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Paper:

Development of Data Logger Separator for Bio-Logging of Wild Seabirds

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The bio-logging technique is extensively used in the fields of ecology and ethology, wherein a data logger, such as a sensor or camera, is attached to the target animal's body to collect the required data. In this method, the efficiency of recovery of the data logger is not ideal. In this study, we proposed a new recovery method, with the aim of addressing the aforementioned problem in bio-logging. The authors previously fabricated a data-logger separator, which weighed approximately 10 g, and was targeted at small seabirds. Because there were some problems associated with the circuit board and the separation performance of this device, we modified the device to overcome the previous drawbacks. We fabricated a flexible printed circuit to improve the operation of the mounted actuator and wireless microcomputer, and improve the efficiency of the fabrication process. We conducted an experiment to determine the proper length and position at which the actuator is attached, in order to achieve a stable motion. We thus fabricated a new prototype with these improvements and performed an operational test at low temperatures from a particular distance, simulating actual usage in a natural environment. The results demonstrated that separation occurred without failure, thus indicating that the separator can be efficiently used in practical environment.

Keywords: separation device for data-logger, bio-logging, flexible printed circuits (FPC)

1. Introduction

The bio-logging technique is widely used in the fields of ecology and ethology, mainly because of its standout features as compared to conventional methods [1–4]. In this method, small data loggers, such as a 3-axis acceleration sensor or global positioning system (GPS) receiver, are attached to an animal's body to collect data related to the animal's behavior, physiological state, or environment for research purposes [5–8]. This is a highly effective biological research method because downsizing of electronic devices such as data loggers and sensors has enabled its use in diverse animals, which was previously difficult to study [9, 10].

In a typical bio-logging method, a logger is attached to an animal that has been captured, and it is recovered after a certain period of time. However, it is not easy to capture a wild animal, and even more so to recapture the same animal to recover the logger. This is mainly because a wild animal that has already been captured becomes more cautious and aggressive, which makes it difficult to approach it.

A separator is a device that enables efficient recovery of the logger. This device consists of a wireless connection or is equipped with a timer, and it is attached to the animal along with the logger. It separates the logger from the animal's body at the time of recovery. The separated logger is left in the field and can be recovered by the researcher without capturing the animal. Different separation methods are used depending on the type of animal. Various methods are implemented for different animals, such as the use of explosives in the case of large animals, chemical reactions between sea water and metal in the case of marine animals, or the use of servomotors for medium-sized mammals [11–14]. The separators are often used in medium to large animals. The use of separators is attributable to the weight limit of the attachable devices used on animals. Attaching a heavy device may restrict the animal's behavior or place its life at risk. For instance, for birds, the weight of the device weight must be kept within five percent of the animal's weight [15–17]. Thus, the integration of a separator to a small animal, such as a seabird, is a major issue in bio-logging.

In this study, we aimed to develop a small lightweight separator that is intended for use on small seabirds wherein the typical separators cannot be used. Because these separators are intended to be used for seabirds weighing 500–600 g (e.g., black-tailed gull and streaked shearwater (*Calonectris leucomelas*)), the total weight limit is 30 g. By subtracting the weight of the logger, which records the acceleration and position information, of 20 g, the wight of the separator must be equal to or less than 10 g. Because the sound or impact of separation could have an adverse impact on the individual being logged or other birds in the vicinity, these values should be as low as possible. However, there are few existing separators that satisfy these conditions [a]. The authors previously fabricated a separator that weighed 10.3 g, and employed a connecting mechanism that allows quiet separation. This device can be engaged at the desired time from a remote position through wireless communication. The feasibility of the device is verified in actual environments, by a separation experiment under various temperatures and for waterproof performance, which indicates that it is ideal for use in actual environments [18].

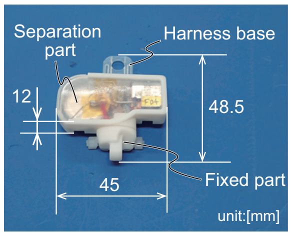
However, several problems are associated with the implementation of this method. The major issues include operational instability, such as the occurrence of disconnections during operation due to the fragile circuit board, poor maintainability for assembly, disassembly, inspection, and the weight of the device which exceeded the targeted 10 g limit. Although the use of lightweight batteries will make them lighter, lowering the capacity of the battery capacity is undesirable from the standpoint of long-term usage.

In this paper, we evaluate and discuss the improvements that are brought about in the separator to resolve the aforementioned issues. We specifically describe the design and fabrication of the drive circuit board using a flexible printed circuit (FPC), the stable operation of the shape memory alloy actuator, and the resulting improvement in the tensile force. Further we evaluate the performance of the device by verifying its operation from a remote location premised on actual usage, and also verified the operation with respect to long-term usage. First, we present an outline of the previously fabricated separator and its issues. Next, we describe the specific improvements that were incorporated and verify the feasibility of the device by a separation experiment using a prototype.

