Wireless and Low-Power Water Quality Monitoring Beat Sensors For Agri and Acqua-Culture IoT Applications

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***Abstract* — This paper presents water quality monitoring IoT Beat Sensors. The interval times of ID code transmitted wirelessly from Beat Sensor nodes correspond to amount of salinity, water levels, and pH, so that receivers can acquire these parameters from many sensor nodes in agriculture and aquaculture fields. In experiments, this system can measure salinity in range 0.58%~6.48% with average power consumption of 500uW, water level in range 3.5~10.5cm with average power consumption of 90 uW and pH in range 3.45~9.58 with average power consumption of 70 uW.**

Keywords—Low power, Sensor networks, Salinity sensing, Water Level sensing, pH sensing, IoT, Near-zero power sensor

I. Introduction

Nowadays, the wireless IoT sensors are desired into variety of such applications as agriculture, aquaculture, and security. Specifically, water quality monitoring IoT sensors are already applied. However, wireless and low-power system is needed.

Beat Sensors such as Power Beat Sensor [1] and Temperature Beat Sensor [2], and DC current Beat Sensor[3] have been proposed as persistent and low-power IoT sensors. In Beat Sensors, only the ID code is transmitted, the interval time of the ID transmission represents such parameters as power consumption, temperature and DC current. The Beat Sensors have a lot of advantages as IoT sensors on such as low power, size, cost, and energy harvesting also. Data obtained by the Beat Sensors have high accuracy, and the reliability of the data is enhanced by the data correction algorithms[4].

This paper proposes water quality monitoring Beat Sensors, which sense data of salinity of water, water level, and pH of the water. These water quality monitoring Beat Sensors also have the same advantages as already reported Beat Sensors.

II. Circuit and System Structure

Fig. 1 shows schematic of the Temperature Beat Sensor node. The operation of sensor node is described in [1][2][3][4]. No ADC is needed in this circuit that it could reduce power consumption.

Fig. 2 shows structure of Beat Sensors system. When multi-sensor nodes like temperature, salinity, water level, pH sensor nodes are distributed, each sensor node will transmit only ID codes to a receiver which connects to the PC. The receiver receives the ID codes and transmits them to a PC which analyzes the signals to calculate physical parameters from the ID codes and their timings[4].

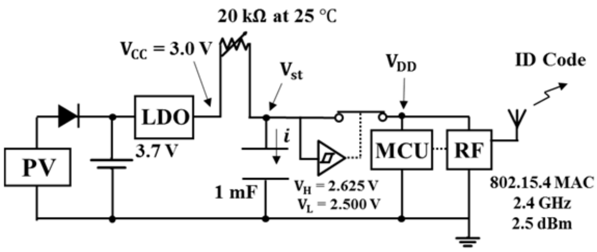

Fig.1. schematic of the Temperature Beat Sensor node [4]

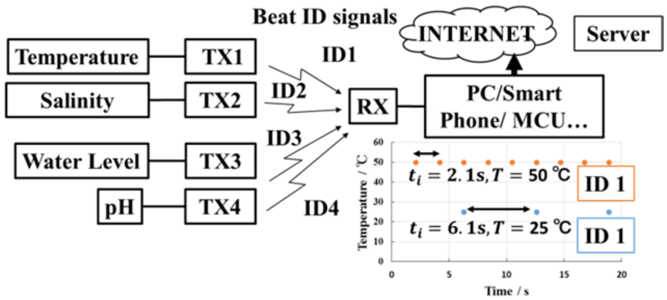

Fig.2 Beat Sensors System Concept[4]

A. *Salinity Beat Sensor circuit*

Fig. 3 shows circuit block diagrams of the proposing Salinity Beat Sensor. The sensor node is formed of a self-making salinity sensor, a storage capacitor of 2mF, a voltage detector(VD) with a power switch, MCU(MB9AF132KB) [5] and 2.4GHz RF module (NRF24L01) [6]. As shown in Fig. 4, the self-making salinity sensor is formed of carbon electrodes to avoid rust off. A plastic board is used to fix the distance of the carbon electrodes. The thermal contraction tubes are used to connect carbon electrode to the polyvinyl insulated wires which connect to the circuit. Since water is conductive, when the electrodes are in water, current flows from one carbon electrode to the other, and charges up the storage capacitor. The electrical resistance of salinity sensor changes depending on salinity of water.

