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Application of SHT71 Sensor to Measure Humidity and Temperature with a WSN

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Abstract— **This paper presents the advantages of smart sensors, among which stands out the SHT71 temperature/humidity sensor. This sensor is suitable for the development of embedded systems for monitoring environmental parameters. The paper is divided into two parts. The first part will cover the details regarding the sensors, including their specification, interface and communication protocol. The second is an application example of the sensor of measure humidity and temperature. The application involves the design and implementation of a wireless sensor network (WSN) to monitoring relative humidity and temperature using a SHT71 sensor, two microcontrollers and two Xbee modules. Processed data can be displayed by LCD, but also can be sent to the host computer or store in an external SD card. The results show that the system has a simple structure.**

Keywords— Intelligent sensor; WSN; temperature and humidity measurement, Zigbee.

I. INTRODUCTION

Relative humidity and temperature are two very important ambient parameters that are directly related to the human comfort. Their measurement and control has a significant appliance in industry, science, healthcare, agriculture and controlling technological processes. These parameters strongly influence each other and it is critical in some applications to measure them in parallel [1]. Using modern technologies, it is possible to combine a temperature measurement element, a humidity measurement element, an amplifier, adc, a digital interface, a calibration memory and a CRC calculation logic in a single chip with very small size [2], [3]. Using this kind of intelligent sensors can shorten the development time and cost. Integrating adc and amplifier into sensor's chip allow developers to optimize sensor elements for accuracy and long-term stability . And that is not all integrating digital interface logic simplifies connectivity and management of sensors. In this paper we use SHT71 intelligent sensor as an application example and present its advantages and measurement procedures. This application was realized and tested.

II. SHT71 SENSOR

SHT71 is a member of the Sensirion's SHT series of digital sensors, which are capable of measuring both temperature and relative humidity and provide fully calibrated digital outputs.
The device includes a capacitive sensor element (polymer sensing element) and a band-gap sensor for measuring relative humidity and temperature respectively. This means the presence of moisture in air changes the dielectric constant of the material between the two plates of a parallel-plate capacitor, and hence varies the capacitance [3].
The required signal conditioning, 14 bit ADC (analog-to-digital converter), and serial interface circuitries are all integrated into the sensor chip. This results in high signal quality, a fast response time and insensitivity to external disturbances (EMC).
Each SHT71 sensor is individually calibrated with different methods and instruments. The calibration coefficients are programmed into the OTP memory. The 2-wire serial interface and internal voltage regulation allow easy and fast system integration [2]. Fig. 1 shows the composition of the sensor by a block diagram.

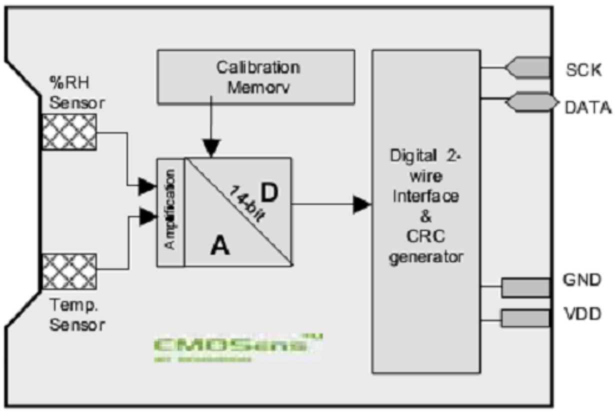

Fig 1. SHT71 block diagram [2]

Joining temperature and humidity sensing elements in single chip enables precise determination of dew point, without incurring errors due to temperature gradients between elements. This will not introduce error because of the

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temperature difference of temperature and humidity. The signal amplification near the sensor allows the polymer layers to be optimized not for signal strengths, but rather for long-term stability. Performing analog-to-digital conversion “inside chip” makes the signal extremely insensitive to noise. A checksum generated by the chip itself is used for additional reliability. The calibration data loaded on the chip memory guarantees that humidity sensors have identical specifications and thus they are 100% replaceable [1], [2].