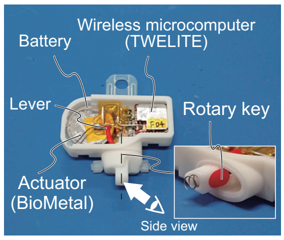
2. Overview of Separator and its Issues

2.1. Overview of Separator

We present an overview of the separator, by referring to our previous study [18]. The views of the separator are shown in **Fig. 1**, and a conceptual diagram showing its attachment to a bird is shown in **Fig. 2**. The device is attached to the back of the seabird through a harness, and the logger is mounted at the top surface of the separator. The researcher visually captures the target when it is kept still on the ground when he or she wishes to separate the logger and transmits a separation command using a remote controller from a distance. This communication engages the actuator in the separator and executes the separation process, which causes the separator and logger to detach from the bird. The primary specifications of the separator are as follows:



(a) Photo of prototype separator.



(b) Photo of the internal structure of prototype separator.

Fig. 1. Overall view of prototype of separator.

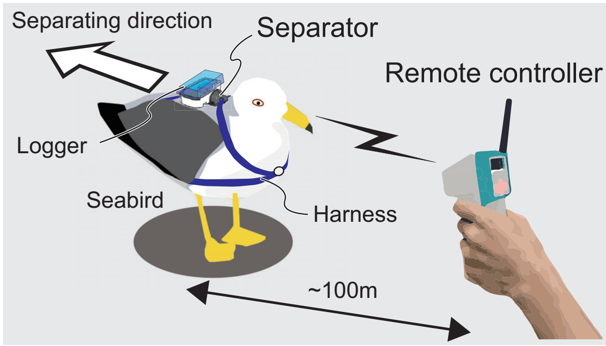


Fig. 2. Concept of separator.

- Device weight: 10.3 g.
- Mechanical separation mechanism with no use of explosives.
- Wireless communication from a maximum distance of approximately 100 m.
- Communication for over a month based on the battery.

The separator consists of a rotary key mechanism that executes separation, the fixed part, and rotary keys. The separation part in the separator consists of an actuator (BioMetal) that drives the rotary keys, a wireless microcomputer (TWELITE) that carries out communication, and a battery that supplies power to these units. The separation part, harness base, rotary keys, and waterproof cover were fabricated using photo-fabrication-type 3D printers Forms 2 and 3. The separation part and rotary keys were made from White, a photo-curing resin with properties similar to ABS resin, and the harness base and waterproof cover were made from durable, tough, flexible photo-curing resin. These materials had densities of $1.2–1.3 \times 10^{-3}$ g/mm^3.

2.1.1. Separation Mechanism

To allow quiet separation without the use of explosives, the separator employs a connecting mechanism that uses rotary keys, as shown in **Fig. 3**. The mechanism consists of the separation and fixed parts, and both parts consist

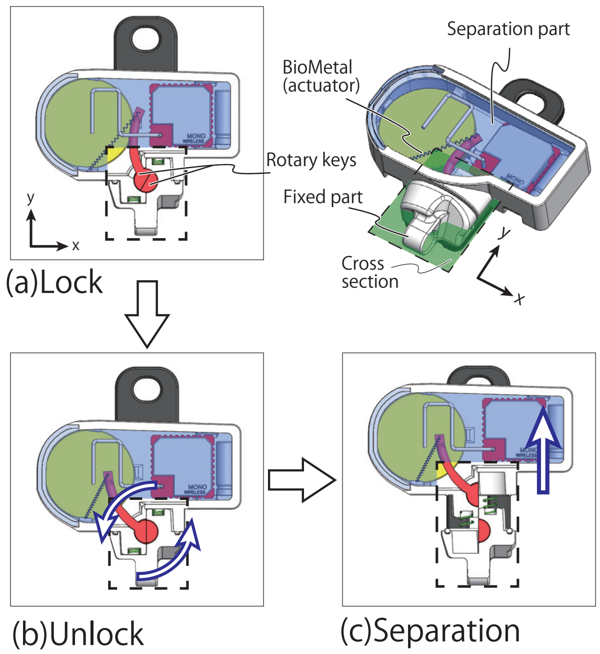


Fig. 3. Separation mechanism.

of a rotary key and semi-spherical indentation that holds these keys. The semi-spherical rotary keys are in contact with one another through the flat surfaces, and they are mounted in semi-spherical indentations in the separation and fixed parts. When the rotary keys are turned in this condition, the engagement between the rotary keys and their mounts changes, thus causing the locked state to disengage and separate the two parts. **Fig. 3(a)** shows the state in which the rotary keys and mounts are engaged. When the rotary keys are turned in a counterclockwise motion from this state, the engagement is released, and it changes to the state shown in **Fig. 3(b)**, which allows separation to occur. Further, the repulsive forces of the compressed coil springs in the protruding ends of the separation and fixed parts cause separation, as shown in **Fig. 3(c)**. The actuator that turns the rotary keys consists of BioMetal (BioMetal Helix BMX150, Toki Corporation). It is a shape memory alloy actuator, and it contracts when an electric current is applied to generate heat. One end of the actuator was attached to a lever that was integrated with a rotary key, and the other end was affixed to the side of the separation part, so that the contraction of the BioMetal turns the rotary keys.