The operation of sensor node has the same operation of the Temperature Beat Sensor node. The storage capacitor is charged by the current i via the water, resistance of which corresponds to the salinity, as shown in Fig. 5. When V_{st} reaches the defined high voltage V_H = 2.6V, the switch is turned on by the voltage detector. Then, the RF module transmits the Beat ID signals. The V_{st} falls off while the MCU and RF module operate, then V_{st} becomes the defined low voltage V_L = 2V. So, the switch is turned off by the voltage detector, followed by cutting off power of the MCU and RF module. After that, the storage capacitor starts being charged again. The transmitters transmit only the ID codes to the receiver. The interval time t_i corresponds to charging time of the storage capacitor which corresponds to salinity of water. As shown in Fig. 6 when the salinity of water changes, the interval time t_i changes. The signals of the ID codes are named as "The Salinity Beats." Thus, the average values of Water Salinity are represented by the interval time t_i.

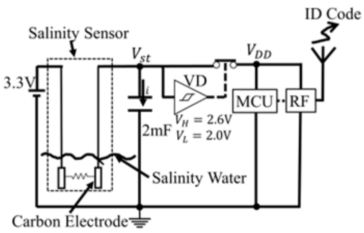

Fig. 3. Circuit diagram of the Salinity Beat Sensor node

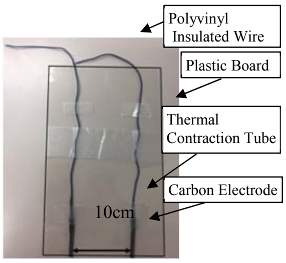

Fig. 4. self-making Salinity Sensor

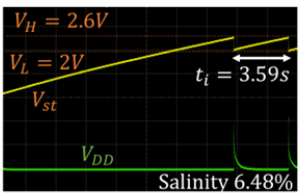

Fig. 5. Operating waveform of V_{DD}, V_{st} at salinity of 6.48%

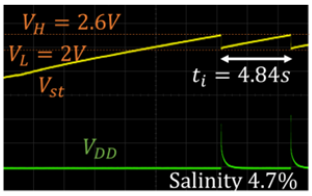

Fig. 6. Operating waveform of V_{DD}, V_{st} at salinity of 4.7%

B. Water Level Beat Sensor circuit

Fig. 7 shows circuit block diagrams of Water Level Beat Sensor. The sensor node is formed of self-making water level sensor, a storage capacitor of 2mF, a VD with a power switch, MCU module[5] and RF module[6]. As shown in Fig. 8, the self-making water level sensor is formed of carbon electrodes to avoid rust off. A ruler and the battery size changers are used to fix the distance of the carbon electrodes. The polyvinyl insulated wires and the thermal contraction tubes are used to connect one carbon electrode to the other.

The operation of the circuit is the same as Salinity Beat Sensor. Since the electrical resistance changes depending on water level. The interval time t_i changes depending on water level.

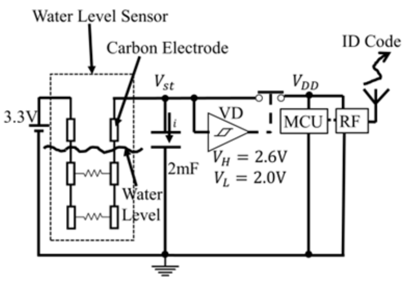

Fig. 7. Circuit diagram of the Water Level Beat Sensor node

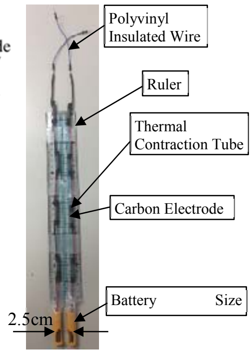

Fig. 8. self-making Water Level Sensor

C. pH Beat Sensor circuit

Fig. 9 shows circuit block diagrams of pH Beat Sensor. The sensor node is formed of a bipolar transistor, an operational amplifier of OPA379AIDCKR[7], a glass electrode type pH sensor, a storage capacitor of 2mF, a VD with a power switch, MCU module[5] and RF module[6]. In Fig.9 a glass electrode type pH sensor is considered as a voltmeter with high internal impedance. OPA was used as a buffer circuit to reduce impedance.