Some of the advanced functions of the SHT171 are available through the status register. For example: selecting measurement resolution to optimize for precision or for fast response, End-Of-Battery (EOB) detection (low voltage detection), use of OTP reload or using the heater. Status register size is 8 bits but only four of them are used [2].

The SHT71 sensor can be interfaced to any microcontroller through a digital two-wire (SDA for data and SCK for clock) serial interface which looks like I2C (see fig 2).

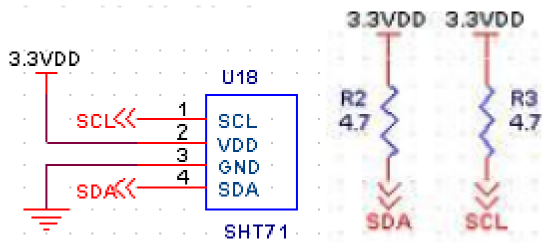

Fig 2. Conection circuit of SHT71 sensor to the MCU.

An external pull-up resistor is required to pull the signal high on the SDA line. However, the SCK line could be driven without any pull-up resistor.

Two wires are used to transfer serial clock (SCK) and data (DATA) or SDA [1]. SCK is used to synchronize the communication between microcontroller and SHT71. Since the interface consists of fully static logic there is no minimum SCK frequency. The DATA tri-state pin is used to transfer data in and out of the sensor. For sending a command to the sensor, DATA is valid on the rising edge of the SCK and must remain stable while SCK is high. After the falling edge of SCK the DATA value may be changed [2].

III. Measurement Of Temperature And Relative Humidity

A measurement using SHT71 is a two step procedure. First, it is necessary to send command for measurement to the sensor and get the data through the digital interface. Second, it is necessary to convert data from sensor to real physical values and to calculate the temperature compensation of the humidity data [2].

A. Sending a command and receiving data

To initiate a transmission, a “transmission start” sequence has to be issued. It consists of a lowering of the DATA line while SCK is high, followed by a low pulse on SCK and raising DATA again while SCK is still high [2].

The subsequent command consists of three address bits (only 000 is currently supported) and five command bits. The SHT11/71 indicates the proper reception of a command by pulling the DATA pin low (ACK bit) after the falling edge of the 8^{th} SCK clock. The DATA line is released (and goes high) after the falling edge of the 9th SCK clock. Two bytes of measurement data and one byte of CRC checksum are transmitted. The µC must acknowledge each byte by pulling the DATA line low. All values are MSB first, right justified. Possible commands are: “get temperature”, “get humidity”, “change measurement resolution”, “get status register value”, “set status register value” [2].

Communication terminates after the acknowledge bit of the CRC data. If CRC-8 checksum is not used the controller may terminate the communication after the measurement data LSB by keeping ACK high. The device automatically returns to sleep mode after the measurement and communication have ended. [1]

B. Conversion of the output to physical values

To compensate for non-linearity of humidity sensing element and to obtain the full accuracy it is recommended to convert the readout with the following formula [2]:

$$RH_{linear} = c_1 + c_2 + c_3.SO_{RH}^2 \quad (1)$$

Coefficients C_1, C_2 and C_3 depend only on measurement resolution.

TABLE I. Humidity conversion coefficients.

SORH	C1	C2	C3
12 bit	-2.0468	0.0367	-1.5955E-6
8 bit	-2.0468	0.5872	-4,084E-4

For temperatures significantly different from 25°C the temperature coefficient of the humidity sensor should be considered [2]:

$$RH_{true} = (T_{°C} - 25).(t_1 + t_2 + SO_{RH}) + RH_{linear} \quad (2)$$

Where $t_1 = 0.01$ and $t_2 = 0.00008$ for 12 bits and $t_2 = 0.00128$ for 8 bits of resolution.

