Avian influenza surveillance system in poultry farms using wireless sensor network

著者別名	鈴木 耕太郎
journal or publication title	Design Test Integration and Packaging of MEMS/MOEMS (DTIP)
page range	253-258
year	2010-05
URL	http://hdl.handle.net/2241/00123669

Avian influenza surveillance system in poultry farms using wireless sensor network

[*,***]Hironao Okada, [**,***]Koutarou Suzuki, [**,***]Tsukamoto Kenji, and [*,***]Toshihiro Itoh
[*]National Institute of Advanced Industrial Science and Technology
1-2-1, Namiki, Tsukuba, Ibaraki 305-8564 Japan
[**]National Institute of Animal Health
3-1-5 Kannondai, Tsukuba, Ibaraki 305-0856, Japan
[***]CREST, JST, Japan

***Abstract*- We evaluate an availability of a method for detecting chickens infected with the highly pathogenic avian influenza (HPAI) viruses at the early stage in poultry farms using a wireless sensor node with temperature sensor and accelerometer. Chicken infection experiments by using the developed prototype wireless sensor node showed that weakness and fever of the infected chickens would be the early signal for the outbreaks. We propose a detection method using body temperature and acceleration data at an early stage in consideration for construction of wireless sensor node. The result of the simulation using the infection experiment indicates that the infection can be detected before more than about 10 hours of the death and measurement of 1 axis acceleration is enough. We also design a wireless sensor node with small button battery which works continuously for period of longer than 2 years without battery replacement, and demonstrate the basic operation. This study indicates a possibility that the wearable wireless sensor node would be a useful tool for detecting the HPAI outbreaks at the farms.**

I. Introduction

A network of sensors represents a distribution of large number of wireless micro-sensor nodes attached to, or embedded into, a human body or other objects so that their conditions and related ambient data can be monitored. The sensor networks can be applied to systems for realizing safe [1] and secure society, monitoring of human health [2], and so on. The wireless sensor node, consisting of sensors, a micro control unit (MCU), transceiver IC, supporting electronics and a battery, has been dramatically improved in its performance and functions and miniaturized thanks to recent advance in microelectromechanical systems (MEMS) technology. Recently, a digital output sensor for wireless sensor node has been developed in order to reduce the power consumption of a device [3].

As an application of wireless sensor network, our group has been developing a global avian influenza surveillance system by monitoring the health of chickens with wireless sensor nodes in poultry farms [4]. The highly pathogenic avian influenza (HPAI) virus (H5N1) infection in birds has continued, and has acquired pathogenicity not only in birds but also in mammals [5]. The more cases of migratory birds and domestic fowls increase, the more human cases increase and the variation of the virus progresses. Consequently, risks of occurrence of a pandemic flu with transmissibility among humans increase. Therefore a global avian influenza surveillance system for the early-stage detection of birds cases must be effective to defend human beings from an influenza pandemic.

The concept of our avian influenza surveillance system is initial diagnosis. Several percentages of chickens in poultry farms are attached with wireless sensor nodes. When the surveillance system detects an unusual state of the chickens, the system automatically alerts administrators through the internet. The system can also report a history of health conditions obtained by sensors such as the fever and weakness. Finally, using these data, the administrators decide whether this incident is caused by avian influenza or not. On the other hand, since large numbers of wireless sensor nodes are distributed, the cost of the node has to be reduced. For these reasons, a temperature sensor and accelerometer are used in this node without using a sensor which directly detects a virus.

In this study, we evaluate the availability of the surveillance system using wireless sensor node with temperature sensor and accelerometer. First, we need to obtain basic data of chickens infected with influenza viruses. We have developed a prototype of wireless sensor node for carrying out infection experiments. Then a method for

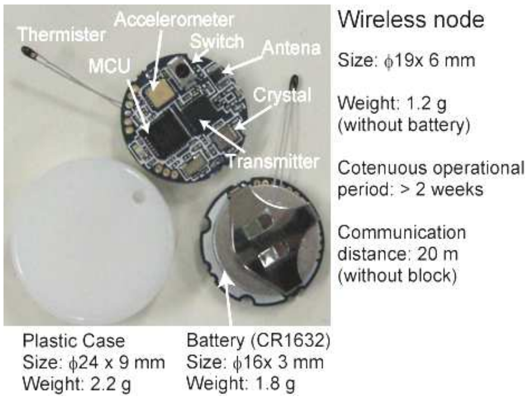

Fig. 1. Photograph of the developed prototype wireless sensor node.