The operation of the circuit is the same as Salinity Beat Sensor in A and Water Level Beat Sensor in B. The storage capacitor is charged through the PNP bipolar transistor. The current I_c is calculated by (1), so that the interval time t_i changes depending on the value of pH.

$$I_C = \beta \frac{1/2V_{cc} - V_{pH} - V_{be}}{R_B} \qquad (1)$$

,where β is the current amplification factor of the PNP bipolar transistor.

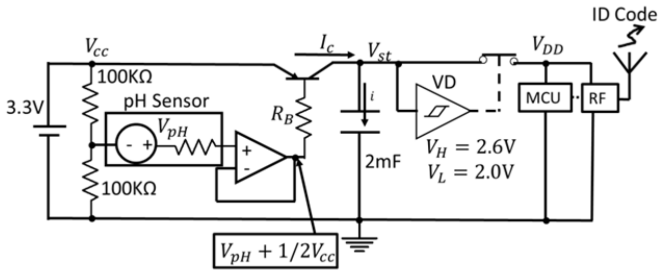

Fig. 9. Circuit diagram of the pH Beat Sensor node

III. Experiment and Result

A. Salinity Beat Sensor

Fig. 10 shows the experiment set up for the measurement of Salinity Beat Sensor. When the ID codes are transmitted. The receiver receives the ID codes for the salinity and transmits them to a PC. An application software running in the PC measures the interval times of the ID codes. Fig. 11 shows the correspondence between the interval time t_i and salinity of water. The interval time is 111.74s at salinity of 0.58% and 3.59s at salinity of 6.48%, where the salinity is calculated by (2). Therefore, the salinity of water can be measured by the interval time of the ID codes from the Salinity Beat Sensor.

$$\text{salinity}(\%) = \frac{\text{salt intake}(\text{g}) \times 100}{\text{quantity of water}(\text{cc})} \quad (2)$$

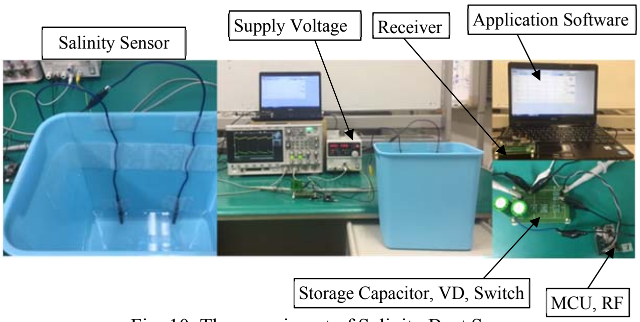

Fig. 10. The experiment of Salinity Beat Sensor

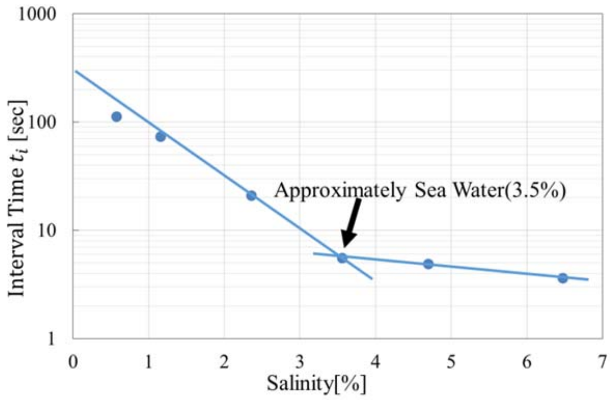

Fig. 11. The correspondence between the interval time t_i and salinity

B. *Water Level Beat Sensor*

Fig. 12 shows the experiment set up for the measurement of Water Level Beat Sensor. The interval time is changed depending on water level. Fig. 13 shows the correspondence between the interval time t_i and water level. The interval time is 31.59s at water level of 3.5cm and 7.57s at water level of 10.5cm. Therefore, the water level can be measured by the interval time of the ID codes from the Water Level Beat Sensor.