The bandgap PTAT (Proportional to Absolute Temperature) temperature sensor is very linear by design. Use the following formula to convert from digital readout (SO_T) to temperature [2]:

$$Temperature = d_1 + d_2.SO_T \quad (3)$$

TABLE II. *TEMPERATURE CONVERSION COEFFICIENTS.*

VDD	d1(°C)	d1(°F)
5V	-40.1	-40.2
4V	-39.8	-39.6
3.5V	-39.7	-39.5
3V	-39.6	-39.3
2.5V	-39.4	-38.9

SOT	d2(°C)	d2(°F)
14bit	0.01	0.018
12bit	0.04	0.072

IV. WSN FOR MONITORING TEMPERATURE AND RELATIVE HUMIDITY IN A GREENHOUSE

A. System Descripction

The System consists on a sensor node and a coordinator device communicating with each other. The sensor node is essentially a data acquisition unit, and it is responsible for collecting variables as temperature and relative humidity. In addition, the system transmits the collected data to the coordinator device through Xbee modules, based on Zigbee [4], [5], [6]. SHT71 sensor is integrated to the system and provides a range from 0 to 100% for relative humidity, and -40°C to 125°c for temperature. Temperature accuracy is ±0.4°C and the accuracy of the relative humidity is less than ±3.0%. The coordinator system, which acts as central node, is responsible for receiving the acquired data by the sensor node forming a star topology wireless network. This system process, stores, and provides to the user a convenient and easy way to display information to a GUI (graphical User Interface) and a LCD. The functional diagram of the system is showed in Fig 1.

B. Sensor Node

The sensor module is responsible for collecting information about temperature and relative humidity. The processing module stores and processes collected data by the sensors, and controls the operation of the sensors node; which are achieved by using a microcontroller (MCU). An HCS08 MCU, MC9S08JM16 [7], was selected as the main control chip of the sensor node. The wireless communication module communicates with other nodes, allowing the data exchanging (receiving/transmitting). The power supply module provides energy to the sensor, processing and the wireless communication modules. The power supply of the sensor node corresponds to a 9V lithium-ion battery. On the other hand, the Xbee module, SHT71 sensor and MC9S08JM60 microcontroller [8] require 3.3V, which are provided by an LM1117 LDO voltage regulator. The block diagram of the sensor node or end device is shown in Fig 2.

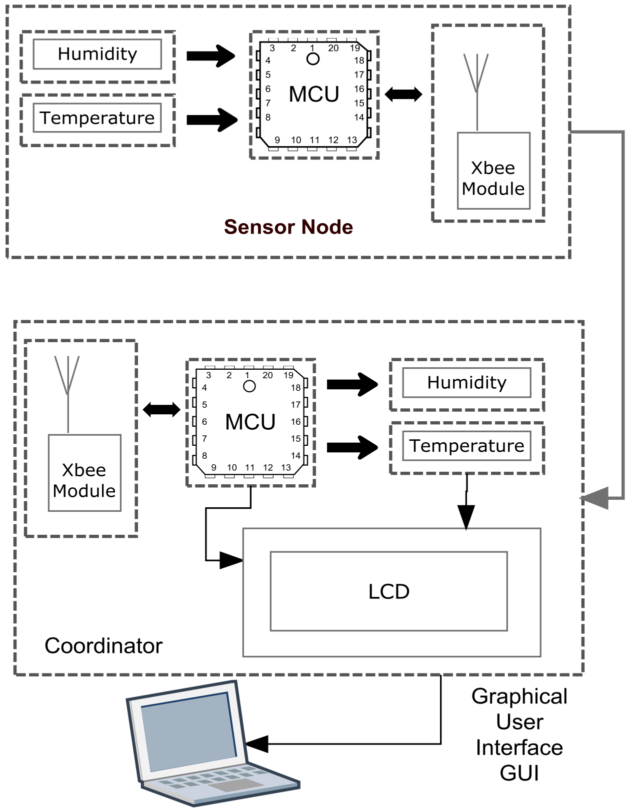

Fig. 1. System Overview.

