Advancement of Infrastructure Monitoring using Zero-Energy High-Sensitivity Camera - Report on Field Experiments and Functional Evolution in Next-Generation Model -

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With the growing severity of natural disasters in recent years, there is an increasing need for constant, continuous monitoring of the safety and other conditions of infrastructures. However, rising costs and a shortage of personnel to perform the monitoring tasks have become problems.

OKI offers the Zero-Energy IoT Series, a sensor network system that is easy to install and does not require wirings for power or communication (**Photo 1**). In 2022, OKI developed the Zero-Energy Gateway with high-sensitivity camera, also referred to as Zero-Energy high-sensitivity camera (**Photo 2**, **Table 1**). This device enables remote monitoring of objects, day or night, thereby providing low-cost and more efficient infrastructure maintenance and management[1]. Currently, OKI is developing a next-generation Zero-Energy high-sensitivity camera to improve imaging capabilities in difficult lighting conditions, such as at night.

Photo 1. Zero-Energy IoT Series
(Left: Stand-Alone, Center: With Ultrasonic Water Level Gauge, Right: With Pressure Water Level Gauge)

Photo 2. Zero-Energy Gateway with High-Sensitivity Camera

Table 1. Specification of High-Sensitivity Camera Unit

Shooting mode	Still images and automatic high-sensitivity shooting
Brightness	Usable at 0.01lx
Maximum pixels	1920×1080 (Full HD equivalent)
Shooting timing	Regular intervals
Sensor integration	Switches to alert mode when tilt or water level is abnormal
View angle	Horizontal: 109° / Vertical: 59°
Compression method	JPEG
Operating conditions	-20°C～60°C, 10%～95%RH

This article reports on the field experiments that have been conducted and the study on functional evolution in the next-generation Zero-Energy high-sensitivity camera.

Field Experiments using Zero-Energy High-Sensitivity Camera

(1) Stormwater Reservoir Monitoring

A Zero-Energy high-sensitivity camera (hereinafter, ZE camera) and a Zero-Energy Gateway with pressure water level gauge (hereinafter, ZE water gauge) were installed to monitor the condition of a stormwater reservoir. An example installation is shown in **Figure 1**. The ZE camera captures images of the reservoir and its surroundings while the ZE water gauge measures the water level of the reservoir.

This experiment evaluated the camera's ability to capture images outdoors in low-light conditions. Images were captured both during the day and at night, and each image was evaluated based on whether the condition of objects within the field of view could be confirmed. In particular, to evaluate the camera's ability to capture images in low-light conditions as specified in the product specifications, nighttime images were evaluated using images with illuminance values close to that listed under the brightness heading in **Table 1.**

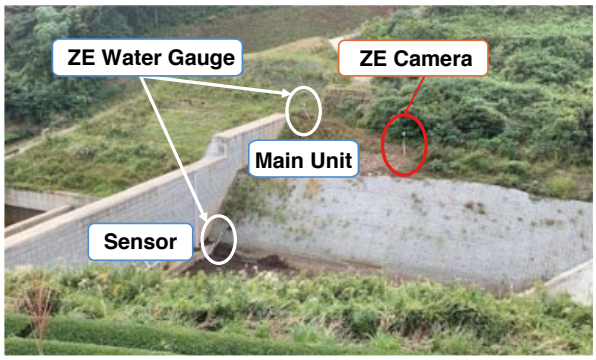

Figure 1. Installation of Stormwater Reservoir Monitors

Photos 3 and **4** show images captured with the ZE camera. **Table 2** shows the date/time of the images, the water level measurements, and the illuminance measurements for **Photos 3** and **4**. The water level of the reservoir can be confirmed both during the day and at night. It is possible to see clearly that the water level has risen significantly in **Photo 4**, even though the image was captured at night. Furthermore, images with sufficient brightness were obtained even when captured in an illuminance environment (0.0103lx) equivalent to the ZE camera's brightness specification (0.01lx). These results confirm that the ZE camera can obtain images with sufficient brightness regardless of the weather, as long as the illuminance is above the specification value, and that remote monitoring using images is possible.