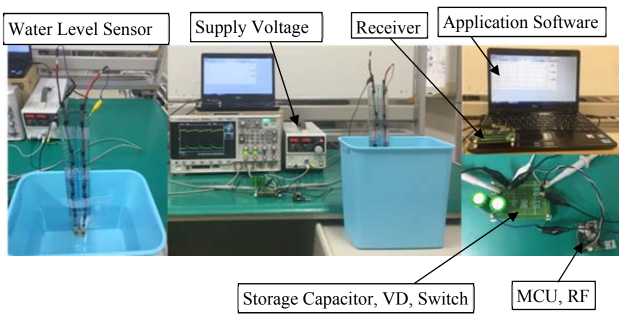

Fig. 12. The experiment of Water Level Beat Sensor

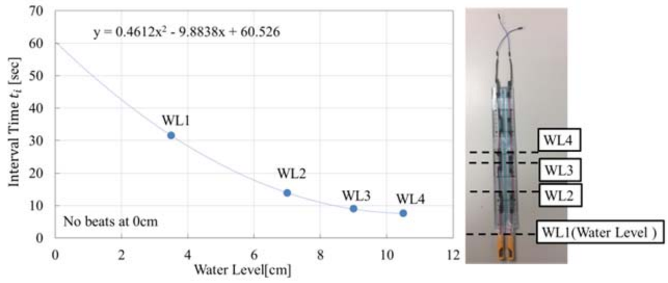

Fig. 13. The correspondence between the interval time t_i and water level

C. *pH Beat Sensor*

Fig. 14 shows the experiment set up for the measurement of pH Beat Sensor. Fig. 15 shows the correspondence between the interval time t_i and the value of pH. The interval time t_i is 47.43s at pH of 3.45 and 30.98s at pH of 9.58. The values of pH are also measured by digital pH-201 meter. The interval time decreases linearly on pH, so that pH Beat Sensor can measure pH and transmit it wirelessly.

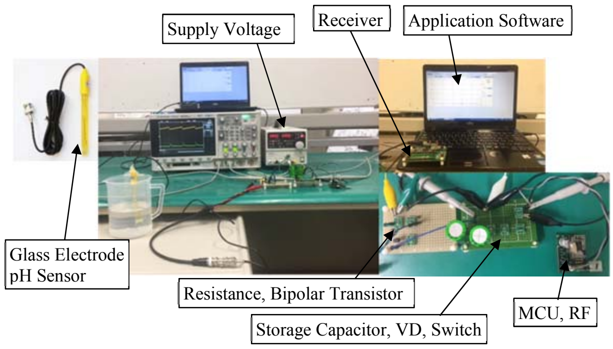

Fig. 14. The experiment of pH Beat Sensor

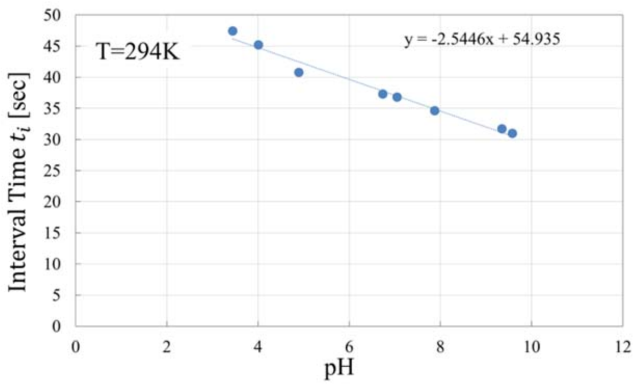

Fig. 15. The correspondence between the interval time t_i and pH

IV. Power Consumption of the Beat Sensor Node

Energy consumption of the system for the time of one Beat(E_B) is shown in (3)[2].