Because the separation mechanism creates a gap between the surfaces of the separation and fixed parts in contact, it must be waterproof. This was accomplished using a silicone rubber O-ring (Sakura Seal Co., Ltd.). The O-ring is attached to the fixed part, while the protruded part that makes contact with the O-ring is attached to the separation part. This mechanism maintains sufficient waterproofing for short inundation periods, which corresponds to the feeding behavior of seabirds.

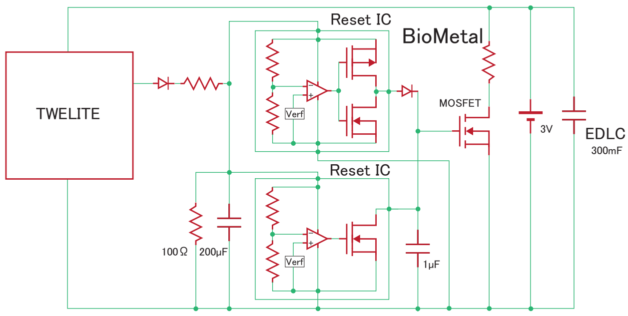


Fig. 4. Circuit diagram of separator. Digital output of TWELITE is received, drive time of MOSFET is secured according to time constant of RC circuit, and BioMetal is driven by the output assist of EDLC. Drive voltage is monitored by the reset IC to perform stable operation.

2.1.2. Drive Circuit

The drive circuit of the separator is illustrated in **Fig. 4**. To reduce the weight, a single battery is used to drive the wireless microcomputer and actuator. A communication range of several tens of meters is sufficient in this case because the separator is intended for use with a seabird in a colony. However, considering situations wherein it is difficult to approach the target due to topographical factors or weather, we assume a maximum communication range of approximately 100 m. Therefore, we used TWELITE by Mono Wireless Inc., which is a wireless microcomputer module with a maximum communication range of 3 km. The microcomputer weighed 0.93 g and had a drive voltage of 2.0–3.6 V. Rather than being constantly driven, we set a sleep period to reduce current consumption and achieve long-time drive. Although setting a long sleep time will result in a long service life, we set this as 10 s in this device considering the operability during separation. The current consumption during this time was 0.0693 mAh.

For the implementation of this device, it is necessary to drive the microcomputer to enable constant communication for a period of one month or more, between its attachment and separation, and then drive the BioMetal at the recommended drive current of 200–300 mA at separation. We employed a lithium button cell based on the battery capacity and weight. The employed battery has capacity of 165 mAh and weighs 2.3 g. When only the battery is used to drive the BioMetal, the voltage drop causes the source voltage to fall below the drive voltage of the microcomputer. This causes the BioMetal to stop contracting before it has sufficiently contracted. This is prevented by employing a holding circuit. This circuit uses a reset IC to monitor the voltage and maintains the MOSFET's drive voltage for a certain time period based on the RC circuit time constant. This ensured that the BioMetal was driven for a sufficient time. Furthermore, the battery output is insufficient to drive BioMetal in a stable manner. Therefore, a large-capacitance electric double-layer capacitor (EDLC) is connected in parallel with the battery. The EDLC provides a stable power when the battery out-

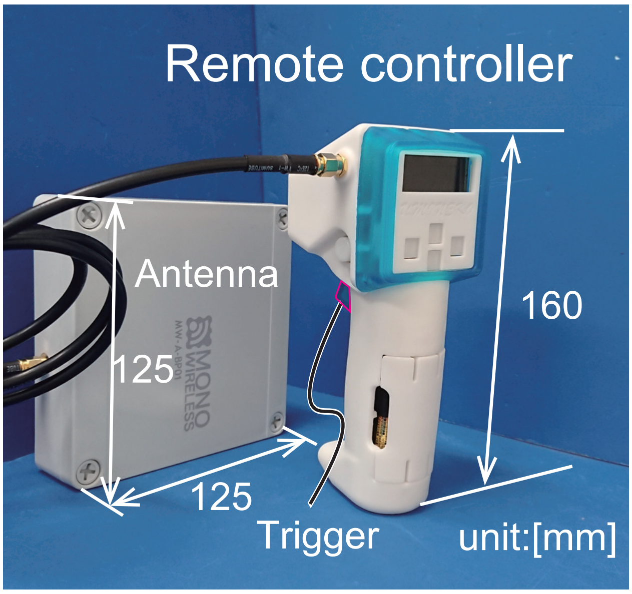


Fig. 5. Overview of remote controller.

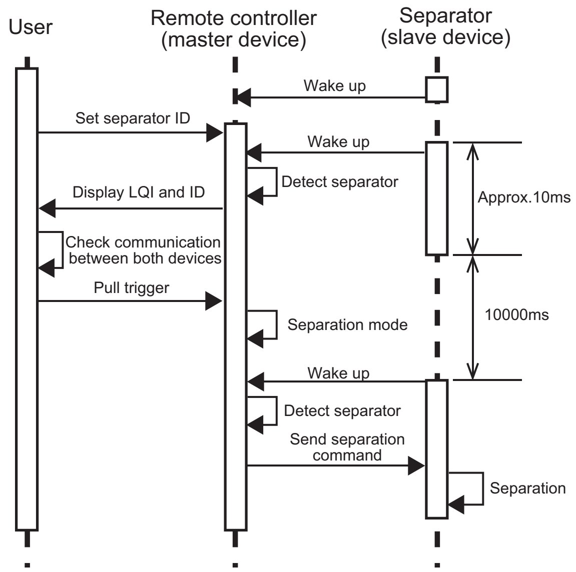


Fig. 6. Sequence diagram showing the operation and processing of separator, remote controller, and user.

put falls, making it possible to drive BioMetal in a stable manner.