Photo 3. Daytime Image of Normal Condition

Photo 4. Nighttime Image of Rising Water Level

Table 2. Stormwater Reservoir Monitoring: Measurements for Captured Images

	Normal Condition **(Photo 3)**	Rising Water Level **(Photo 4)**
Date/Time	2023/05/29 15:05	2023/06/02 19:35
Water Level	0.966m	8.536m
Illuminance	1096lx	0.0103lx

(2) Bridge Bearing Monitoring

A ZE camera was installed to monitor the condition of road bridge bearings. In this experiment, there were no streetlights or other light sources to directly illuminate the target area. Focusing on the areas surrounding the target, the environment in Field Experiment (1) was wide open, allowing moonlight and other distant light sources to easily reach the target. However, in this example, the target area was obscured by vegetation and the bridge itself, blocking off distant light. As a result, the illuminance at night was relatively low, making it unlikely that the minimum illuminance required for imaging could be achieved. On the other hand, bridge bearings were located relatively close to the camera.

OKI hypothesized that in a situation where the illuminance is extremely low, adding lighting to illuminate the target would be effective if the target is close to the camera. To verify this hypothesis, a ZE camera equipped with a 1W white LED was prototyped for the experiment.

To evaluate the effect of lighting, two devices were set up: (1) a regular ZE camera, and (2) a ZE camera equipped with a 1W LED light (**Figure 2**). **Photo 5** and **6** show images captured without and with lighting, respectively. **Table 3** shows the illuminance measurement when each image was captured.

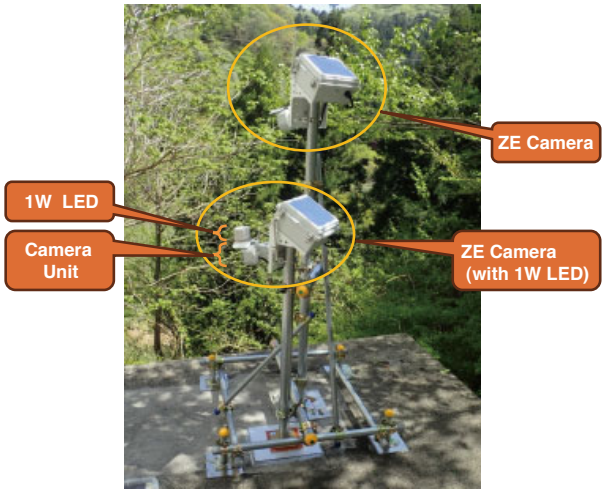

Figure 2. Installation of Bridge Bearing Monitors

Figure 3. Daytime Image and Bridge Bearing Positions (circled)

Photo 5. Nighttime Image without Lighting

Photo 6. Nighttime Image with Lighting

Table 3. Bridge Bearing Monitoring: Measurements for Captured Images

	Without Lighting **(Photo 5)**	With Lighting **(Photo 6)**
Date/Time	2024/05/09 00:00	2024/05/09 00:02
Illuminance	0.0030lx	0.250lx

The image captured without lighting (**Photo 5**) has low overall brightness and significant noise. While the outline of the superstructure is faintly distinguishable, the details are indistinguishable. Likewise, of the three bridge bearings within the field of view, only the closest one is faintly distinguishable, while the two at the back are indistinguishable. In comparison, the image captured with lighting (**Photo 6**) shows significantly improved brightness. The measured illuminance increased approximately 83 times, from 0.00300lx to 0.250lx, bringing the image within the brightness specification required for the ZE camera. The structure, including the three bridge bearings, is clearly distinguishable, and the goal of on-site monitoring is also achieved. Therefore, using lighting to illuminate the target is effective when capturing images in low-light environments.

The lighting is turned on when the image sensor is receiving light. Turning on the lighting only during the time of the shooting eliminates unnecessary power consumption.

Study on Functional Evolution

Study is currently being conducted on the functional evolution with the goal of improving nighttime capabilities and other aspects that will raise the value of the ZE camera. This section discusses the following two points:

(1) Revision of key components to improve low-light performance

(2) Addition of high-output LED lighting

Prerequisite for each study was to maintain power-saving performance. This is important considering that the Zero-Energy IoT series is characterized by its ability to operate on solar power.

