Zero Energy Gateway -Realization of Low Cost Infrastructure Monitoring System with Solar Powered IoT Gateway-

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Infrastructures such as bridges constructed during the period of high economic growth are aging and require continuous monitoring and maintenance, but increase in manual inspection costs and shortage of engineers with specialized knowledge are posing serious issues. In addition, risk of climate change due to global warming is increasing, which necessitates disaster prevention and mitigation measures in preparation for torrential rains and other large-scale natural disasters. For this reason, monitoring systems using sensor and wireless network technologies are attracting attention from the perspective of solving labor shortages and improving inspection accuracy.

OKI has already commercialized a battery powered wireless acceleration sensor that combines power saving 920MHz multi-hop wireless technology with sensor data analysis technology, and has been working on the development of a system that monitors the deteriorating condition of infrastructures. Additionally, in response to river flooding caused by torrential rains that have been increasing recently, OKI sells high-precision solar powered crisis management water level gauges, which are available either as an ultrasonic type or pressure type.

A monitoring system requires a gateway that sends data collected from each sensor to the cloud or server via the Internet. However, a conventional gateway requires a commercial power supply, and power wiring a gateway for field operation is a substantial burden in terms of cost and time.

To address this issue, OKI has developed the easily installable “Zero Energy Gateway” (hereinafter referred to as ZE-GW), which does not require a power supply or communication wiring. This IoT gateway is equipped with 920MHz multi-hop wireless “SmartHop®*1)” and LTE wireless communication functions, and its solar power support allows easy outdoor installation.

This article introduces the power saving technology developed for the ZE-GW and examples of infrastructure monitoring using the ZE-GW.

*1) SmartHop is a registered trademark of Oki Electric Industry Co., Ltd.

Monitoring System Using ZE-GW

Figure 1 shows the three types of ZE-GW that is available, and **Table 1** shows the specifications. In addition to operating as a stand-alone gateway, ZE-GW can be integrated with an ultrasonic or pressure type water level gauge both of which have proven records in river monitoring. The type to use is selected according to application. All three types meet IP65 water and dust resistance specifications, and have an operating temperature range of -20 to 60°C.

Figure 1. View of ZE-GW Types
(Left: Stand-Alone, Center: With Ultrasonic Water Level Gauge, Right: With Pressure Water Level Gauge)

Table 1. ZE-GW Specifications

Specifications	
Communication Functions	920MHz multi-hop wireless
	LTE-Cat.1
Power	Solar powered
Continuous operation without sunlight	9 days
Operating temperature	-20~60°C, 10~95% RH
Water/Dust resistance	IP65 compliant
Dimensions	(W) 230 x (D) 284 x (H) 378 mm
Device monitoring	Internal temperature and humidity
	Battery voltage

Figure 2 shows the configuration of a monitoring system using the ZE-GW. A wireless acceleration sensor is one type of sensor that can be connected to the ZE-GW. The

sensor is a battery-powered device that can be installed on an infrastructure to collect natural frequency and inclination data of the target structure. Since the ZE-GW and wireless acceleration sensor can mutually relay and wirelessly transmit information using SmartHop, a monitoring system covering a wide area can be flexibly constructed. Data from each sensor is transmitted using SmartHop to the master ZE-GW where they are aggregated and sent to the cloud via LTE. Building a sensor data analysis function and a mechanism to send alarms according to the results in the cloud, necessary information can be provided to the administrators of social infrastructure such as bridges and roads.

Conventional gateways often use equipment equivalent to a small PC that consume several watts of power. For solar power operation, these gateways would require a large solar panel and a large-capacity storage battery, which is heavy. On the other hand, ZE-GW's excellent low-power performance enables a small 165x150mm solar panel and a secondary battery to fit in an integrated housing. Even with its small size, the ZE-GW is capable of operating normally for nine continuous days without sunlight. This makes it possible to easily install the ZE-GW outdoors, regardless of location. Furthermore, the ZE-GW with an integrated sensor can further reduce installation cost. These features of the ZE-GW are expected to reduce the cost of implementing infrastructure monitoring solutions.

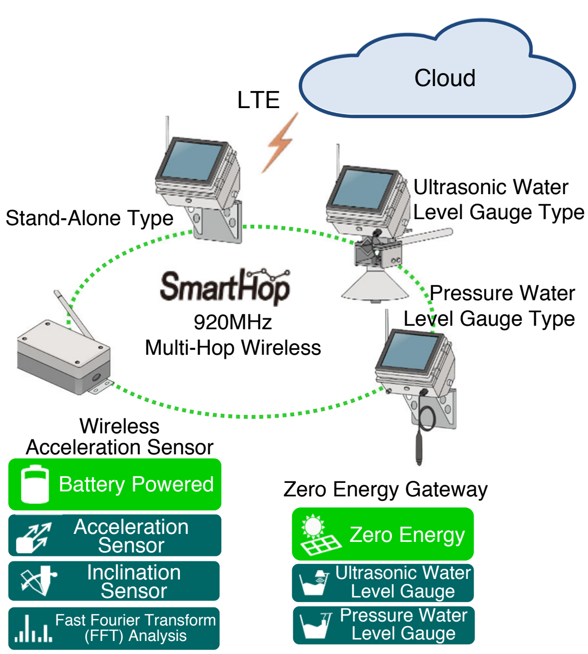

Figure 2. Configuration of ZE-GW Monitoring System

ZE-GW Power Saving Technologies

The three power saving technologies supporting the ZE-GW are described below.