2.1.3. Remote Controller

The remote controller used to operate the separator is illustrated in **Fig. 5**. The controller and the antenna weighed 220 and 235 g, respectively. The remote controller uses the same type of wireless microcomputer (TWELITE) as the separator. A directional antenna, which emits strong radio waves in a given direction, is used to extend the communication range. This antenna is pointed in the direction of the target for communication. The operator holds the antenna in one hand and the remote controller in the other, and presses the trigger button to transmit the separation command. The separator and remote controller have a slave-master relation, wherein the remote controller is the master. The remote controller can communicate with multiple separators, each of which is assigned a different identification number. The communication sequence is shown in **Fig. 6**. For efficient communication, the separator, which is the slave, transmits data such as identification number to the master when starting up from the sleep period (10 s in this device). The master, which is always on standby, receives this signal, and the operator can press the trigger to transmit the separation command, thereafter. When the slave receives this command, the actuator is driven, and the logger and separator are detached.

2.2. Issues in Separator

Figure 7 shows the drive circuit of the separator. To ensure that the device is lightweight, the surface-mounted components are soldered onto a universal board and connected directly to TWELITE and BioMetal through enamel wires. The components are fabricated manually, the enamel wires are bent, and the parts are stacked to house the assembly within the limited space of the separator. The fabrication of the drive circuit requires technical skills because small parts need to be soldered in a relatively less time. Furthermore, the device is prone to problems such as contact failures or disconnections. In particular, the solder at the connecting parts with the enamel wires tends to come off because of the exerted load when the wires were bent during assembly. Similar problems occurred during the device drive test or maintenance, and these problems prevented a stable operation of the separator.

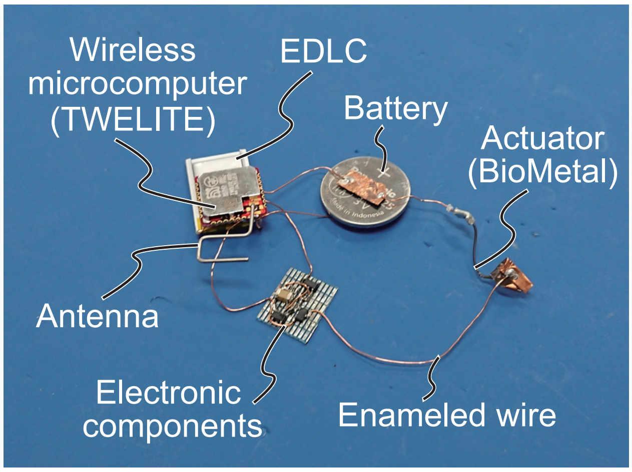
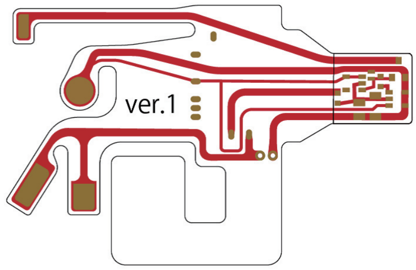


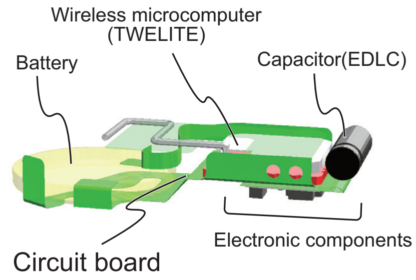
Fig. 7. Overview of separator's circuit.

Furthermore, the operation of the separator is unstable because of the short circuit that resulted from the contact between the BioMetal and TWELITE antenna within the separation part. This further stopped the contraction of the BioMetal in mid-process. The BioMetal and antenna were positioned in the same area, and they were stacked on top of each other, to save space and reduce weight, such that the TWELITE arrangement caused these parts to come into contact. Although the short-circuit can be prevented by applying an insulation tape between the BioMetal and antenna, there were cases wherein the tape shifted or peeled off. In some cases, the shifted tape was caught within the antenna, which prevented separation. If these problems can be resolved, the separator is expected to operate stably and fabrication efficiency can also be improved.

The device weighed 10.3 g, which exceeded the targeted weight by 0.3 g. It is essential that the separator is lightweight because it creates an extra load for the animal that is carrying it. Furthermore, the weight of the logger can be increased within the imposed weight limit if the separator is lighter, which makes it possible to increase the battery capacity or the number of sensors. Because this should make it possible to collect a greater amount of data within a single session, or extend the observation period, weight reduction is an important issue. In the present study, we aimed to reduce the weight to 10 g or less.



(a) Circuit blueprint



(b) Assembly image of FPC

Fig. 8. Circuit design.