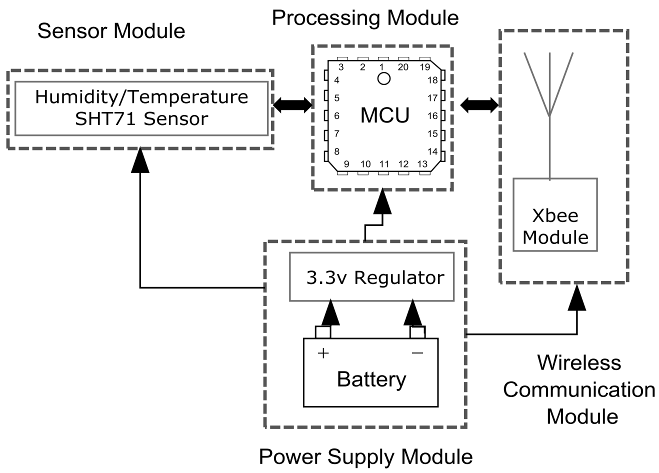

Fig. 2. Block diagram of sensor node

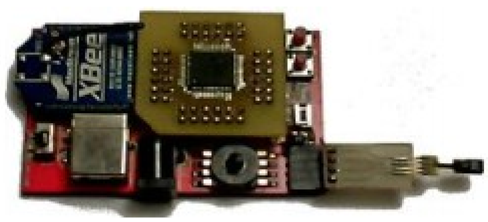

Fig. 3. Sensor node.

C. Communication between the microcontroller and the sensor

The communication between the microcontroller and the sensor is trough 2-line interface (data and synchronization). A C-library based on the software interrupts of the MC9S08JM16 microcontroller is made for this communication. This library has the following functions:

- Writebyte() // writes a byte and checks the acknowledge
- ReadByte() // reads a byte form the Sensibus and gives an acknowledge in case of "ack=1"
- Start() // generates a transmission start
- Conreset() // communication reset
- SoftReset() // resets the sensor by a softreset
- Measure() //makes a measurement with checksum
- Calc SHT71() //calculates temperature [°C] and humidity [%RH]

These functions are used to control the sensor trough the 2-wire interface and to get temperature and humidity data. This data is stored in the microcontroller memory and then converted using formulas for non-linearity and temperature compensation. The flow chart showed in the Fig. 4, illustrates the general order of events to be followed to request the sensor to take measurements and read the information placed on the Data Line by the sensor.

D. Coordinator Device

The coordinator receives the signals from the sensor node, and then it integrates and stores the data automatically. The coordinator is composed by five parts: processing module, wireless communication module, power module, display module, and USB communication module. The processing module controls the operation of the sensor nodes; and, stores and processes the collected data. The wireless communication module is responsible for receiving/transmitting data from/to the sensor node. The power supply module provides power to the other modules. The data logger is responsible for storing the sensor data, which are displayed on a LCD. The union of these allows the coordinator to periodically receive data from the sensor node. The block diagram of coordinator system is shown in Fig 4.

