Real Time Temperature Measurement for Industrial Environment

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***Abstract*—Temperature measurement is critical for several applications, where the detection of any environmental changes can be triggered by sever problem, such as fire, aeration irregularity and system fault. Considering, Wireless Sensor Networks (WSNs) in industrial monitoring applications presents as an alternative solution for real time and continuous measurement systems. They enable to have a complete overview of the monitored area and the state of the system itself as well. A real time measurement system based on WSNs is proposed to monitor the temperature in industrial environment. In this work, energy efficient, and cost effective sensor nodes were chosen for the WSNs in order to enable to extend the lifetime of the network and reduce the maintenance fees. For this reasons, the low power wireless platform panStamp NRG 2.0 is used. To measure the environmental temperature, two sensors were used; SI7021 and DHT11.**

***Index Terms*—WSNs, industrial monitoring, real time measurement, temperature sensor, panStamp NRG 2.0, IoT.**

I. INTRODUCTION

According to Moores law, the number of transistors fabricated on a chip doubles every two years [1]. This increasing complexity leads to a trade-off between the complexity and cost. Moreover, the power consumption has a limitation which curbs the Moores law when the design aspect comes into picture. Therefore, excessive in the number of embedded transistors limits the storage capacity and hence, the performance of the node. Thus, a compromise between size, energy consumption, computational power and cost should be considered during the design of the sensor node. Recently, System on Chips (SoC) are all connected to the Internet of Things (IoT). Hence, real time data transfer and retrieval is necessary to have a complete and continuous overview of the system [2]. In fact, IoT system requires several sensing platforms, which require low power consumption to avoid the cost and scalability challenge of battery replacement in large scale network or inaccessible areas, such as industrial zones [3], [4]. Therefore, more interest is given to embed Wireless Sensor Networks (WSNs) with IoT system to achieve better performance in term of accessibility, response time, energy consumption, data storage and cost [5].

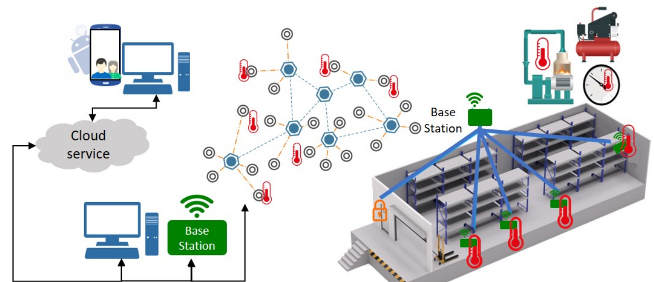


Fig. 1: General overview of an IoT temperature monitoring system for industrial environment based on WSNs.

In recent trends, monitoring and control system are becoming more relaying on both WSNs and IoT systems to ensure a better traceability and efficiency of the system in real time, such as for industrial monitoring and control activity in a production chain [6]. In such monitoring application, certain environmental and physical parameters are eager to be controlled continuously, which its increase may have critical and dramatical impact of the whole system, like the surrounding temperature of the industrial environment or moreover the inner temperature of the electronic component of the controlling system. In fact, WSNs based system, during nodes communication, the temperature of the micro-controller may show a sudden increase due to communication load, computation effort and data processing tasks. This may induce some variation in the data measurement reliability and in the stability of the system. Also, an increase in the temperature of the surrounding environment may trigger a alert for unusual event such fire or systematic problem. Hence, a temperature measurement system within industrial environment is required, where wireless nodes, equipped with temperature measurement system, can be deployed easily and all over the network. These nodes are connected to the cloud in order to ensure a continuous and real time overview of the network as well (see figure 1).

The paper is structured as follows; in the second section, a brief reminder of some traditional temperature systems is provided, after that the proposed temperature measurement system based on WSNs and IoT components is detailed, then some results showing the feasibility of the proposed solution are remarked.