3. Method of Improvement

3.1. Fabrication of Circuit Board

We attempted to fabricate a flexible printed circuit (FPC) to resolve the problems in the circuit board. Because the universal board and TWELITE were stacked to fit within the given space, the FPC can be an ideal solution because it can be flexibly bent within the available space. Thus, we employ P-Flex by Elephantech Inc., which is a single-sided FPC.

The P-Flex is an FPC fabricated by the pure additive process, wherein metal nanoparticles are inkjet-printed followed by the electroless deposition of metal [b]. The specific design is described below. **Figs. 8(a)**, **(b)**, and **9** show the designed FPC, an image of the assembled state, and a diagram of the folding process.

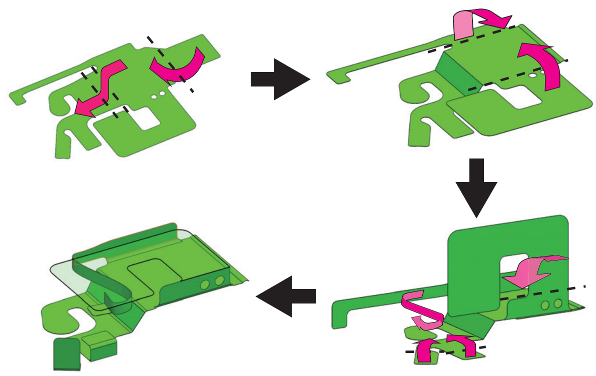


Fig. 9. Folding image of FPC. Each part is folded according to the pink arrow in the order of upper right, lower right, and lower left from the upper left figure. The lower left figure matches **Fig. 8(b)**.

Rounding the corners in the exterior pattern of the FPC to prevent peel-offs or cracks when it is bent is a common design practice. The present design observed this practice and followed the P-Flex design specifications provided by Elephantech Inc.

To reduce the weight of the circuit, the EDLC was changed to a lighter cylinder with a capacitance of 300 mF and maximum current of 0.5 A. The present circuit adopted the same arrangement as the previous one, placing the electronic components underneath the TWELITE. Because P-Flex is a single-sided FPC, the electronic components can be arranged beneath the TWELITE by folding the circuit board, as shown in **Fig. 9**. Although a reinforcing plate is usually installed in the section where electronic components are mounted to minimize bending of the printed board and prevent the components from becoming detached, this arrangement increases the thickness of the circuit. Because achieving lightweight and compactness in the present device is important, the reinforcing plate was installed only in a section that had a high concentration of electronic components, but not at the TWELITE. The substrate consisted of 0.05 mm-thick PET, and the reinforcing plate consisted of 0.3 mm-thick glass epoxy. In addition to the wiring of the electronic components, a cover was designed to prevent the interference and contact between the battery's contact terminals, TWELITE antenna, and lever. The role of the cover is to prevent the interference with the turning of the rotary keys as well as short circuits between the BioMetal and antenna.

The pattern width for sections carrying a large current was set at 1.0 mm based on the datasheet that showed

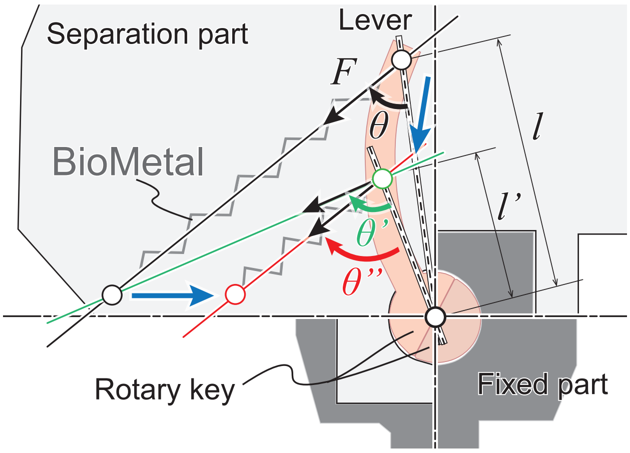


Fig. 10. Schematic diagram of BioMetal mounting position. F is the force of BioMetal, l is the distance from the center of rotation of the lever to the mounting position on the lever of BioMetal, and θ is the angle between the lever and BioMetal. When the mounting position of the BioMetal changes to the green and red positions, the angle with the lever θ changes to θ' and θ'', respectively.

the relation between current and temperature rise. The dimensions of the fabricated FPC were 58×37.1 mm, and its weight was 1.7 g. The TWELITE and surface-mounted components were mounted by Elephantec Inc., while the BioMetal and EDLC were manually soldered because their positions and lengths need to be adjusted at the time of assembly.

3.2. Prevention of Contact Between BioMetal and Antenna

Although the BioMetal and antenna are stacked vertically, and a sufficient space is left between them to prevent contact, they may still come into contact if the TWELITE or antenna is tilted. To resolve this problem, we changed the attachment position of BioMetal.