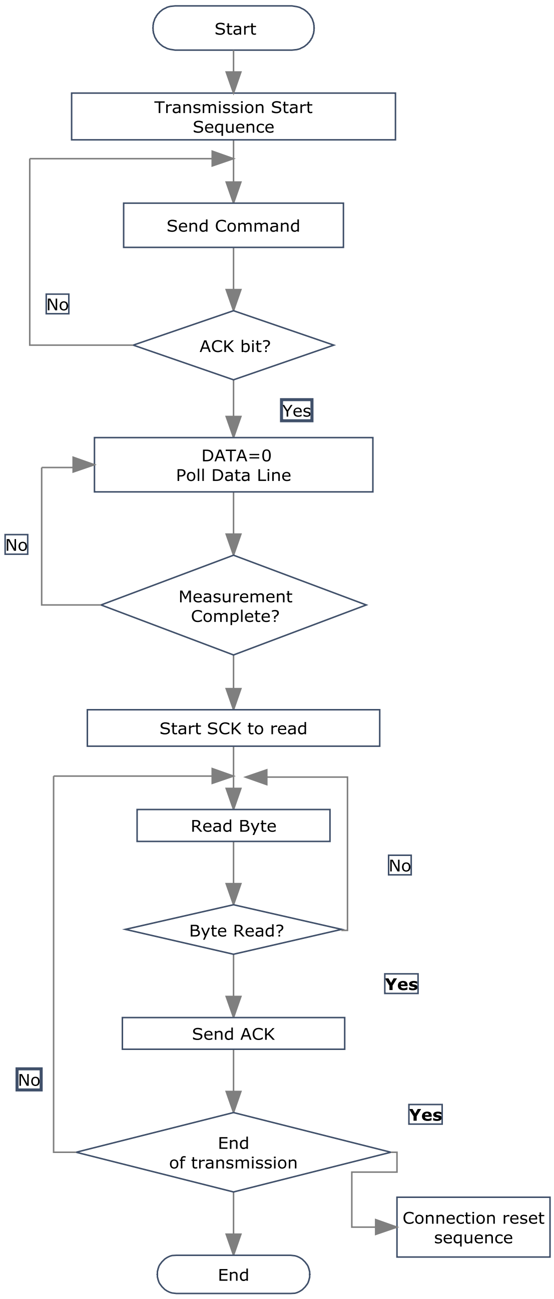

Fig. 4. Communication sequence flow chart

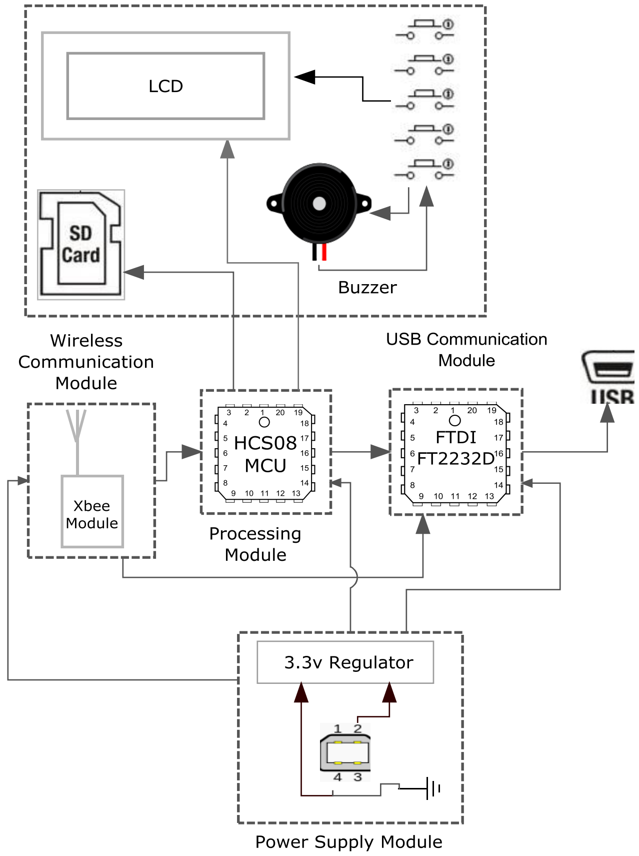

Fig 4. Block diagram of coordinator device.

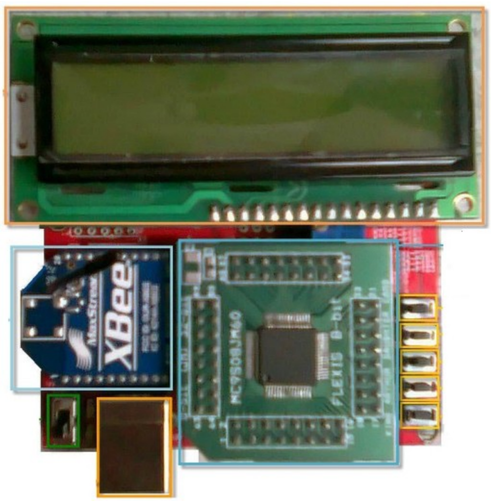

Fig 5. Coordinator Device.