(1) SmartHop

ZE-GW uses SmartHop as a communication means for collecting sensor data. SmartHop is a 920MHz wireless module and uses a power saving technology called sleep router technology[1]. With sleep router technology, the module remains in sleep mode for much of the time and sends/receives when it intermittently becomes active. In addition to this standard technology, a proprietary sleep control technology enables low power consumption with low delay. Moreover, if the sensors working in conjunction with the ZE-GW also use SmartHop, they can be easily networked, and since security functions such as device authentication and encrypted communication are provided at the module level, system expansion can be performed safely.

(2) Energy Harvesting

ZE-GW is solar powered, but since the amount of power generated by solar energy depends on the weather, there is a risk that the system will stop during continuous rain. Furthermore, the charging efficiency of the secondary battery drops when the charging current is low during cloudy weather. ZE-GW solves this problem by combining a capacitor that can be charged with high efficiency even with low current and a large-capacity secondary battery. As shown in **Figure 3**, under sunny weather, the charging current is sufficiently high to directly charge the secondary battery. When the charging current becomes low in cloudy weather, the capacitor is first charged and then the secondary battery is charged from the capacitor. The charging efficiency is raised by securing sufficient current for the battery. **Figure 4** shows the ZE-GW's charging current and battery voltage data acquired outdoors. During the period from January 22nd to 25th, 2021, sufficient sunshine could not be obtained and the charging current was as low as 10mA or less on average, therefore the secondary battery could not be charged directly. However, it can be seen that even during this period, charging from the capacitor improved charging efficiency and raised the battery voltage.

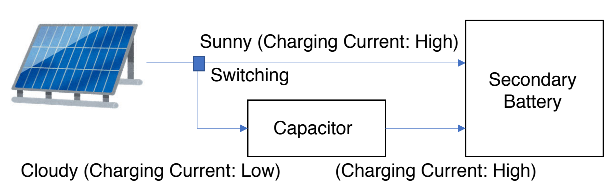

Figure 3. High Efficiency Charging

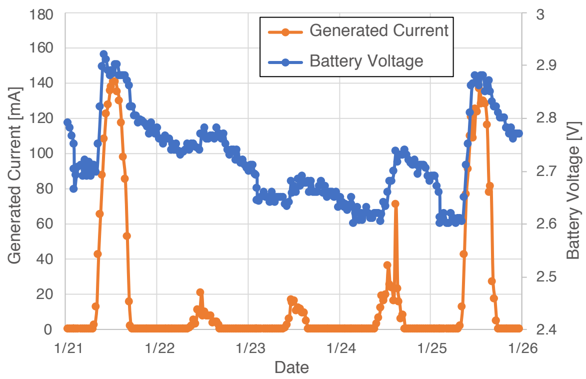

Figure 4. Verification of Charging Current and Battery Voltage

(3) LTE Communication Control

ZE-GW is equipped with an LTE module for connecting to the Internet from outdoors, but the LTE module consumes a great deal of power, and it is difficult to keep the module operating continuously using a small solar panel. Therefore, appropriate control is necessary to activate the LTE module only when communication with the cloud is required. **Figure 5** illustrates the control mechanism for power saving LTE communication. ZE-GW buffers data collected from various sensors. When a certain amount of data is accumulated, the LTE module is activated to transmit the buffered data. This shortens the LTE communication time and reduces power consumption. However, buffering in the ZE-GW will cause a delay in data transmission, which is undesirable if an urgent notification is being sent by a sensor. To remedy the problem, the ZE-GW provides an interface that enables external signals to control the LTE communication buffer. That is, when a sensor transmits urgent data, it simultaneously sends a control signal that will release the buffer control of the ZE-GW. Although the ZE-GW's power consumption will increase temporarily, it will be possible to communicate with the cloud immediately and send data with minimal delay during an emergency.

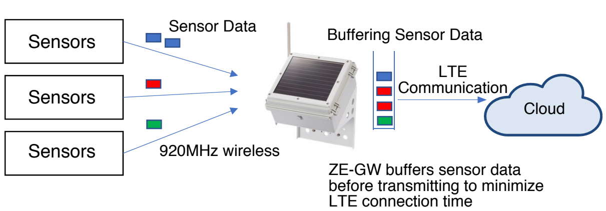

Figure 5. Power Saving Control for LTE Communication

Infrastructure Monitoring Using ZE-GW

The following are examples of infrastructure monitoring that makes the best use of the ZE-GW advantages.