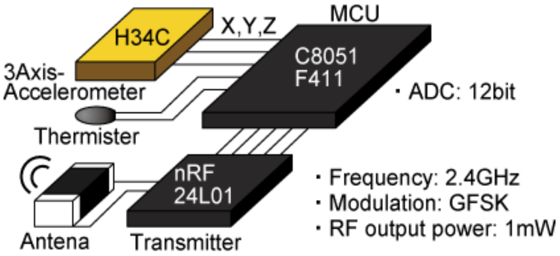

Fig. 2. Block diagram of the developed prototype wireless sensor node.

Fig. 3. Photograph of the infection experiment.

detecting the infection with body temperature and activity data at an early stage is examined in view of a construction of low power wireless sensor node. We also proposed a system of the node which works continuously for period of longer than 2 years without battery replacement and demonstrate the basic operation.

II. Development of Prototype Wireless Sensor Node

The weight of the wireless sensor node need to be less than 10 g since chickens can not move freely if the attached node is heavy. In addition, the lifetime of the wireless sensor node used in influenza infection experiments has to be period of longer than 2 weeks. We designed the wireless sensor node satisfied these conditions. Fig. 1 and Fig. 2 show the photograph and the block diagram of the prototype wireless sensor node, respectively. A temperature sensor of surface mount type is not suitable for measuring body temperature of chickens because it is difficult to touch the sensor to the skin of a chicken. A thermister is used as a body temperature probe. The H34C (HITACHI Metals Ltd.) of 3-axis accelerometer with 1 μA current consumption during sleep mode state is used for an activity sensor. A MCU and a transceiver IC are a C8051F411 (Silicon Laboratories) [6] with 12 bit analog digital converter (ADC) and a nRF24L01 (Nordic Semiconductor ASA) [7] with 900 nA current consumption in power down mode. The operating frequency of this transceiver IC is the industry-science-medical (ISM) band at 2.4-2.4835 GHz and the modulation method is gaussian filtered frequency shift keying (GFSK) modulation. The communication distance is about 20 m without a block. The size and the weight of the wireless sensor node are ϕ19× 3 mm and 1.2 g, respectively. In order to prevent the node from damaging by pecking, a plastic case with ϕ24× 9 mm size and 2.2 g weight is also developed. The body temperature probe is pulled out from an opening of the plastic case. The total weight of the wireless sensor node is 5.2 g. In order for the node to work continuously for period of longer than 2 weeks without battery replacement, uni-directional system and 20 seconds intermittent operation are adopted. The 3-axis acceleration is measured 20 times per one measurement which takes about 0.14 milliseconds. The activity (A) is calculated as:

$$A_x = \sum_{n=1}^{20} \left| a_{xn} - a_{x(n-1)} \right|,\ A_y = \sum_{n=1}^{20} \left| a_{yn} - a_{y(n-1)} \right|,\ A_z = \sum_{n=1}^{20} \left| a_{zn} - a_{z(n-1)} \right| \quad (1)$$

$$A = \sqrt{A_x^{\ 2} + A_y^{\ 2} + A_z^{\ 2}} \quad (2)$$

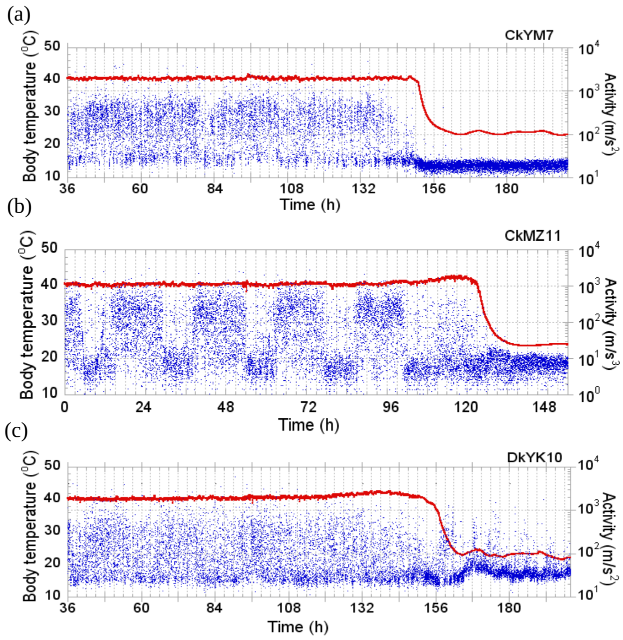

Fig. 4. Examples of body temperatures (red line) and activities (blue dots) of chickens infected with influenza viruses((a)CkYM7, (b)CkMZ11, (c)DkYk10).

