Wireless Sensor Node Design

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***Abstract*— Remote monitoring system is a part of Internet of Thing (IoT) application whether in healthcare, logistic or even agriculture. The system consists of several nodes including wireless sensor node which is a compulsory end-device part in remote monitoring system for data acquisition and processing. This paper discusses the available design of wireless sensor node from different hardware and interfaces, comparison and reasoning of the available design for the hardware such as the microcontroller and transceiver. A propose design provided in this paper using an ARM based microcontroller for raw data processing and nRF24L01 transceiver in wireless communication**

***Keywords*— Remote monitoring system, LPC2103 Microcontroller, DHT 11, nRF24L01**

I. INTRODUCTION

Fast development in networking, internet connection, security and also technologies made the idea of Internet of Things (IoT) possible in our time. In [1], the term IoT clarified as a connected set of anything including human, time, service and even networks which made the object become smart and ideal for connecting and interacting with others to share its information. The application of IoT varied from healthcare such as in [2], [3], [4], [5], [6] to agriculture in [7] and also building structure monitoring in [8]. All the readings related to the concept of remote monitoring system consist of a few important parts, which are the sensor nodes, router or gateway and the database. The sensor nodes are where the data acquired, pre-processed and arranged in packet based on the protocol used in a remote monitoring system, since the sensor nodes are all scattered, a wireless system is compulsory for data communication compared to disorganize and complex cabling system. The router or gateway is a network connector which overcomes the wireless range limit if the system requires larger network area. Next is the database of the system where the data analysis and display take place. An example of remote monitoring system is depicted in Figure 1. The sensor nodes serve as the raw data acquisition and process before it is transmitted to the next node. A reliable data is mandatory for a monitoring system to maintain its accuracy and reliability. Therefore, a good design of wireless sensor node is an obligation for a proper data analysis in remote monitoring system.

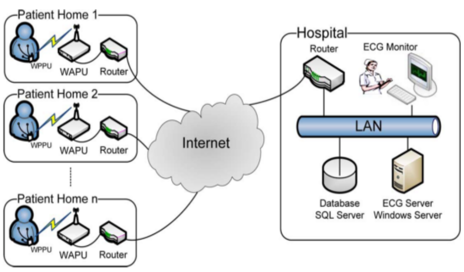


Fig. 1. Show a remote monitoring system for multiple ECG patients [3]

The purpose of this paper is to review the available designs from others in the literature review in Section II and also discusses the design based on the paper reviewed in Section III. A novel proposed design of wireless sensor node is provided in section IV and finally the conclusion of this paper in Section V.

II. LITERATURE REVIEW

Research in [3] states the study for a wireless communication solution for multiple patients in a single physiological monitoring system as shown in Figure 1. Wireless Patient Portable Unit (WPPU) or the sensor node is directly applied to the patient for data collection. The

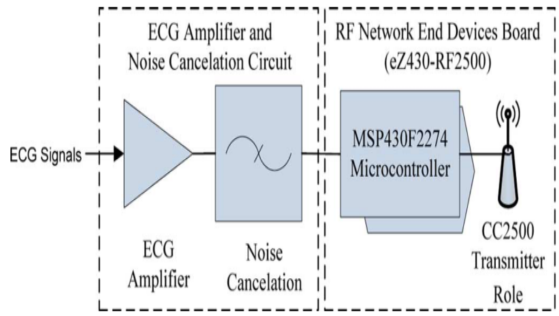


Fig. 2. Show the wireless sensor node or WPPU from journal in [3].

