratories Ltd.
Mr. Mouri is currently engaged in the development of signal processing technology for IoT sensor nodes.

Yuichi Murase
Fujitsu Laboratories Ltd.
Mr. Murase is currently engaged in development of user interfaces and sensing technologies that use ubiquitous devices.

Shoichi Masui
Fujitsu Laboratories Ltd.
Dr. Masui is currently engaged in the development of wireless and sensing technology for IoT sensor nodes.

Hiroyuki Nakamoto
Fujitsu Laboratories Ltd.
Mr. Nakamoto is currently engaged in the development of wireless and power technologies for IoT sensor nodes.