Temperature Beat Sensor for Energy Efficient, Long Range Smart Monitoring Systems

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Abstract— **Beat sensor has shown its large potential to address issues of smart environment monitoring such as real time drought management. This paper presents an efficient temperature Beat sensor for energy efficient, long range smart monitoring systems by combining a new technique of Beat sensor with long range (LoRa) communication protocol. With the compact circuit size and the low energy consumption, the proposed sensor can be applied for Internet of Things based smart monitoring systems. The analysis and experimental results have clarified the advantages of the proposed temperature Beat sensor and its potential applications.**

Keywords: Beat sensor; IoT; smart monitoring

I. INTRODUCTION

The climate change and global warning have been appeared as an emerging issue in recent decades. Hence, real time environment monitoring is required to effectively solve these issues. Recently, Internet of Things (IoT) is one of key approaches for smart environment monitoring and it is a part of the fourth industrial revolution [1]-[4]. Especially, according to Cisco report, the number of connected devices is predicted to 50 billion by 2020 [1]. Hence, in the past few decades, there have been a large number of researchers focus on applications related to Wireless Sensor Networks (WSNs), Wireless Body Area Networks (WBANs) and IoT with a variety of different platforms. In IoT systems, energy efficient sensors are highly demanded. Therefore, many researchers have tried to proposed efficient sensor designs for such applications.

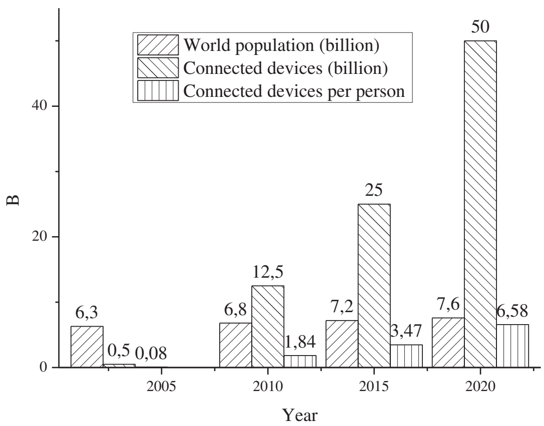

Fig. 1. The prediction of development of IoT toward 2020 by Cisco [1].

Invented by K. Ishibashi *et al*. [5], Beat sensors are very promising for IoT applications. Figure 1 presents the general structure of the Beat sensors and identification (ID) code timings from the Beat sensor node. In the Beat sensors, different sensors are attached to transmitters where each transmitter is assigned by one ID code. Unlike conventional IoT sensors, in Beat sensors, the only ID signals are transmitted and the interval times correspond to the physical parameters of the sensor. The receiver obtains the ID signals, and calculates the physical parameter by the interval times of the ID signals. Hence, Beat sensors have many advantages as IoT sensors on such as low power, size, cost, and for energy harvesting also. The data obtained by the Beat sensors have high accuracy, and the reliability of the data could be enhanced by the data correction algorithms [6]-[7].

However, more improvements and application specific optimized techniques are required for Beat sensors so that they could be employed in the wide range of real systems. Therefore, in this paper, we propose a new method to implement the temperature Beat sensor for smart monitoring with LoRa (Long Range) communication protocol.

The remainder of this paper is organized as follows. Section II presents the proposed Beat sensor design and Section III shows the implementation results. Finally, the conclusion and future plan are included in Section IV.

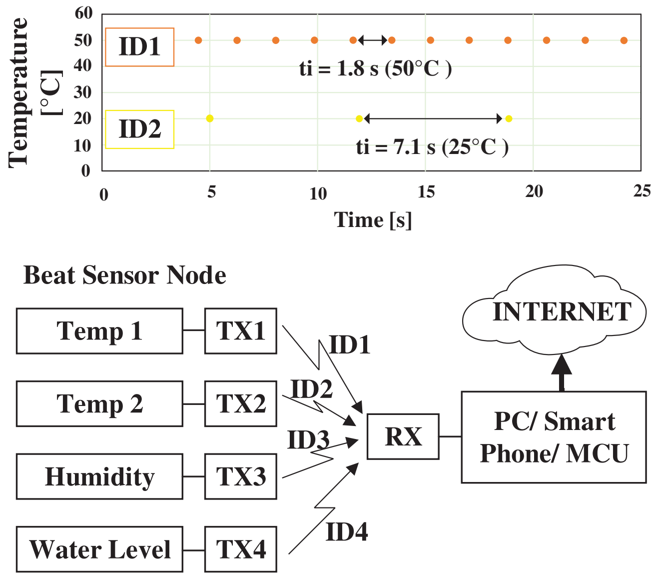

Fig. 1. Beat sensor concept [3].