3.2.1. Arrangement of Attachment Position of BioMetal

A simplified diagram showing the attachment position of BioMetal is shown in **Fig. 10**. The BioMetal is attached to the lever at one end and to the side of the separation part at the other end. The physical contact can be avoided by shifting its attachment to the lever toward the center of rotation. In this case, the value of l' in **Fig. 10** is equal to or less than 10 mm. However, this reduces the torque required to turn the rotary keys unless the attachment to the side is changed. In this case, the torque is reduced because the angle between BioMetal and the lever increases (corresponding to θ' in **Fig. 10**). Thus, the attachment on the side must be changed. This change will be essentially accompanied by a reduction in the length of the BioMetal.

Therefore, we measured the variation in the BioMetal's output depending on its length using the present drive circuit to investigate the suitable length. The experiment is described in Section 3.2.2. It should be noted that the BioMetal's output must be increased to obtain the same torque (12 Nmm) as in the previous design. Specifically, the present BioMetal, whose length is 10 mm, produces an output of approximately 0.8 N, but will be required to produce approximately 1.2 N after the attachment position has been changed. The output of BioMetal varied with the heating rate. A large output can be produced if the BioMetal is heated instantly, but this will require a large current. Although this can be achieved by using a high-output battery, it will increase the weight, which is unsuitable for the present device. On the other hand, the resistance of BioMetal will be reduced by shortening its length from its present value (10 mm), thus resulting in an increased current.

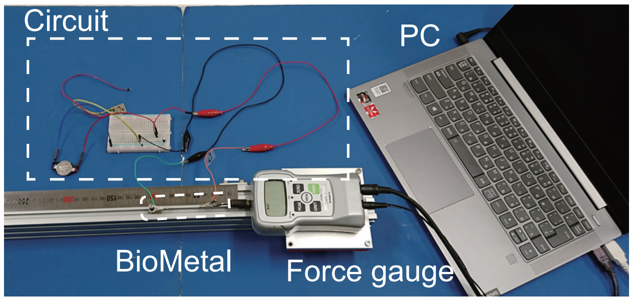


Fig. 11. Overall view of experimental setup.

3.2.2. Measurement of BioMetal Output

The BioMetal output was measured with a force gauge (FGPX-0.5, Nidec-Shimpo Co., Ltd.). One end of the BioMetal was fixed, while the other end was attached to the force gauge for measurement. A lithium coin battery (CR2025) was used as the drive circuit for the separator as the power source. A regulated power supply was used to measure the maximum force output by BioMetal. The BioMetal pieces with lengths 5, 8, 10, 12, and 15 mm (in the contracted state) were used. The BioMetals with lengths of 10 mm and higher were used to obtain the characteristics. The experimental setup is shown in **Fig. 11**, and the procedure is described below.

1. The BioMetal was stretched to twice the length of the contracted state, and one end was attached to the force gauge and the other to a fixture.
2. Using the drive circuit, the current was passed through the BioMetal, following which its output was measured.
3. Ten measurements were carried out for each combination of the length and type of power source, and the maximum output during each measurement was recorded.

The outputs of BioMetal with different lengths are shown in **Fig. 12**. The BioMetal is capable of producing outputs of 1 N and higher when the regulated power

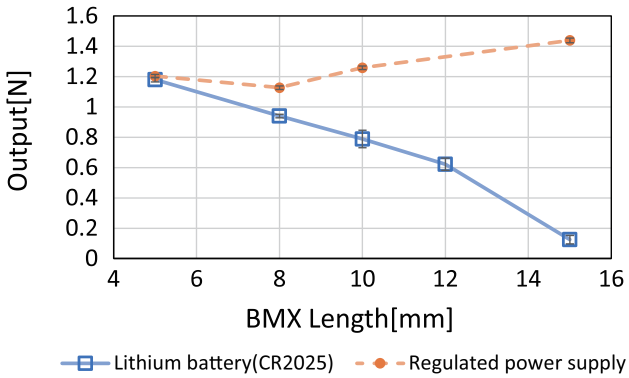


Fig. 12. Output of BioMetal. Rectangle plot shows the output with the circuit of separator, and circle plot shows the output with the regulated power supply.

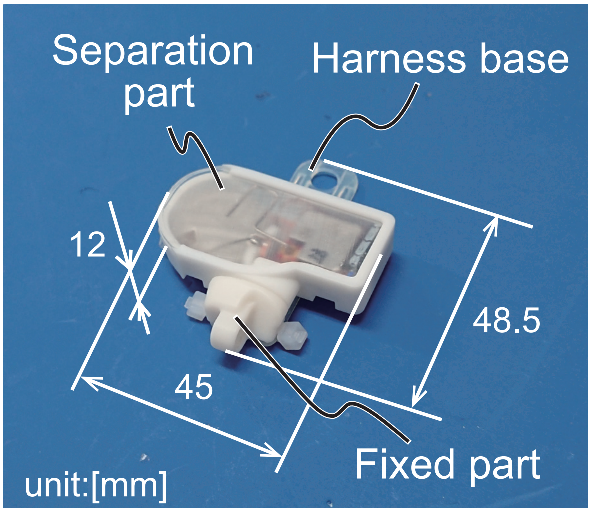
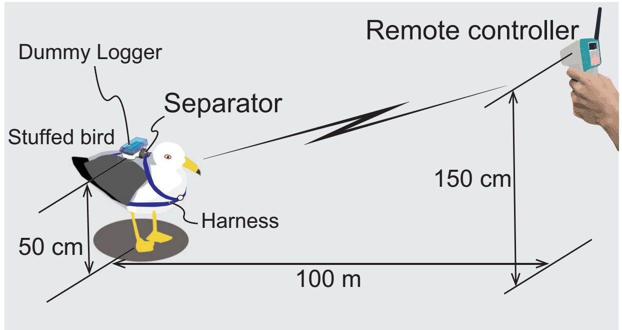


Fig. 13. Overview of prototype with FPC.