where a_x, a_y and a_z are 3-axis accelerations. We confirmed that the lifetime of the developed prototype wireless sensor node is more than 2 weeks.

III. Infection Experiment

Fig. 3 shows the photograph of the infection experiment. The developed prototype of wireless sensor node was attached to abdominal skin surface of a chicken by no stretching sport tape. Four-week-old specific-pathogen-free (SPF) chickens were used for the infection experiments. The wireless signals were sent to a universal serial bus (USB) type receiver placed outside of isolators. Three kinds of H5N1 HPAI viruses (A/chicken /Yamaguchi/7/2004(H5N1); CkYM7, A/chicken/Miyazaki/ K11/2007(H5N1); CkMZ11, A/duck/Yokohama/aq-10/2003 (H5N1): DkYK10) were inoculated into the chickens [8].

Fig. 4 shows the examples of body temperatures (red line) and activities (blue dots) of chickens infected with influenza viruses. Fig. 4(a), (b) and (c) show the data of chickens infected with virus of CkYM7, CkMZK11 and DkYK10, respectively. Although chickens infected with CkMZK11 and DkYK10 had fevers, fevers of the chickens infected with CkYM7 were almost not observed [9]. On the other hand, the activities of chickens infected with every virus become low. This result shows that the infection of the influenza viruses would be detected by activity data at an early stage. While fig. 4 (b) clearly shows a pattern of activities during 24 hours, fig. 4 (a) and (c) do not show the pattern. In four-week-old chickens, there are chickens without 24 hours pattern of behaviors. In the case of fig. 4 (a) and (c), the infection can be detected by observing the low activities. However, in the case of fig. 4 (b), the infection can not be detected by only observing the low activities. Thus, we need to take the behavior patterns into consideration for detecting the infection.

IV. Development of The Method for Detecting The Infection

We have to develop a method for detecting an infection of influenza in consideration of construction of a wireless sensor node. The node has to work continuously for period of longer than 2 years without battery replacement. Because the capacitance of the battery is tens of milliampere-hour (mAh), the power consumption of the node must be decreased. Since the transmission is the largest power consuming operation in the wireless sensor node, we have to decrease the amount of transmitted data. First, we examine whether 3-axis accelerations are needed for detecting the influenza or not. Fig. 5 shows the examples of the A_x, A_y and A_z. It is found that there is almost no difference between them. This means that it would be enough to measure only 1 axis acceleration. In that case, we could decrease the amount of transmitted data.

In addition, the wireless sensor node should work only when a movement or body temperature change required for detecting the influenza occurs. We call this operation mode event-driven operation. In the standby state of this mode, the power consumption must be very low. In order to realize the low power standby state, we use a piezoelectric accelerator, switch type bimetal temperature sensor and a comparator. A piezoelectric accelerator can generate a voltage and a bimetal can bend with only change of environmental temperature. A comparator can work with very low power such as 80 nA at 1.8 – 5.5 V [7]. Using these components, when an acceleration that the accelerator output voltage exceeds a threshold voltage of the comparator is applied to a node, or when the environmental temperature reaches at which the bimetal switch is on state, the node can wake up. Regarding acceleration, we propose a method that infection by influenza is detected at an early stage using the number of acceleration (N_t) which is over only 1 threshold (TH_A) per unit time. In other words, the accelerator is enough to be 1 bit sensor in this method. If the node sends only the N_t per unit time, the amount of transmitted data can be very small.

In order to evaluate this method, three criteria are proposed as follows:

α) Body temperature is more than 42 ˚C.

β) Body temperature is less than 30 ˚C.