II. PROPOSED BEAT SENSOR DESIGN

Figure 2 shows the structure of the proposed Beat sensor to be used as an energy efficient temperature sensor in smart monitoring systems. The photovoltaic (PV) and solar charger module are used to provide supply source for the proposed sensor. A thermistor is also used since its resistance changes with the environment temperature. Unlike the conventional temperature Beat sensor [5], in this work, we propose the use of a low-dropout regulator (LDO) having two roles. Firstly, it provides regulated voltage supply for microcontroller (MCU) and radio frequency (RF) circuits (LoRa module). Moreover, it controls the supply for these parts. A comparator with the threshold voltages of V_H and V_L is used for this supply switching technique. This scheme results in the more stable supply voltage for MCU and RF circuits than that in [5]. In this work, the MCU performs ID assignment and controls the operation of the proposed Beat sensor.

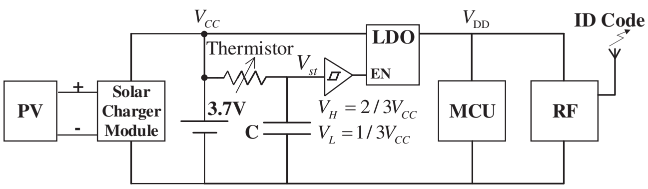

Fig. 2. Proposed temperature Beat sensor structure.

The operation principle of the proposed temperature Beat sensor can be described briefly as follows. From the battery (3.7V), the capacitor is charged via the thermistor, when the voltage V_{st} = $2/3V_{CC}$, the comparator provides the EN signal with the HIGH value, then the LDO gives the supply voltage for MCU and RF circuits in a period so that the corresponding ID is transmitted. When V_{st} = $1/3V_{CC}$, the comparator sets the EN signal with the LOW value.

III. IMPLEMENTATION RESULTS

Figure 3 is the measurement results of the charge and control voltages in the proposed temperature Beat sensor. V_{st} (in yellow) is the charge voltage for capacitor C. V_{EN} (in green) is the supply control voltage (ON/OFF) for MCU and RF circuits.

The time period t between two ID transmitting intervals depends on the environment temperature. Once t is known, the receiver system can calculate the estimated temperature. Table I presents the fitted functions to evaluate the temperature values corresponding to the time period t with the capacitor value of 470 µF. These functions were obtained by fitting the experimental results with the temperature calibrator MicroCal T100+ having the temperature resolution of 0.5°C.

In order to demonstrate the application of the proposed temperature Beat sensor in the smart monitoring systems, the AcSIP LoRa WAN EVK+Antenna KIT S76SXB from AcSIP Technology Corp was used. LoRa board works at 433 MHz, the spectrum spreading factor values of SF = 7, 12, and the bandwidth of 500 KHz. Figure 4 is the illustrated monitoring system using proposed temperature Beat sensor and LoRa communication protocol. The real system experiments show that the maximum distance of 1700 m can be achieved. The experiments have been successful at Hoa Lac High Tech Park, Hanoi, Vietnam.

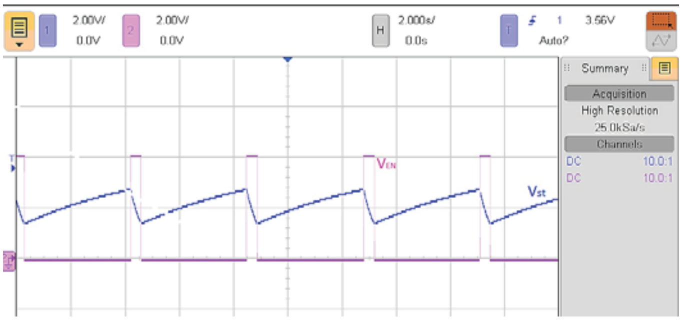

Fig. 3. Charge voltage and control voltage of the proposed temperature Beat sensor.

TABLE I. THE VALUES OF FITTED TEMPERATURE (Temp) CORRESPONDING TO THE TIME PERIOD t.