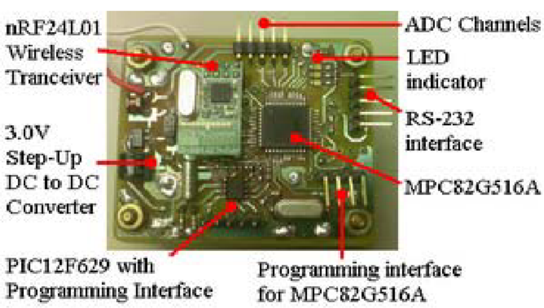


Fig. 3. Show the general node used in sensor node and repeater in [9]

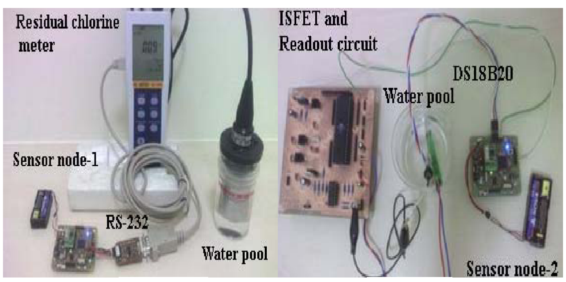
Electrocardiogram (ECG) signals that processed by ECG Amplifier and Noise Cancellation circuit for amplification and filtering of raw data before proceeds to the RF network End Devices Board (Z430F2274-RF2500). The Z430F2274-RF2500 board as shown in Figure 2 is a wireless microcontroller module consists of MSP430F2274 microcontroller board and CC2500 transceiver developed by Texas Instrument that offer features such as 16 bit RISC architecture with specialty in ultra-low power consumption compared to other available microcontrollers and built in 10-bit ADC eliminating the need of external ADC. The processed analog data received by the wireless microcontroller module are then converted into digital data and next wirelessly transmitted to the receiver end of Wireless Access Point Unit (WAPU). Based on the results in [3], the carrier frequency above 2.460 GHz is chosen to avoid Wi-Fi interferences. The acceptable packet loss for ECG signals are less than 5% which means the applicable range between WPPU and WAPU is less than 20 meters range. Thus, to overcome the range limitation, additional router is suggested.

Paper in [6] introduced a system to monitor the blood pressure (BP) in low power consumption and real time to be displayed at the nodes and surveillance center. The sensor node provided with blood pressure sensor (BP3000T), ARM 7 based processor which is a 32-bit RISC LPC2103 controller by NXP which consisted of 8 input channel of analog to digital converter (ADC) and also a real time clock (RTC) which an ease for a software clock display. While, a Zigbee communication module, alarm circuit, button module and also LCD display are the rest of the sensor node parts as shown in Figure 4. The system works only by transmitting the BP data and alarm information in packets when the BP exceeds the threshold value. This way, the power consumption is reduced by only transmitting the crucial BP level. This sensor node gives advantages such that it is more convenient than the conventional blood pressure monitor to be monitored widely and continuously from many patients at once. Based on the result, the data collected are accurate and the sensor need a calibration before used due to zero drift as mentioned in Result section in [6].

Based on [8], a structural health monitoring system to measure the structural health of a building to gives continuous monitoring and avoid death casualties due to structural collapse. This node designed using cortex M3 Arm controller and Xbee transceiver using the Zigbee protocol for the sensor nodes as shown in Figure 7. The sensors provided in the node are accelerometer, temperature and humidity sensors. LPC1768 ARM Cortex-M3 based microcontroller provided with 512kB Flash memory and 64kB Data memory that eliminates the need of external memory also in built 12-bit ADC and integrated power management that reduced power consumption. The test held on a 3 phase AC motor, the collected data received by the base station were analyzed. From the test, the vibration test result clarifies the sensor node ability to capture very low level vibration that is (~2 mg).

In [9], wireless system for water quality monitoring designed and tested on 2 different pools. 2 sensor nodes with different sensors are connected as in Figure 4(a) and 4(b). Sensors that are used in the system are the residual chlorine meter (RC-24P) with RS-232 interface, ISFET (Ion Sensitive Field Effect Transistor) with readout circuit and temperature sensor (DS18B20). As in Figure 3, the node consists of MPC82G516A microcontroller is the processing unit meanwhile nRF24L01 as the communication unit. Additional component such as external timer and step up DC-DC converter were also use to meet the circuit requirement. Other than the external clock not in the sleep mode, the sleep time of the nodes were longer than the working time, so it has become a critical condition to be valued on overall power consumption of the sensor node. Based on the result, a total power consumption of 27mA with input voltage 3V was achieved.

