An Energy Efficient Sensor for Thyroid Monitoring through the IoT

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***Abstract*—This paper presents a thyroid monitoring sensor for Internet of Things (IoT) applications. The proposed architecture is energy efficient and user friendly. Thyroid monitoring can be done either by monitoring the basal body temperature or through blood samples. In this work basal body temperature is the quantity sensed for thyroid monitoring. The temperature acquisition is performed by a ring oscillator along with a counter and a controller. The designed module implements the temperature acquisition module along with the calibration method to dynamically optimize the sensor design. A prototype of the temperature sensor along with the controller which performs the calibration is designed using Simulink®.**

Keywords*—*Internet of Things (IoT), Smart Health, Thyroid Monitoring, Sensor Design

I. INTRODUCTION

The Internet of Things (IoT) is a network of devices where each device can be recognizable in the network [1]. In general, an IoT node consists of a sensor or a device which obtains the required data. Many such sensors are connected to a network and each device can share the data obtained. These sensors are connected to each other through different wireless technologies including IEEE 802.15.4 and WiFi, Bluetooth Low Energy (BTLE) [2]. When there is a way to connect sensors/devices and make the network available in real time, smart health monitoring is a most important application for such a network. Current applications in health care systems include patient monitoring, fall detection, care, and management.

Thyroid disease occurs due to imbalance in production of triiodothyronine (T3) and thyroxine(T4) hormones which is regulated by the Thyroid-Stimulating Hormone (TSH) in the body. The imbalance of these hormones can affect metabolism, muscle strength, weight and body temperature. There are two common ways of monitoring thyroid function continuously: by testing the thyroid hormones in the blood or to continuously monitore the basal body temperature (BBT. In this paper we have proposed an architecture for efficient basal body temperature monitoring, which is the key factor for thyroid monitoring. Since the sensor needs to operate throughout the night, an architecture with two separate components is designed, as shown in Fig. 1.

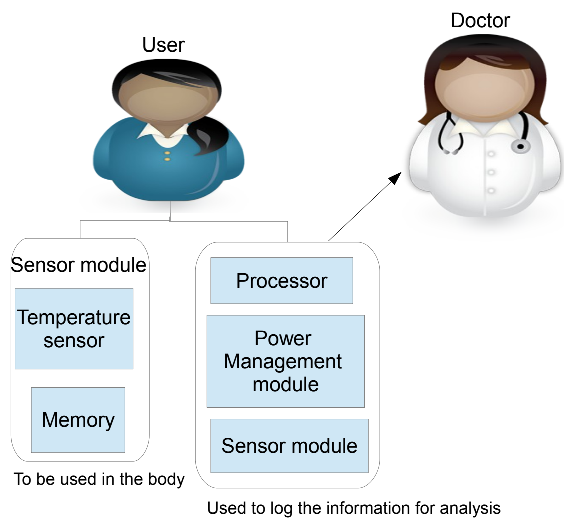

Fig. 1. Sensor module to obtain Basal Body Temperature (BBT).

The rest of the paper is organized as follows: a global picture of thyroid monitoring in smart health monitoring is presented in Sec. II. Existing related research work for health monitoring systems is presented in Sec. III. An overview of the proposed architecture is given in Sec. IV. The detailed design is discussed in Sec. V. The implementation of the designed blocks along with simulation results is discussed in Sec. VI. The paper concludes in Sec. VII.

II. THYROID MONITORING THROUGH IOT: A BROAD SMART HEALTH PERSPECTIVE

A block diagram of a device involved in smart health monitoring as shown in Fig. 2. The components of include a sensor for data acquisition, a processor unit to obtain the information and process it, a transmitting/receiving unit to send/receive the data obtained, and a memory to store the information until connected to a personal computer.

An ideal thyroid monitor needs to be portable, low power and user friendly to make it a device that can be used by people of all age groups. To be power efficient, the proposed

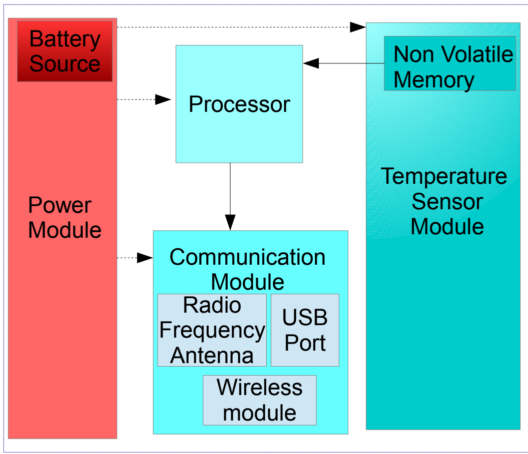

Fig. 2. Basic architecture for smart health monitoring device.

architecture is used in the design. Wireless modules are more power consuming, since they continuously transmit/receive signals. By using this architecture, the temperature sensor, which is the primary element to obtain temperature values, is being employed for a longer period of time whereas the power consuming modules are used only when required.