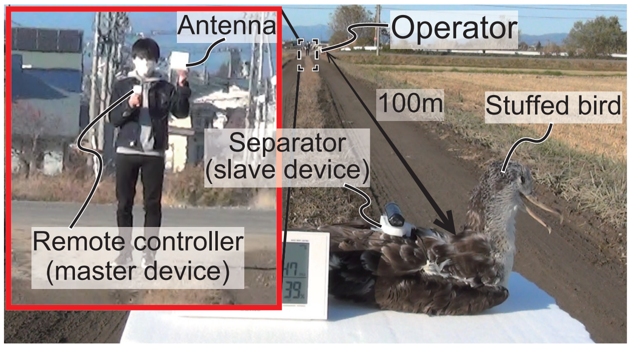
supply is used, and in this case the longer pieces produce a higher output. The output is greater with a shorter length when the button cell is used, because it cannot output a large current. Based on these results, a 5 mm-long BioMetal is considered to be optimal with the present power source.

4. Prototype

The fabricated prototype is illustrated in **Fig. 13**. It integrates the fabricated FPC and employs a BioMetal whose length was reduced from 10 to 5 mm. Owing to the change in position of the BioMetal attachment, the design of the external shape of the separation part and the shape of the waterproof cover were modified to conform to the shape of the battery. In addition, the bottom of the separation part was partially raised to improve the contact between the battery and the FPC terminals. As in the case of the previous prototype, the separation part, harness base, rotary keys, and waterproof cover were fabricated using photo-fabrication-type 3D printers Forms 2 and 3. The



(a) Outline of outdoor separation experiment



(b) Photograph of the outdoor separation experiment

Fig. 14. Overview of outdoor separation experiment.

weight of the device was 9.7 g, which is below the 10 g target.

We conducted experiments to evaluate the feasibility of the fabricated prototype. Two experiments were performed: one to test separation in an outdoor setting, premised on actual usage, and a drive experiment to verify whether long-term operation is possible. Although the actual usage environment was not completely reproduced, we employed a minimally required environment based on practice, specifically with regard to the communication distance and usage period.

5. Verification

5.1. Outdoor Separation Experiment

An outdoor separation experiment was conducted to evaluate the prototype device. The settings are shown in **Fig. 14**. To simulate actual usage conditions, the separator (slave) and remote controller (master) were separated by a distance of approximately 100 m under clear skies with a temperature range of 4.4°C–16.3°C. The experiment was conducted on an open road with no obstructions. To simulate separation when the seabird is at rest (stationary), the separator was attached to the back of a stuffed specimen of streaked shearwater using a harness. A dummy logger with dimensions $28 \times 16 \times 16$ mm and a weight of 20 g was mounted on the separator. The ID number of the separator (slave) was set by the remote controller such that the separation command was only transmitted to the

Table 1. Result of separation experiment in outdoor.

Number of trials	Separation	LQI	Battery voltage [V]	Temperature [°C]
1	○	54	2.78	16.3
2	○	30	2.83	15.3
3	○	57	2.80	14.0
4	○	57	2.85	12.3
5	○	48	2.82	12.7
6	○	51	2.82	11.2
7	○	30	3.10	10.6
8	○	39	2.90	9.8
9	○	39	2.83	4.6
10	○	48	2.82	4.4

correct separator. A directional antenna was used with the remote controller, and it was raised to a height of approximately 1.5 m above the ground during communication.

The specific procedures were as follows.

1. The separator and remote controller were set up at two positions that were 100 m apart.
2. The ID number of the slave device was set using a remote controller, and the communication was confirmed.
3. After confirmation of communication, the separation command was transmitted.
4. A check was made to ensure that separation was attained.
5. The above steps were repeated for ten trials.

Table 1 lists the experimental results. It was confirmed that separation occurred without failure in an environment with varying temperatures. The operation was stable even when the temperature was below 10°C. The battery voltage varied between 2.78 and 3.10 V, but this did not affect the operation. With respect to communication, the link quality indicator (LQI)[1] varied between 30 and 57, which is considered low, but a well-established communication is achieved. In practical usage, it is necessary to approach the target as closely as possible. It may be possible to prevent potential communication failures and improve communication performance by retransmitting the separation command several times following a single transmission.

Although we used a stationary stuffed bird in this experiment, the target may be moving under actual conditions. This may impart some velocity or acceleration to the device and lead to results that differ from those in the stationary state. However, the separator is unlikely to be used when the target is moving at high speed, because it will be used only after the operator has ascertained the location of detachment. Thus, we assume its usage in near-stationary states. The performance in this case did not differ greatly from those demonstrated in the experiment.