II. Temperature measurement system for industrial environment

Different traditional temperature sensing are used to measure the temperature variation of electronic components, mainly with thermocouple sensors, thermistors and semi conductors. Thermocouple sensor is a voltage device that indicates temperature by measuring a change in the voltage. It consists of two different metals: opened and closed. These metals work on the principle of thermoelectric effect. When two dissimilar metals produce a voltage, then a thermal difference exists between the two metals. When the temperature increases, the output voltage of the thermocouple increases, respectively [7]. The most important property of the thermocouple is non-linearity, where mathematical linearisation is needed to convert output voltage to temperature values. For resistance thermometers (RTDs), the resistance is proportional to the temperature, which is made from platinum, nickel, and copper metals. It has a wide range of temperature measurement capabilities as it can be used to measure temperature in the range between $-270°C$ to $+850°C$. However, RTD requires an external current source to function properly. Semiconductor sensors are based on IC, and are classified into different types: Current output temperature sensor, Voltage output temperature sensor, Resistance output silicon temperature sensor, Diode temperature sensors and Digital output temperature sensor. They offer high linearity and high accuracy over an operating range of about. When the temperature inside the enclosure increases, it will also affect the electrical components within. The optimal operating temperature for most of the electrical equipment lies between $40°C(105°F)$ and $50°C(122°F)$. As the internal temperature of the components increase, their lifespan will decrease. Excessive heat can even lead to a leakage in the integrated circuits of microprocessors; however, it wont lead to any permanent damage. Industrial control systems and components which have capacitors are at a greater risk of shortened lifespans due to the high sustained heat. Reasons why Industrial Control Panels Heat up The temperature of industrial control panel enclosures is related to the rate of heat which is generated within the panel and also to the rate of heat that is removed. When the usage of electronic and microprocessor-controlled electrical control gear increases, the control systems are bound to generate more heat. This will be compounded by the increased use of electronic devices that generate waste heat too. Lastly, if there is a lot of equipment inside the control panel and negligible space, the enclosure will heat up more often.

However, all these traditional techniques need a continuous innervation of the user, where he need to operate directly on the area that needs control. Also, these techniques are not useful in case of sudden changes, where real time monitoring system is required. Hence, WSNs are introduced as a real time, easy to monitor and accessible solution. In this work, an alternative solution to monitor the temperature of both surrounding environment and components temperature is proposed. The system is based on the use of WSNs with IoT based solution. The temperature is continuously measured in the test-field and communication to an android application is maintained.

III. Proposed real time temperature measurement system based on WSNs

Industrial environment presents a challenging field, where monitoring both surrounding environment and installed machinery and the industrial process itself. Therefore, more attention should be given to both internal and external factors, that may have direct impact on the performance and security of the complete system and the whole network. In this work, temperature is considered as one of the most important factors that can induce severe changes in the system, such as fire detection and components damages. Two temperature systems are proposed to continuously measure the temperature variation; a first circuit to monitor the environmental temperature of the deployment region and the second circuit is used to measure the temperature of the SoC of the sensor node itself. The proposed system is based on WSNs, where sensor nodes

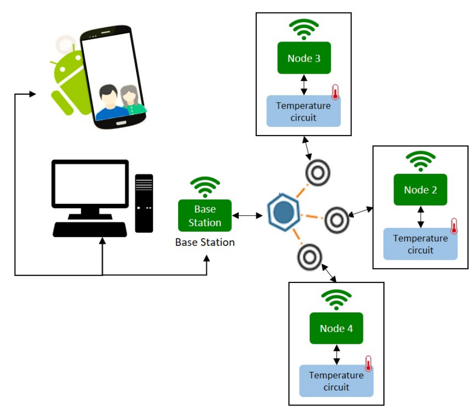


Fig. 2: Schematic presentation of temperature measurement system based on WSNs and IoT for industrial environment.

are used to collect data from the deployment area and then, forwarded to the base station, which is connected to the a monitoring computer. This latest, communicate the gathered sensing values to a fire-base and display these data in an android application, where the user can have a complete overview of all installed nodes (see figure 2).

Having the fact that, sensor nodes are battery powered devices, which makes them limited in both size and energy sources, it is crucial to choose an energy efficient and cost effective sensor node for WSNs applications in order to extend the lifetime of the network and reduce the maintenance costs. For this reasons, in this work, the low power wireless platform panStamp NRG 2.0 is used [8]. In Table I, hardware characteristics of the used sensor node are presented. The panStamp NRG 2.0 node uses the powerful CC430F5137 microcontroller, which is useful for control and monitoring applications. It is based on the MSP430 16-bit RISC CPU and the CC1101 RF transceiver. This offers a complete SoC solution easy to use with improved performance.