III. Related Prior Research

A power efficient architecture for Drug delivery NEMS has been proposed in [3]. An IoT architecture for temperature measurement using 4G health applications based on IPV6 connectivity has been demonstrated in [4]. FPGA based fall detection has been proposed in [5]. In this work, the wireless wearable sensor platform SHIMMER is used to detect the fall detection. The architectures proposed here uses off-chip memory. SHIMMER is a low power wireless sensor used for many bio-medical applications such as temperature detection, and fall detection [6] .The functionality of SHIMMER is expanded by using required daughter boards. In designs where off the shelf components are being used, SHIMMER gives a wide range of applications. In [7] a wearable monitoring device has been proposed for temperature and heart rate monitoring. In [8] a wearable temperature sensor for passive and semi-passive applications has been reported. An energy efficient front end for wireless temperature sensor architecture has been proposed in [9]. In [10] a passive wireless sensor module has been proposed with an external temperature sensor and an ADC where distilled water is used as the temperature sensing material.

IV. The Proposed Novel Thyroid Monitoring Sensor: An Architecture Perspective

In the proposed monitoring system, the temperature sensor module along with the non-volatile memory is used as an in vitro component, i.e. it is placed on the body of the person throughout the night to obtain temperature values. The temperature acquisition is done with the help of an oscillator block as shown in Fig. 3. The basic block diagram involves a control logic block, which gives the enable signal to the ring oscillator. The control logic block is controlled by a digital block which contains the calibration algorithm and memory.

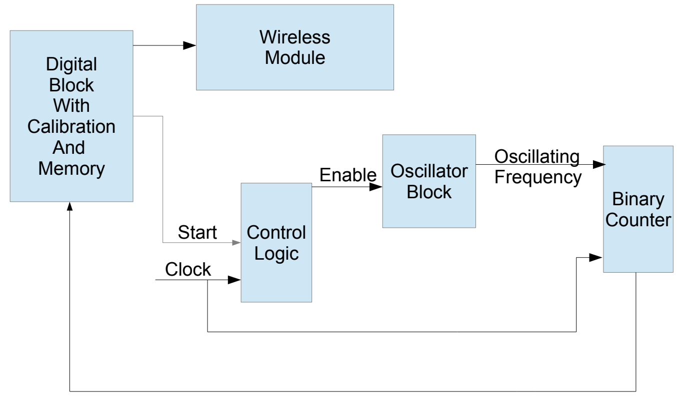

Fig. 3. Block diagram of proposed sensor architecture.

The digital block helps in storing the values throughout the night and is reset when the data is extracted from memory. This block provides the start signal to the control logic, which initiates the temperature acquisition process. It also contains a calibration algorithm which helps in calibrating the temperature sensor. The temperature acquisition is done by using the ring oscillator. The variation in oscillating frequency is compared with the frequency of the system clock and the temperature is analysed. The comparison of clock frequency and oscillating frequency is done with the help of a binary counter. The output of the counter is written to the memory of the digital block. This information can be retrieved using the wireless module present in the sensor design. With the help of a wireless module, many such sensors can connected to the sensor network.

V. Design of the Thyroid Monitoring Sensor

A. Control Logic

The control logic operates in synchronous mode with the binary counter and control block. When the start signal is provided by the control block, the control logic triggers the ring oscillator by providing enable "high". This initiates the temperature acquisition process.