γ) (N_t is less than TH_N) and (R_t is more than TH_R).

where R_t is a ratio between N_t at present and before 24 hours. TH_R is the threshold for R_t. The subscription of N_t and R_t means

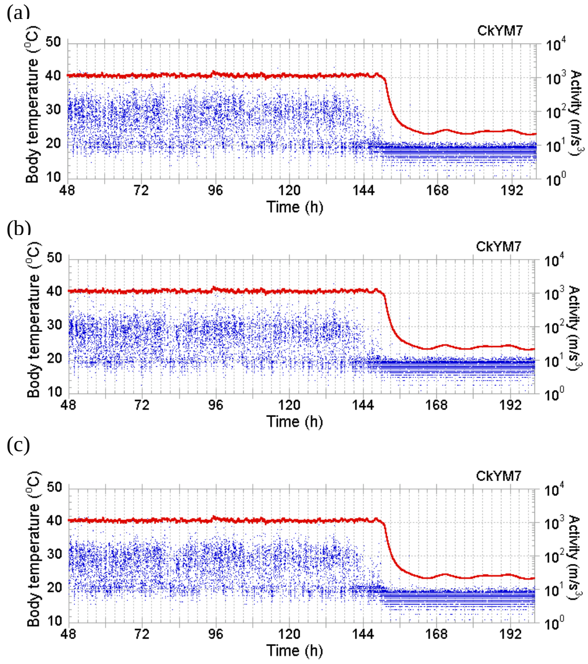

Fig. 5. Examples of (a)A_x, (b)Ay and (c)Az

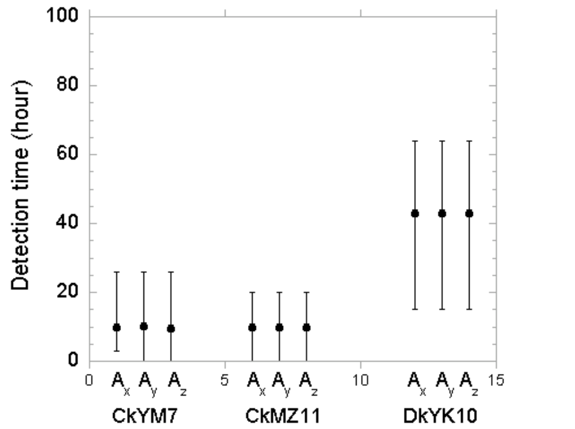

Fig. 6. Detection time for each virus before the death time decided by criterion (β) .

a measuring time. The meanings α), β), and γ) are a fever, a death, and low activity and a change of activity pattern, respectively. The R_t is calculated as:

$$R_t = \min\left(|R_t - R_{t-26}|, |R_t - R_{t-25}|, |R_t - R_{t-24}|, |R_t - R_{t-23}|, |R_t - R_{t-22}|\right) \quad (3)$$

Since a daily activity of a chicken is not always the same, we compare the activity before and after 2 hours. When any criterion is satisfied continuously 2 unit times, we decide that the chicken is infected with influenza. Using the data of infection experiments, we calculate the detection time.

Fig. 6 shows the example of the time of detection by criterion (α) and (γ) before the death decided by criterion (β). In this example, TH_A is 6 G/s, TH_N is 10, TH_R is 5 and the unit time is 1 hour. The infection with CkYM7, CkMZ11 and DkYK10 was detected mainly by criterion (γ), either (α) or (γ), and (α), respectively. It was found that the infection can be detected before more than about 10 hours of the death without wrong