1. An index that expresses the radio field intensity within the range 0–255. LQI below 50 is poor, from 50 to 100 moderately poor, 100 to 150 good, and 150 and above near antenna [c].

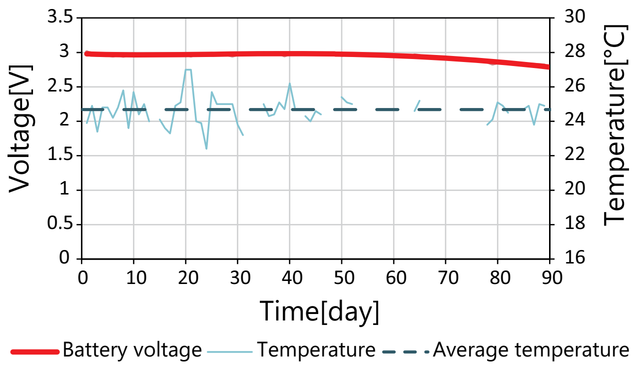


Fig. 15. Transition of battery voltage.

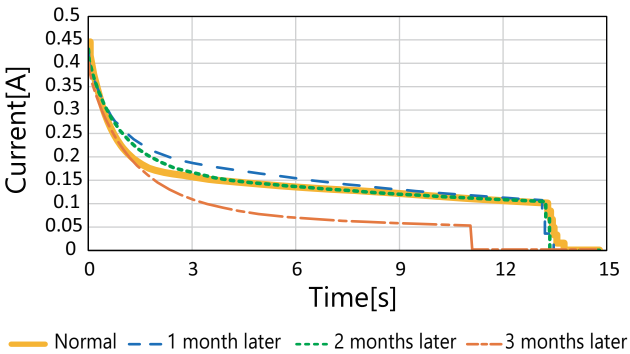


Fig. 16. Output current of actuator.

5.2. Battery Drive Experiment

We assume that the separator will be attached to a bird for a period of two weeks to one month. Although the calculations indicate that the communication should be possible for at least three months, we verified whether it is possible to establish communication and drive the actuator for over a month under actual operating conditions. The experiment was conducted for three months, and it is described below.

The separator was placed in a room with a temperature of approximately 25° and the battery voltage was monitored for three months. Although the drive circuit consisted of the same parts, the previous prototype, that did not consist of the FPC circuit, was used. The source voltage was measured once per day using a tester. A wireless communication was established using the remote controller (master) to drive the actuator exactly one, two, and three months after the commencement of the experiment, and the respective output currents were measured. The variation of the source voltage over this period was observed, and the actuator's output currents at the three monitoring times were compared. The drive voltage of the actuator was measured three times during each session.

The long-term variation of the battery voltage is shown in **Fig. 15**, and a comparison of the actuator's output current is shown in **Fig. 16**. In the latter, the "normal" output current, that is, when the actuator has not been driven for an extended period, is also shown for comparison. In

Fig. 15, the bold curve represents the battery voltage, and the broken line represents the average temperature during the experiment. It should be noted that there are periods during which the temperature data are not available. In **Fig. 16**, the bold curve represents the output under normal conditions, and the broken, dotted, and alternate-long-and-short dash curves the outputs one, two, and three months later, respectively. **Fig. 15** shows that the battery voltage remained nearly constant for two months. Meanwhile, **Fig. 16** shows that the actuator's output current was approximately the same one and two months later, indicating that the actuator was driven stably. These results indicate that the present separator can be driven for a two-month period.

The temperature under actual usage conditions may be lower than that in the experiment. Although the battery voltage may fall in such cases, leading to a shorter battery life, we believe that the device life can be extended by increasing the sleep time of the wireless microcomputer. For instance, the calculations show that the drive period can be extended to approximately 280 days by changing the sleep time from 10 to 30 s.

6. Conclusion

In this paper, we discuss the improvements in the data logger separator for wild animals. The circuit board was designed and fabricated on a flexible printed circuit, P-flex, which reduced the weight and improved the fabrication efficiency and maintainability. Furthermore, we measured the output of the BioMetal in the drive circuit of the separator to achieve stable actuator motion. Based on the results, we fabricated a prototype wherein the length of the BioMetal was changed to 5 mm and its attachment was adjusted at a suitable position. The fabricated prototype weighed 9.7 g, which met the initial requirement. In a separation experiment that simulated an actual environment, we confirmed that separation occurred without failure using wireless communication over a distance of 100 m at low temperatures. We also confirmed that the actuator was driven efficiently for two months. The results indicate that the present device functions adequately as a separator, it can be attached to a small seabird, and it allows data logging for a maximum period of two months. The device enables efficient recovery of the logger, and allows a collection of a greater amount of data. Furthermore, it can be deployed in the later stages of the brooding period, wherein it was previously difficult to carry out field research because of the difficulty in capturing the birds.

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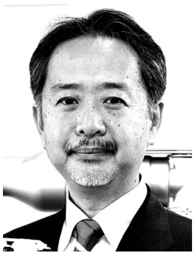

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