B. Thermal Sensor

The temperature acquisition is done by using a ring oscillator. Ring oscillators have been widely used as thermal sensors [11], [12]. In [13] a ring oscillator architecture is proposed for human body temperature monitoring. In [14] a ring oscillator is designed using an odd number of inverters.In order to achieve oscillation the ring should provide a 2π phase shift and have unity voltage gain at the oscillating frequency. The oscillation frequency is given by the following:

$$f_{\text{osc}} = \frac{1}{N_{\text{stage}}(T_{\text{pd,LH}} + T_{\text{pd,HL}})}, \tag{1}$$

where N_{stage} is the number of stages in the ring oscillator and the propagation delays $T_{pd,\ LH}$ and $T_{pd,\ HL}$ are given by:

$$T_{\mathrm{pd,LH}} = \frac{-2C_L V_{\mathrm{Th,p}}}{K_p(V_{\mathrm{DD}} - V_{\mathrm{Th,p}})^2} + \frac{C_L}{K_p(V_{\mathrm{DD}} - V_{\mathrm{Th,p}})} \ln \frac{1.5V_{\mathrm{DD}} + 2V_{\mathrm{Th,p}}}{0.5V_{\mathrm{DD}}} \quad (2)$$

$$T_{\mathrm{pd,LH}} = \frac{2C_L V_{\mathrm{Th,n}}}{K_p(V_{\mathrm{DD}} - V_{\mathrm{Th,n}})^2} + \frac{C_L}{K_p(V_{\mathrm{DD}} - V_{\mathrm{Th,n}})} \ln \frac{1.5V_{\mathrm{DD}} + 2V_{\mathrm{Th,n}}}{0.5V_{\mathrm{DD}}}, \quad (3)$$

where V_{DD} is the supply voltage, C_L is the load capacitance and $V_{\mathrm{Th,n}}$ and $V_{\mathrm{Th,p}}$ are the n and p transistor threshold voltages, respectively. The threshold voltage V_{Th} is very sensitive to temperature fluctuations. Thus as temperature increases the oscillating frequency decreases and the time period increases. This is used to analyze the variation of temperature based on the oscillating frequency.

C. Counter

The oscillating frequency produced by the ring oscillator is compared with the system clock with the help of a counter. A 10-bit counter is designed with the help of JK flip flops. The oscillating frequency is given by the clock pulse and the system clock is given as an input to the counter.

D. Control Block

The control block in Fig. 4 is responsible for processing the information obtained from the user. The output of the counter is given as an input to the calibration block, where the temperature linearity is checked. If the inaccuracy in the temperature value is very high, the oscillator is switched ON through the enable signal. If the inaccuracy is in a tolerable range, then the information obtained is written in memory. Once the information is written, a "done" flag is given to the decision block. As the basal body temperature need not to be monitored during the whole night, the regular interval at which it is taken is given by the clock. When the flags from the clock and memory are both "high", the start signal is generated to enable the oscillator block. This is achieved by using a MATLAB® function in the subsystem.

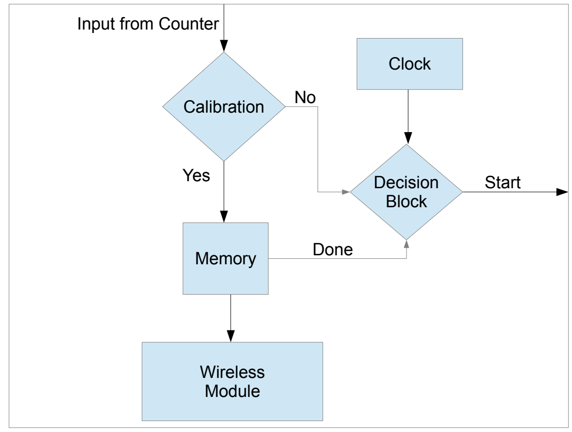

Fig. 4. Block diagram for the control block.

VI. Implementation and Validation of the Thyroid Monitoring Sensor

The operational flow of the thyroid monitoring system is shown in Fig. 5. The 13 stage ring oscillator was implemented using circuit components available in the Simulink® library. The first inverter is replaced with a NAND gate. One of the inputs for the NAND gate is by default given as a HIGH input in order to feed back the output into the oscillator. In the complete architecture, this input is given as an enable signal, which would start the oscillator whenever the Enable signal goes HIGH. The temperature dependence feature is modeled for performing temperature analysis. The prototype of the sensor with all subsystems integrated is shown in Fig. 6. The temperature measured is 28 °C. The ring oscillator starts sensing the temperature and the output is fed to the counter with the clock. The output of the counter and the output of the ring oscillator are sent as inputs to the controller, where the bit count is interpreted in terms of temperature values. The enable signal is triggered whenever the error in calibration is less than or equal to the tolerance level. Since this helps in obtaining accurate temperature values for lower range of temperature, it proves to be efficient for basal body temperature monitoring which helps in thyroid monitoring. Since the human basal body temperature value is of very small range, the temperature values are varied for a smaller range and corresponding variations are observed. In the ring oscillator, by varying the temperature values, the corresponding variation in frequency is observed by using the "bilevel measurement" feature in the scope block. Due to the switching activity of each transistor, it is required to have simulation time as low as possible.