TABLE I: CC1101 radio transceiver parameters at frequency of 868 MHz [9]

Parameters	Values
Data rate(max)	600 kbps
Rx Current(Lowest)	14.7 mA
Tx Current(max)	30 mA at +10 dBm
Receiver Sensitivity	-116 dBm

A. *Temperature measurement of surrounding environment*

In industrial environment, ambient temperature variation can be induced by various reasons, such as components heating, unusual activities like fire and aeration problem. Hence, an accurate and real time temperature measurement is necessary. In this direction, a circuit based on sensor node and temperature sensor are used. Panstamp sensor node is used in combination with two temperature sensors: DHT11 [10] and SI7021 [11] (Fig. 3). A comparison of the sensor performance is provided to highlight the adequate choice of the temperature sensor in term of response time and accuracy.

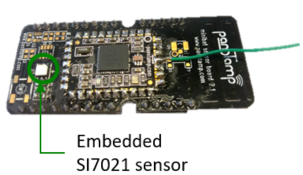


Fig. 3: Panstamp sensor nodes with embedded SI7021 temperature sensor.

DHT11 temperature sensor, uses a calibrated digital signal output. By using the exclusive digital-signal-acquisition technique and NTC temperature sensing technology, it ensures high reliability and long-term stability. The Si7021 temperature sensor is a solid CMOS IC coordinating moistness and temperature sensor components. The sensor offers an exact, low-control, manufacturing plant aligned computerized arrangement perfect for estimating dampness, dew-point, and temperature. Following is the temperature conversion formula for the SI7021 sensor.

$$Tempearature = \frac{175.72 \times TempCode}{65536} 46.85, \quad (1)$$

where, temperature is the measured temperature value in C TempCode is the 16-bit word returned by the Si7021 sensor.

Panstamp nodes with embedded SI7021 temperature sensor were deployed with DHT11 sensor as well. Three nodes were deployed inside the room and are communicating the sensing data to base station, which is connected directly to the computer, where data are processed and evaluated. Obtained results are illustrated in **??**, which show that the embedded SI7021 sensor provides better results than the DHT11 sensor, in terms of response time and accuracy. The temperature was maintained at approximately 25 °C. DHT11 sensor requires further operating time to stabilize the reading of temperature, as illustrated in the figure with approximately 15 min later then SI7021. Similarly, for the sensor accuracy, SI7021 sensor outperforms the DHT11 sensor, as it shows an average error of $\sim$ 0.4°C compared to $\sim$ 0.9°C for DHT11.

Furthermore, to identify the system stability under different

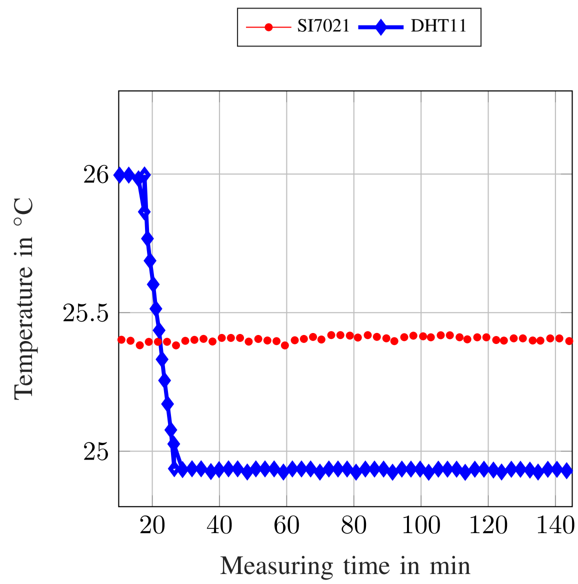


Fig. 4: Observation of temperature reading results at a room temperature of $\sim$ 25°C: Evaluation of response time and reading accuracy of DHT11 and SI7021, (b) Evaluation of SI7021 reading results for different temperature variations.

conditions, three scenarios were tested and temperature results were noted. First nodes were installed in the room with consideration of the room temperature. Second, one node were tested under heating temperature by using a warmed air and last, one node were put in the freezer under a temperature of approximately $\sim$ -10 °C. Obtained results, illustrated in figure 5, show that the embedded sensor within the panstamp node is able to detect the temperature variation with a response time of some seconds. To have a continuous and real time measurement, an IoT android application is introduced to monitor the temperature measurements. A firebase system is used to store retrieved data, which provides a historical overview of the network. In figures 7 and 8, some screenshots of the developed android application are provided.