V. Experimental Results

A. Experimental Setup

Experiments were carried out to test the accuracy of the SHT71 sensor used in the sensor node. In order to emulate a greenhouse environment, it was set a space containing two ornamental plants. Near each plant, a sensor node was located for measures relative humidity and temperature around the plants. The sensor node outcomes are visualized on the LCD. The measurement samples were taken for an hour at intervals of 1 minute. The results obtained from the experiments are presented in the next sub-section (figures 6 to 7).

B. Results

This sub section presents the results obtained from the experiments done with the sensor.

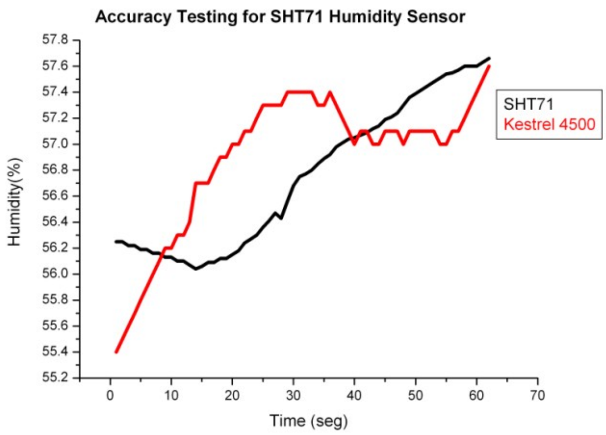

Fig 6. SHT71 experimental results (humidity).

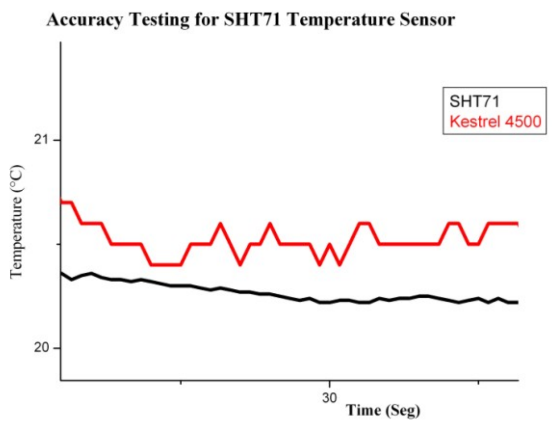

Fig 7. SHT71 Experimental results (temperature).

The results obtained from the experiments show small variations between the readings of the sensor, for humidity and temperature. From statistical analysis it was possible to deduce an accuracy of ±0.29 %RH and ± 0.11°C. These results, data collected from the sensor, were compared with a portable weather station pre-calibrated, the Kestrel 4500 Pocket Weather Tracker.

Other experiment consisted on verifying the communication between the two Xbee modules. Figure 8 describes the distances that separate the sender (red icon) of the receptor (blue icon). Measures were taken of packet reception and level RSSI (Received Signal Strengh Indicator) of the received packet to 30 m, 60 m and 100 m away. For the test there were used two Xbee devices, two laptops and two USB development kit from digi. In the X-CTU software was used Range-test option with its default settings. This configuration is sending 32 bytes of data from one device to another, which returns the data frame to the origin. Others experimental results were based on the Lost Packets with values between 0 to 1000 and LQI within typical values between -95dBm and -18dBm according to IEEE 802.15.4. The results of the experimental measures of three sequences, with 5, 10 and 20 bytes of payload size per packet, and a Zigbee Network implementation with monitoring environmental variables network are shown in the Fi 9. The measures of LQI and lost packages are shown respectively for 5 bytes in payload per packet.