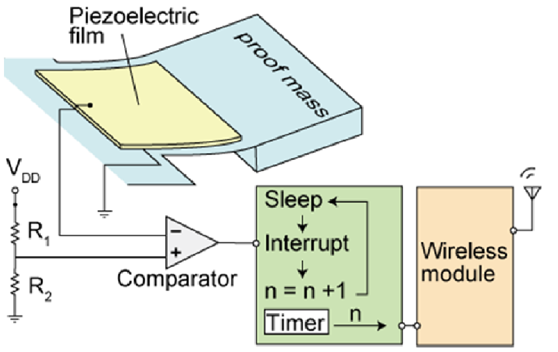

Fig. 7 Images for the concept of proposed node

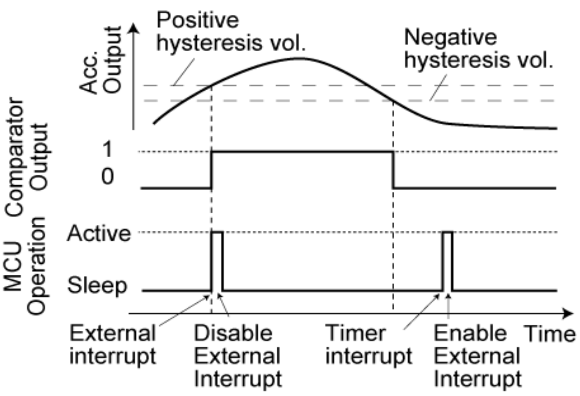

Fig. 8 Images for the concept of proposed node

detections and the detection times calculated using every axis acceleration are almost the same. This result indicates that measurement of 1 axis acceleration is enough to detect influenza. However, the parameter such as TH_A or TH_N needs to be optimized.

V. Design of The Wireless Sensor Node

In this study, we design the wireless sensor node with only accelerator. Fig. 7 shows the conceptual images of the proposed wireless sensor node which realize to get the acceleration data as stated above and to operate with low power consumption. The main components of the node are a piezoelectric accelerometer, a comparator, a MCU, and a wireless module. We count up the number of acceleration which exceeds a threshold by the MCU during a unit time. The MCU sends the number of wake-up to the wireless module every unit time. A problem with this node is that the output voltage from a small sized piezoelectric accelerometer, applied an acceleration of very small magnitude, is only of the order of a few millivolts, which is not sufficient enough be able to trigger the MCU to its wake-up state. To address this difficulty, a comparator is introduced, which can detect very small differences in the input voltages.

The comparator output transitions from logic 0 to 1, when the acceleration above the threshold is applied to the accelerometer. Since the threshold voltages are expressed as $R_2/(R_1+R_2)$, (see Fig. 7), the value of the resistance can be freely selected. Using resistors with high values their power consumption becomes negligible. However, we should optimize the voltage because the accelerometer can be miniaturized. In the case of low threshold voltage, the comparator output would be easily affected by noise. Later in this paper, the results of the investigation are described.

Fig. 8 shows the relationship between the output of the accelerometer and the comparator; and it shows the operations of the MCU when acceleration is applied to the accelerometer. The entire cycle begins at the MCU being in sleep mode. When the output voltage from the accelerometer exceeds a threshold voltage, the comparator output transitions from logic 0 to logic 1. The MCU wakes up with the comparator output signal and enters the active mode. After the MCU counts up the number of wake-ups, it then falls back into its sleep mode. The operation time during these processes is extremely short where the wake-up duration is close to 2 μs. On the other hand, animal behaviors are much slower than the clock frequency of the MCU. And if an interrupt from the comparator (external interrupt) is enabled during the MCU sleep mode, then the MCU wakes up again. This is because the comparator continues to remain at its output of logic 1. To avoid the unnecessary wake-ups of the MCU, the external interrupt must be disabled before the MCU enters the sleep mode and the operation mode has to be kept until the comparator signal becomes logic 0. For this reason, a timer interrupt is used in order to enable the external interrupt again.

Table I shows the power consumption of the node in the case of 30 minutes transmission intervals and 1000 wake-up times. The MCU and transceiver IC selected in this study are C8051F930 (Silicon Labs)[7] and nRF24L01 (Nordic)[8]

Table I Power consumption of the node in the case of 30 min transmission intervals time and 1000 wake-up times from the sleep mode. The current of C8051F930 at sleep mode was measured and the other values were calculated using the references[7, 8].

	C8051F930			nRF24L01		
	Current (μA)	Time (μs)	Average current (μA)	Current (μA)	Time (μs)	Average current (μA)
Sleep mode	1.1	1.8×10^8	0.5	0.9	1.8×10^8	0.9
Sleep mode (Time ON)	0.6	1.0×10^9	0.3			
Active mode for the count	6590	2000 (2 μs /event)	7.3×10^{-3}			
Transmission			5.7×10^{-4}			8.8×10^{-4}

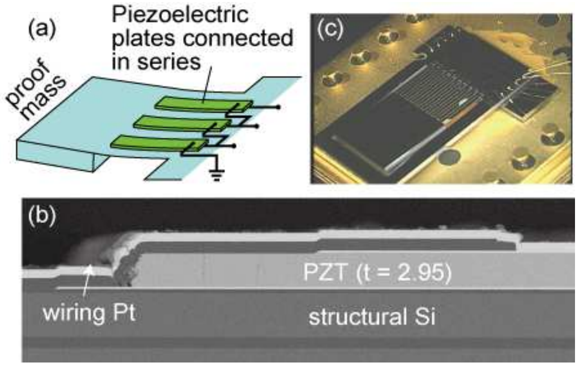

Fig. 9 (a) Schematic image of the accelerometer. (b) Cross-sectional SEM image. (c) The overview.