IV. Conclusion

The wireless temperature sensor nodes based on panstamp nodes is presented in this work. Experiment results show that the temperature wireless sensor node can meet the requirement

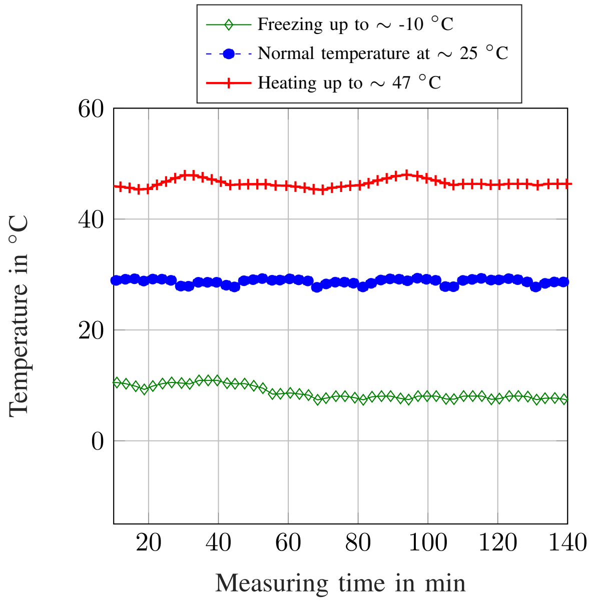
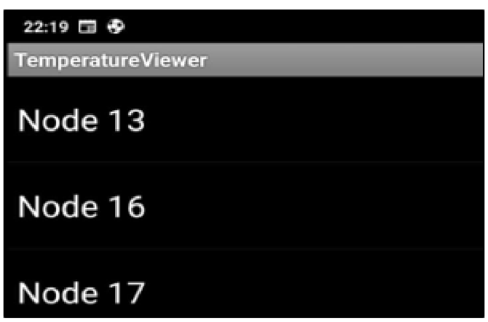
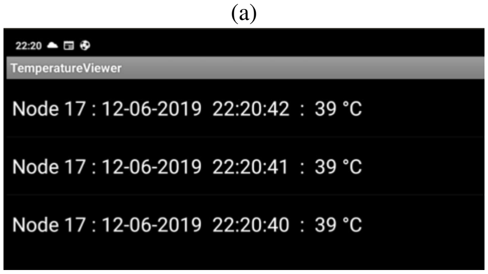


Fig. 5

Fig. 6: Observation of temperature reading results at a room temperature of ∼ 25°C: Evaluation of SI7021 reading results for different temperature variations.



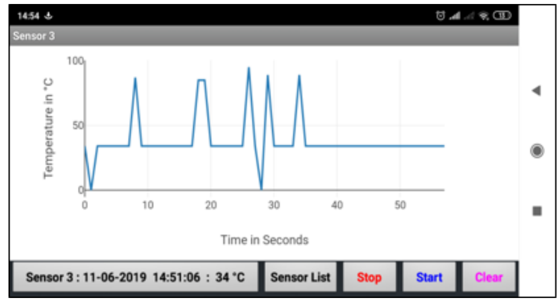
(a)



(b)

Fig. 7: Representation of the android application for temperature measurement system based on SI7021 sensor: (a) list of deployed sensors, (b) temperature results at each node.

of the system function, and has the features such as low power dissipation, small volume, stable performance and long lifespan. Further investigation should be given to study the temperature variation of the SoC of deployed sensor nodes and its effect on the performance of the node itself.



(a)

(b)

Fig. 8: Representation of the android application for temperature measurement system based on SI7021 sensor: (a) graph presentation of the temperature sensor installed within node 3, and (b) historical temperature measurement of sensors.

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