$$E_B = 1/2(\, C_{st}\,(V_H^{\,2} - V_L^{\,2})) = 2.76 \text{ mJ} \quad (3)$$

,where C_{st} is the capacity of the storage capacitor. The average power of sensor node (P_{sn}) is shown in (4)[2].

$$P_{sn} = E_B / (t_i) \quad (4)$$

,where t_i is the interval time of the ID transmission. As shown in Fig. 18. The average power consumption of the pH Beat Sensor node is 70uW at pH of 7. As for the power of the water level sensor, the power increases as the water level increases. It is notable when the water level is “0”, or there is no water in the sensor head, the Beat Sensor nodes does not consume any power, which is suitable to monitor flood in the river or town.

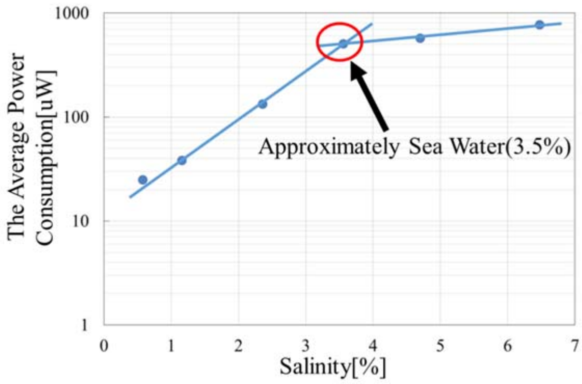

Fig. 16. P_{sn} is depended on salinity of water

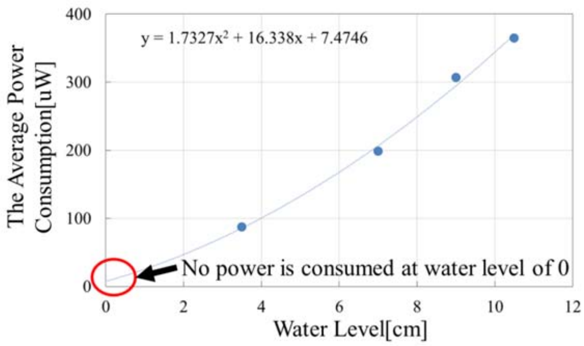

Fig. 17. P_{sn} is depended on water level

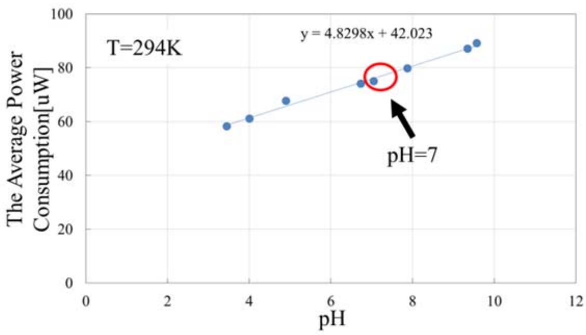

Fig. 18. P_{sn} is depended on the value of pH

V. CONCLUSION

This paper presents a water quality monitoring system based on the Beat Sensors. The Beat Sensors successfully measures salinity, water level and pH of water. As shown in Table I, they consumes average power of 500uW, 90uW, and 70uW, respectively. These low power nature could realize energy harvesting, and wireless water quality monitoring Beat Sensor, which can be applied to application of Agri and Acqua-Culture.

Future work should be focused in the study related to the practical applications of these systems.

TABLE I. The performance of this paper

	Salinity beat sensor	**Water level beat sensor**	**pH beat sensor**
Measure range	0.58 to 6.48%	3.5 to 10.5cm	3.45 to 9.58
Power consumption	500uW at salinity of 3.5%(Sea Water) ≤20uW at no salinity	90uW at 3.5cm No power consumption at water level of 0	70uW at pH=7

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