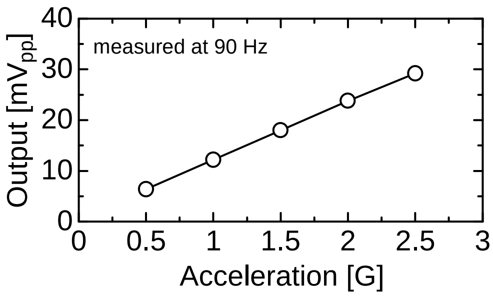

Fig. 10 Relationship between the peak-to-peak values of the output voltage for 10 PZT plates connected in series and acceleration.

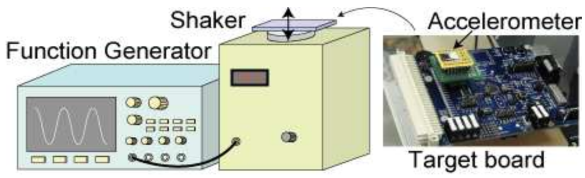

Fig. 11 Experimental setup for the investigation of the availability of comparator with hysteresis

which are generally used for low power devices. The required supply voltages for C8051F930 and nRF24L01 are 0.9 V-3.6 V and 1.9 V – 3.6 V, respectively. In this study, the supply voltage was 3 V and the comparator in the MCU was used.

Since the average current at the transmission and the time that the number of wake-up of the MCU is counted, can be negligible, the total average current is about 1.7 μA. Thus, the button batteries with more than 29.7 mAh capacity need to be used so that the node works continuously for a period of longer than 2 years. For example, we can use CR1025 of button battery with 30 mA h capacity, 10 mmϕ, 2.5 mm height, and 0.6 g weight.

VI. Piezoelectric Accelerometer

We have fabricated a piezoelectric accelerometer from the multilayer of Pt/Ti/ $Pb(Zr,Ti)O_3$ (PZT) (2.95 μm)/Pt/Ti/SiO_2 deposited on silicon-on-insulator (SOI) wafers (structural Si: 3.85 μm) through MEMS technique. Figs. 9(a), 9(b), and 9(c) show the schematic images of the accelerometer, the cross-section, and the overview, respectively. This type of accelerometer was also utilized for the characterization of PZT film in a previous study[9]. Although 10 PZT plates are arrayed in parallel and are electrically connected in series, the PZT plates of the accelerometer used in the proposed node do not need to be designed in this fashion.

The output voltage of one PZT plate can be expressed as:[10]

$$V_{out} = \frac{d_{31} \cdot E_p \cdot Z_p \cdot \frac{1}{2} \cdot (L_m + l) \cdot l}{\sum_i E_i \left(\frac{1}{12} \cdot h_i^3 + h_i \cdot Z_i^2 \right)} \cdot \frac{1}{C_p + C_{others}} \cdot m \cdot \alpha \quad , \quad (1)$$

where d_{31} and E_p are the transverse piezoelectric constant and Young's modulus of the PZT thin films, respectively. Z_p is the distance between the center of the PZT thin films and the position of the neutral plane. L_m and l are the lengths of the proof mass and of cantilever beam, respectively. E_i and h_i are Young's modulus and the thickness of each layer on the cantilever beam, respectively. Z_i is the distance between the center of each layer and the neutral plane of the cantilever beam. C_p is the capacitance of the PZT thin film. C_{others} is the capacitance of other components including the measurement system. The symbols m and α represent the weight of the proof mass and acceleration applied to the accelerometer, respectively. We designed the output voltage of 1 PZT plate as 78.4 mV_{pp}/G. We assume that the acceleration of chicken's movement is 0.05 G and the positive threshold voltage is 5 mV. In this case, the voltage of 2 PZT plates connected in series is above the threshold.