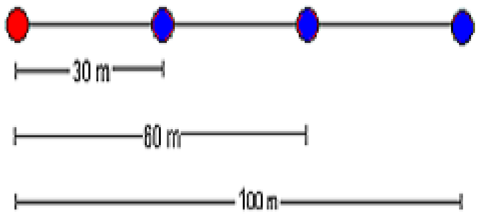

Fig. 8. Diagram for test of outdoor.

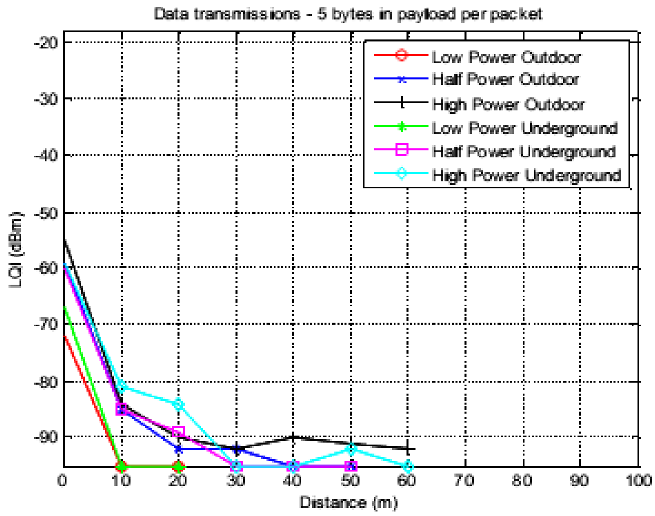

Fig. 9. Graphics of LQI vs. distance between devices.

C. Node Power Consumption

Low power consumption is an important criterion in the WSN deployment to make sure it is able to operate in long time with minimum maintenance [9].

The table 3 shows the average current consumption of the sensor node, measured for both during active and sleep mode condition.

TABLE III. *CURRENT CONSUMPTION OF THE SENSOR NODE*

State	Current Consumption (mA)
Active	75.8
Sleep	62.5

During the measurement, the end device is configured to be in a timer sleep mode condition. The node is configured to wake up at every 5 minutes interval for 120ms just to send the data to the base station. For the rest of the time, the end device is in a sleep condition.

The node power consumption mainly includes Xbee module current consumption, leds, buttons, regulator and sensors on the board. Because the coordinator in this application can be powered from an external power supply besides batteries. Based on the above result, the lifetime of the battery can be calculated as follow.

Power consumption during active mode:
= 75.8 mA x 120ms / (60 x 60 x 1000)
= 2.52667E-09 Ah
=0.0000252 mAh

Power consumption during sleep mode:
= 62.5 mA x 5 minutes/60
=5.208 mAh

Total power consumption = 5.208 + 2.52667E-09 ≈ 5.208 mAh

Battery capacity = 750mAh
Expected battery life time = 750/5.208 = 144 hours

Based on the measurement result, the sensor node is able to operate for 6 days without the need of installing a new battery. The obtained result however, can be improved if circuitry for the power supply module is carefully considered to use a component with very low power consumption plus a smart power management that can reduce the voltage supply necessary for the module during the sleep mode [10]. In adition, a better and longer life time can be expected by having a longer sampling interval or using larger capacity batteries. The programming of tasks carried out in the module can also be customized to further reduce the current consumption, for example using the lower consumption modes of the microcontroller: In order to reduce power consumption, modes: Run, Wait, Stop1, Stop2, and Stop3.

VI. CONCLUSIONS

Intelligent sensors have advantages over other kind of sensors. These advantages, for SHT71, like combining temperature and humidity sensing elements, integrating ADC, amplifiers and serial interface make development of measurement system easier. These advantages also decrease the development time and the size of the product.

In addition, it is presented a wireless solution for greenhouse monitoring. The system is based on HCS08 Freescale MCU´s, which monitors environmental variables through SHT71 humidity/temperaure sensor and uses and Xbee modules. Also, it is shown the design of the wireless nodes, network establishment and the software system. Monitoring system is based on ZigBee standard and provides nearly unlimited installation of transducers, which increase network robustness and scalability.

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