The temperature values along with frequency and time period values are listed in Table I. The values obtained are plotted and it iss observed that as the temperature increases, the oscillating frequency decreases and the propagation delay increases. The graph obtained for variation in frequency with respect to temperature is shown in Fig. 7. The characterization of the sensor design is listed in Table II. It can be observed that the power dissipation is in the range of nW for the proposed system.

TABLE I. Frequency and Time period values for various temperatures.

	Temperature (C)	Frequency (MHz)	Time Period (ns)
1.	25	42.906	23.307
2.	28	42.942	23.287
3.	30	42.967	23.274
4.	32	42.991	23.261
5.	34	43.013	23.249
6.	36	43.035	23.237
7.	36.5	43.043	23.233
8.	37.2	43.05	23.229
9.	38	43.059	23.224

VII. Conclusions and Future Research

A prototype of a temperature sensor which can be used for thyroid monitoring is implemented in Simulink® using a bottom-up approach [15]. The architecture proposed is proved

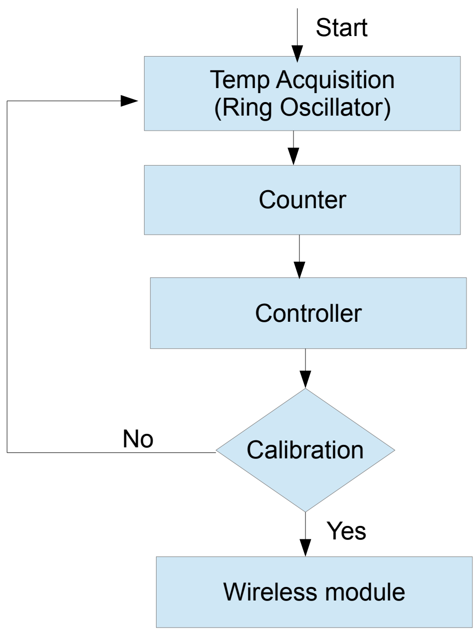

Fig. 5. Design flow of the Thyroid Monitoring Sensor.

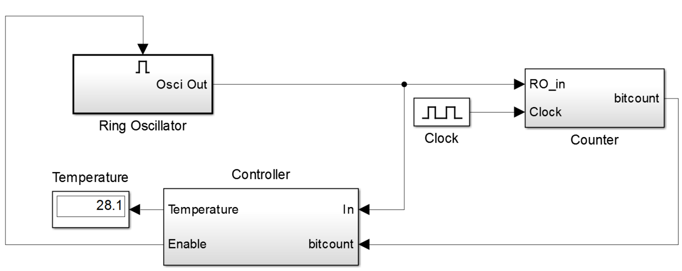

Fig. 6. Prototype of the sensor in Simulink®.

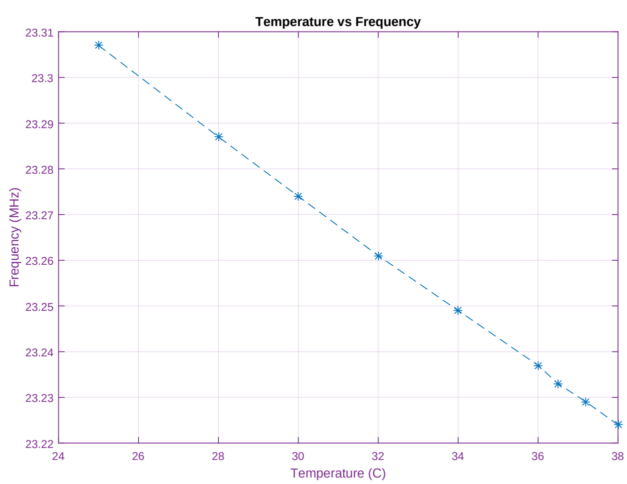

Fig. 7. Temperature versus frequency plot.

TABLE II. CHARACTERIZATION OF THYROID MONITORING SENSOR.