VII. Investigation of The Availability of Comparator

The packaged accelerometer was fixed on the stage of a shaker (Showa Sokki Model-8100) controlled by a function generator (Tektronix AFG 3022) where the output voltage of the accelerometer was directly measured by an oscilloscope (Tektronix TDS2004B). Fig. 10 shows the relationship between the applied acceleration and the output voltage of the 10 PZT plates connected in series. Although the accelerometer exhibits good linearity toward acceleration, the measured output voltage is only 10-20% of the calculated value. The leakage current in the PZT thin films and C_{others} may cause a decrease of the voltage. This accelerometer, however, can be utilized in the following experiment using the 10 PZT plates connected in series.

Fig. 11 shows an experimental setup for investigating the hysteresis voltage of the comparator. The packaged accelerometer is inserted into a target board of the C8051F930 fixed on the stage of the shaker controlled by the function generator. The input port of the comparator is directly connected to a pad that joins the 10 PZT plates in series, whereas the other port of the comparator is grounded. The output signal from the accelerometer is not rectified. The applied acceleration frequency is 50 Hz. At first the MCU is in sleep mode, and then the acceleration is increased gradually. The measurements were carried out 3 times. When the hysteresis voltages were 5 and 10 mV, the MCU was successfully awaked up at 0.79 ± 0.01 G and 1.88 ± 0.03 G, respectively. The results indicate that the hysteresis voltage can be decreased to less than 5 mV.

VIII. SUMMARY

We evaluated the availability of the surveillance system using wireless sensor node with temperature sensor and accelerometer. Chicken infection experiments by using the developed prototype wireless sensor node showed that weakness and fever of the infected chickens would be the early signal for the outbreaks. We proposed a detection method using body temperature and the number of 1 axis acceleration which exceed a threshold at an early stage. The result of the simulation using the infection experiment indicates that the infection can be detected before more than about 10 hours of the death and measurement of 1 axis acceleration is enough. We also design a wireless sensor node which works continuously for period of longer than 2 years without battery replacement. In this design, the required capacitance of the battery is more than 30 mAh and necessary output voltage of accelerator is more than 5 mV at the threshold acceleration.

REFERENCES

[1] S. G. Taylor, K. M. Farinholt, E. B. Flynn, E. Figueiredo, D. L. Mascarenas, E. A. Moro, G. Park, M. D. Todd, and C. R. Farrar, “A mobile-agent-based wireless sensing network for structural monitoring applications,” Meas. Sci. Technol. vol. 20, 2009, pp. 1-14.
[2] A. Purwar, R. Myllyla, and W. Y. Chung, “A wireless sensor network compatible triaxial accelerometer: Application for detection of falls in the elderly,” Sens. Lett., vol. 6, 2008. pp. 319-325.
[3] T. Itoh, T. Kobayashi, H. Okada, T. Masuda and T. Suga, “A DIGITAL OUTPUT PIEZOELECTRIC ACCELEROMETER FOR ULTRA-LOW POWER WIRELESS SENSOR NODE”, Proc. IEEE SENSORS 2008., pp. 542-545.
[4] http://www.jst.go.jp/kisoken/crest/intro/pdf/crest_eng_2007-2008Dec. pdf
[5] http://www.who.int/csr/disease/avian_influenza/en/index.html
[6] https://www.silabs.com/products/mcu/smallmcu/Pages/C8051F41x.aspx
[7]http://www.nordicsemi.com/index.cfm?obj=product&act=display&pro=89#
[8] K. Suzuki et al. under preparation
[9] K. Suzuki, H. Okada, T. Itoh, T. Tada, M. Mase, K. Nakamura, M. Kubo, K. Tsukamoto, “Association of Increased Pathogenicity of Asian H5N1 Highly Pathogenic Avian Influenza Viruses in Chickens with Highly Efficient Viral Replication Accompanied by Early Destruction of Innate Immune Responses,” J. Virol., 2009, pp. 7475-7486
[10] Q. Zou, W. Tan, E. S. Kim, and G. E. Loeb: J. Microelectromech. Syst. 17**,** 2008, pp. 45.

BRIEF BIOGRAPHY

Hironao Okada received the M.S. and Ph.D. degree in precision engineering from the university of Tokyo. He is currently a researcher at National Institute of Advanced Industrial Science and Technology (AIST). His research interests include energy loss mechanisms in micro resonators and MEMS packaging.