(1) Inclination / Water Level Monitoring of Railroad Bridge Piers (Example 1)

Figure 6 shows a photo of a demonstration experiment to monitor the inclination of railroad bridge piers. An inclination sensor and a ZE-GW with an ultrasonic water level gauge are installed on a pier. During the rainy season or a typhoon, rise in the water level will increase water flow, which may cause riverbed scouring near the piers and lead to disasters such as inclination and collapse of the piers. In the past, rail operation was controlled by monitoring water levels through direct visual observation of a staff gauge, which indicates the distance from the bridge girder to the water surface. The ZE-GW enables water level and inclination monitoring in real-time without the need to make trips to sites that may be flooded and dangerous. In inclination monitoring, water level and pier inclination are measured every ten minutes, and the ZE-GW sends the data to the monitoring system every hour via LTE. When the water level rises above a certain level, the ZE-GW enters an alert state in which the measurement frequency is shortened to every two minutes, and the LTE communication control function shortens the transmission delay to the monitoring system. On the monitoring system, the water level and inclination of each pier can be visualized in a graph, and an alert mail can be sent to notify the administrator when a warning state is reached.

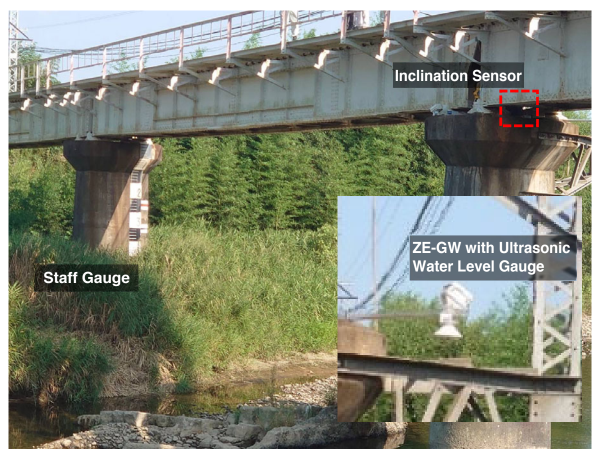

Figure 6. Inclination / Water Level Monitoring of Railroad Bridge Piers

(2) Deck Monitoring of Road Bridges (Example 2)

There is an effort to use vibration frequency analysis utilizing an acceleration sensor to monitor decks and girders of road bridges[2]. It has been reported that the vibration frequency changes when rigidity deteriorates due to deterioration of the deck slab or corrosion of steel in the concrete, and that change is monitored using an acceleration sensor. Even in the monitoring of road bridges, power supply wiring at the time of installation is an issue, but it can be resolved using the ZE-GW. **Figure 7** shows the visualization screen of the monitoring system. A bridge-installed sensor is selected from a map, and the spectrogram for a specific period can be viewed allowing the frequency fluctuation to be checked over an extended period of time. During the monitoring demonstration, a power outage occurred due to a typhoon, and data was lost from the conventional gateway using commercial power. On the other hand, the ZE-GW was able to maintain its mobile line connection and continued to collect data. Therefore, the ZE-GW is also effective for immediately grasping the damage condition of road bridges in the event of a disaster such as an earthquake or typhoon. In addition to acceleration sensors, there are cases where corrosion and strain sensors are also used to monitor road bridges, and the ZE-GW can be combined with these and various other sensors as well.

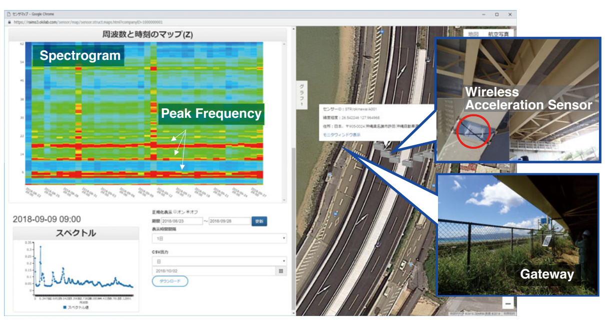

Figure 7. Monitoring of Road Bridges

(3) Monitoring of Slope Inclinations (Example 3)

Figure 8 is an example of installing inclination sensors on a slope that gave way due to heavy rain and caused a landslide. Installing a ZE-GW and inclination sensors at such a site and quickly detecting changes in the slope, safe evacuation guidance can be issued and help disaster mitigation. A camera was also used to monitor this site, but due to the difficulty of shooting at night, inclination sensors, which can handle night time operation, were set up. Although the slope to be monitored covers a wide range in terms of surface area, if the size of the collected data is small such as inclination information, dozens of places can be measured simultaneously. Installing numerous sensors and using SmartHop, situational awareness of the slope over a wider range becomes possible.

Figure 8. Monitoring of Slope Inclinations

Future Prospects

Three actual examples of ZE-GW application have been introduced. However, in infrastructure monitoring, there is a demand for situational confirmation of a site not only with sensor data but also with images. Image sensors consume more power than other sensors, and if it is to be used for disaster countermeasures, technical issues such as night photography need to be addressed. To address these issues, OKI plans to use a highly sensitive image sensor and develop a camera sensor-equipped ZE-GW with low power image compression technology. Additionally, in an aim to expand the ZE-GW's applications, other battery-powered sensors such as wind direction, wind speed, and rainfall sensors will be introduced, and in order to improve monitoring accuracy, an advanced monitoring system that interworks between the sensors and servers will be realized. ◆◆

References

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