	Characteristics	Values
1.	Temperature range	25°C to 40°C
2.	Power Supply	4 V
3.	Accuracy	+0.1°C
4.	Power dissipation	28.65e^{-6} W
5.	Frequency range	42.906 - 43.5 MHz

to be energy efficient and an accuracy of +0.1°C is achieved in the range of 25°C to 40°C . Future research involves implementing this architecture in real time and further integrating many such blocks for IoT applications.

REFERENCES

[1] V. Bhuvaneswari and R. Porkodi, "The Internet of Things (IoT) Applications and Communication Enabling Tehnology Standards: An Overview," in *Proceedings of the International Conference on Intelligent Computing Applications*, 2014, pp. 324–329.

[2] S. L. Keoh, S. S. Kumar, and H. Tschofeing, "Securing the Internet of Things: A Standardization Perspective," *IEEE Internet of Things Journal*, pp. 265–275, 2014.

[3] S. P. Mohanty, D. Ghai, E. Kougianos, and B. Joshi, "A Universal Level Converter Towards The Realization of Energy Efficient Implantable Drug Delivery Nano-Electro-Mechanical-Systems," in *Proceedings of the 10th International Symposium on Quality of Electronic Design*, 2009, pp. 673–679.

[4] R. S. H. Istepanian, A. Sungoor, A. Faisal, and N. Philip, "Internet of M-HEALTH Things "m-IoT"," *IET Seminar on Assisted Living*, pp. 1 –3, 2011.

[5] H. Rabah, A. Amira, and A. Ahmad, "Design and Implementation of a Fall Detection System using Compressive Sensing and Shimmer Technology," in *Proceedings of the 24th International Conference on Microelectronics (ICM)*, 2012, pp. 1–4.

[6] A. Burns, B. R. Greene, M. J. McGrath, T. J. O'Shea, B. Kuris, S. M. Ayer, F. Stroiescu, and V. Cionca, "SHIMMER - A Wireless Sensor Platform for Noninvasive Biomedical Research," *IEEE SENSORS Journal*, pp. 1527–1534, 2010.

[7] K. Malhi, S. C. Mukhopadhyay, J. Schnepper, M. Haefke, and H. Ewald, "A Zigbee-Based wearable Physiological Parameters Monitoring System," *IEEE Sensors Journal .,vol, 12,no 3*, pp. 423–430, 2012.

[8] S.-M. Yu, P. Feng, and N.-J. Wu, "Passive and Semi-passive Wireless Temperature and Humidity Sensors Based on EPC Generation-2 UHF Protocol," *IEEE Sensors Journal, Vol. 15, No. 4*, pp. 2403–2411, 2015.

[9] B. Wang, M.-K. Law, A. Bermak, and H. C. Luong, "A Passive RFID ag Embedded Temperature Sensor with Improved Process Spreads Immunity for a -30oC to 60oC sensin range," *IEEE Transactions on Circuits and Systems*, pp. 337–346, 2014.

[10] J. Virtanen, L. Ukkonen, T. Bjorninen, L. Sydanheimo, and A. Z. Elsherbeni, "Temperature Sensor Tag for Passive UHF RFID systems," in *Sensors Applications Symposium(SAS)*, 2011, pp. 312–317.

[11] S. Park, changwook Min, and S. Cho, "A 95nW Ring Oscillator-based Temperature Sensor for RFID Tags in 0.13um CMOS," in *IEEE International Symposium Circuits and Systems*, 2009, pp. 1153–1156.

[12] B. Datta and W. Burleson, "Low-power and robust on-chip thermal sensing using differential ring oscillators," in *Midwest Symposium Circuits and Systems*, 2007, pp. 29–32.

[13] A. Vaz, A. Ubarretxena, I. Zalbide, D. .Pardo, H. Solar, A. Garcia-Alonso, and R. Berenguer, "Full Passive UHF Tag with a Temperature Sensor Suitable for Human Body Temperature Monitoring," *IEEE Transactions on Circuits and Systems- II:Express Briefs, Vol. 57, No. 2*, pp. 95–99, 2010.

[14] O. Okobiah, S. P. Mohanty, and E. Kougianos, "Geostatistical-inspired fast layout optimisation of a nano-CMOS thermal sensor," *IET Circuits Devices and Systems ., Vol.7,NO 5*, pp. 253–262, 2013.

[15] S. P. Mohanty, *Nanoelectronic Mixed-Signal System Design*. McGraw-Hill Education, 2015, no. 9780071825719 and 0071825711.