(1) Revision of Key Components to Improve Low-Light Performance

1) Adoption of high-sensitivity, low-noise image sensor

When shooting in low-light environments, the amount of light captured by the image sensor is extremely low. When the intensity of incident light is insufficient compared to the image sensor's light-receiving sensitivity, even if a slower shutter speed is used or the signal gain is increased, the signal-to-noise ratio (SNR) of the output signal will be low, reducing the likelihood of obtaining a clear image.

A high-sensitivity, low-noise image sensor will be adopted in the next-generation ZE camera. This will improve the SNR of the output signal, increasing the likelihood of obtaining clear images even in low-light environments. Furthermore, higher sensitivity allows for faster shutter speeds, thereby shortening the ZE camera's operating time and reducing the power consumed for shooting.

A next-generation ZE camera will be prototyped and evaluated with the goal of capturing clear images even

in low-light environments beyond the limits of the current model.

2) Adoption of high-precision illuminance sensor

The ZE camera uses measurements from the illuminance sensor to calculate shutter speed and other exposure settings. This method eliminates the need for pre-shooting to adjust brightness, thereby minimizing the image sensor's operating time. In general, the power consumption of an illuminance sensor is extremely lower than that of an image sensor, therefore the amount of power required to capture a single still image is reduced. However, when the measured illuminance drops close to the resolution of the illuminance sensor, the brightness of the output image fluctuates significantly.

An illuminance sensor with high measurement accuracy and resolution will be adopted in the next-generation ZE camera. This will enable more accurate measurement of the lighting conditions in the shooting environment, especially in low-light environments, and increase the likelihood that the brightness of the output image will fall within the appropriate range.

In the prototyping and evaluation of the next-generation ZE camera, the degree of improvement in the accuracy of image brightness will be verified.

(2) Addition of High-Output LED Lighting

No matter how high the image sensor's performance, in a completely dark environment, where even street lights and starlight are absent, image of the target object cannot be captured. Field experiment (2) confirmed the effectiveness of using a 1W LED light when capturing close-up objects in low-light environments.

However, the lighting output is insufficient for distant subjects, resulting in insufficient surface illumination and a reduced signal-to-noise ratio (SNR). Furthermore, to achieve sufficient image brightness while suppressing noise, a slower shutter speed is required, which extends the time the camera is in operation. This increases the ZE camera node's power consumption and shortens its continuous operating time when running under battery power.

To address these issues, the next-generation ZE camera will be equipped with a high-power LED lighting unit. The lighting is turned on as needed during shooting to enhance the surface illumination of the target. Using a high-power LED ensures sufficient surface illumination even for relatively distant targets. This enables clear images to be captured even in complete darkness or when the target is far away.

From the perspective of power consumption, turning on the lights increases power consumption. On the other hand, improving the surface illumination of the target allows the shutter speed to be faster, which in turn shortens the camera's operating time and reduces power consumption.

The final power consumption will depend on the shutter speed, but is expected to be about the same as when shooting without lights. Even if power consumption increases, there are operational benefits such as improved shooting quality and more reliable data acquisition at night and in darkness as mentioned previously.

Having determined the distance to illuminate and illuminance level to achieve, a prototype LED lighting unit has been created. It will be incorporated into the next-generation ZE camera for evaluation and verification.

Future Developments

A next-generation ZE camera will be prototyped and performance evaluations will be conducted in both indoor and outdoor environments.

As a future feature enhancement, a function to generate HDR composite images is being considered. Large differences in illumination within the field of view increases the chance of blown out highlights and blocked up shadows. By implementing this function, it will be possible to clearly capture each area of an image, even in situations with large illumination differences, thereby further expanding the scope of application for ZE cameras.◆◆

* Location cooperation: Field experiment (1) River Department, Numazu City Construction Division

References

1) Hiroshi Hashizume, Yuki Kubo, Atsushi Yoda: Zero Energy High-Sensitivity Camera -Take Clear Pictures of Remote Sites Day and Night with Easy Installation-, OKI Technical Review, Issue 239, Vol. 89 No. 1, May 2022

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TIPS【Glossary】

Bearings
In bridges, bearings are components installed between the superstructure, such as bridge girders, and the substructure, such as piers. The superstructure deforms due to temperature and load changes, but the bearings absorb this deformation and transmit only the load to the substructure. If the function of the bearings deteriorates, the risks of unevenness in the road surface at the end of the bridge girder, damage to the superstructure or substructure, and bridge collapse increase.