Temperature range [°C]	Function (C = 470µF) (Temp [°C], t [s])
-20 to -10.5	Temp = $15.205 - 1.74t + 0.02t^2$
-10 to -0.5	Temp = $27.385 - 3.09t + 0.06t^2$
0 to +9.5	Temp = $40.635 - 5.48t + 0.16t^2$
+10 to +19.5	Temp = $55.584 - 9.70t + 0.46t^2$
+20 to +29.5	Temp = $75.843 - 18.22t + 1.36t^2$
+30 to +39.5	Temp = $91.665 - 28.12t + 2.89t^2$
+40 to +50	Temp = $118.236 - 49.08t + 7.02t^2$

Fig. 4. The demonstrated monitoring system using proposed temperature Beat sensor and LoRa communication protocol.

The results of energy consumption of the proposed temperature Beat sensor node with the capacitor 470 µF at 22°C are shown in Fig. 5. The energy consumption to transmit one ID (the yellow rectangle) is only 0.05462 Ws (54.62 mWs). On the other hand, the energy consumption without ID transmitting (the green rectangle) is 0.00315 Ws (3.15 mWs).

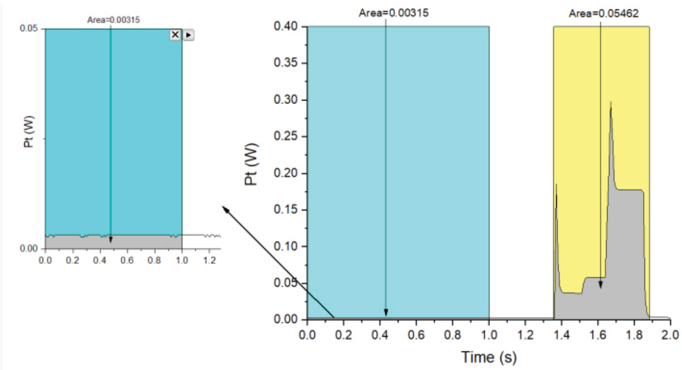

Fig. 5. Energy consumption of the proposed temperature Beat sensor node with the capacitor 470µF at 22°C.

Moreover, Fig. 6 presents the relationship between the communication distance and the probability of successful communications with different SF values and bandwidth of 500 KHz. It can be seen that with higher SF value, the longer communication distance can be achieved. To provide real time monitoring and early warning tool, a small IoT sever was built with Raspberry Pi 3 mode B+ and Linux OS. Obviously, the experiment results have confirmed the operations and potential of the proposed temperature Beat sensor for IoT based smart monitoring systems. However, for the real applications, the proposed temperature Beat sensor needs to be tested in more operation conditions to verify its stability and combined with other Beat sensors. Moreover, for the secure, energy efficient IoT based environment monitoring applications, the encryption algorithms such as AES [8] should be embedded.

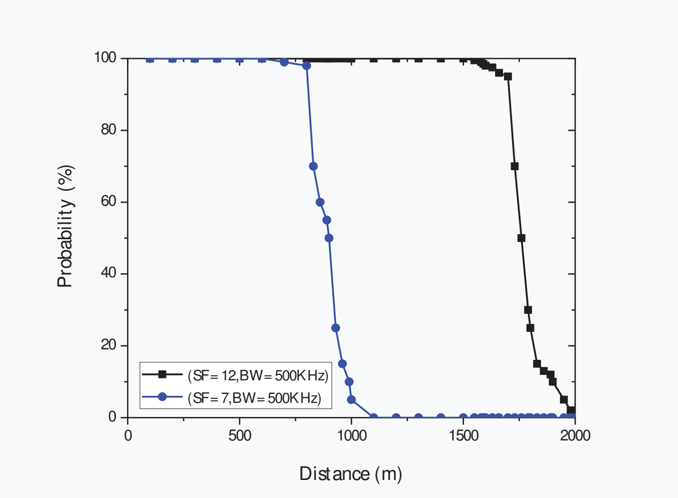

Fig. 6. Relationship between communication distance and the probability of successful communications with different SF values and 500 KHz bandwidth.

IV. CONCLUSIONS

This paper has presented an energy efficient, long range temperature Beat sensor for smart monitoring systems with the temperature range of -20°C to 50°C with the temperature resolution of 0.5°C. With the low energy consumption of only 54.62 mWs during transmitting period and long communication range of 1700 m, the proposed sensor can be applied for long range IoT based smart monitoring systems. For the future work, the proposed temperature Beat sensor needs to be tested in many operation conditions, combined with other Beat sensors and encryption algorithms for the secure, energy efficient IoT based environment monitoring applications.

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