In [10], the cold storage system for fruits stated needing a monitoring system in such large storage for preventing deteriorations of fruits using sensor nodes based on Figure 6 which consist of sensors, Arduino Board microcontroller and



(a) (b)

Fig. 4. (a) Show the sensor node 1 connection while (b) show the sensor node 2 connection [9]

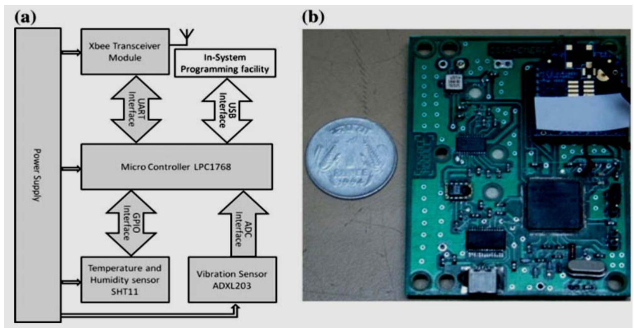


Fig. 5. Show the sensor node block diagram for the cold storage system [8]

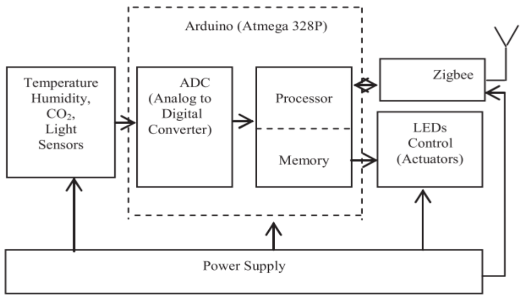


Fig. 6. a) show the block diagram of sensor node, while b) show the hardware of the sensor node [8]

Zigbee module for the wireless communication system. The sensors used are temperature, humidity, carbon dioxide concentration and light intensity. ATmega328p from the Arduino Family comes with features such as built in 10-bit ADC. The Zigbee module was connected directly to the Arduino board as shown in Figure 6. The LEDs work as the indicator for each sensor used. When one of the sensors does not meet the threshold value, the LED will light up as a warning sign and the monitoring PC also give warning to the users. Based on the result, the data below threshold value gives the desired output and alarm. Carbon dioxide concentration is constant due to the lab environment.

III. COMPARISON DISCUSSION

Based on Table 1, the sensor node information are collected from journal [3], [6], [8], [9] and [10]. Comparisons are made based on the processors capability such as the memory size and operating voltage. The wireless module also compared based on the type of transceiver and the network protocol.

The sensor node physical architecture has several similarities in device usage such that these devices are compulsory in basic design for the sensor node. Firstly, the sensors used depend on the function of the system. Next, the microcontroller used as data storage and processing the data to be collected in packet before sent to the last stage of sensor node system, the wireless module. The wireless module which composes of transmitter and receiver device sends the data packet through a transmitter on the sensor node and is received by the receiver at the other node. From the comparison table, the MSP 430 processor in [3] and ARM processors in [6] and [8] are competitive processors as mentioned by Hopkins, E. in [11]. But the ARM Core M3 processor is on the winning side for its power, price and performance [11]. The transceiver module varied from CC2500, nRf24L01, MC13192 and Xbee that shows different range in communication distance. Given in table, the Nordic's transceiver in [12] give the best range compared to other transceivers which is between 30 meter to 100 meter.

TABLE I. SHOW THE 5 SELECTED PAPER COMPARISON

JOURNAL		[3]	[6]	[7]	[9]	[8]
APPLICATIONS		Remote ECG monitoring	Blood pressure monitoring system	Structural health monitoring system	Wireless Water Quality Monitoring	Monitoring system of Cold Storage
MCU TYPE		MSP430F2274 (TI)	LPC2103 ARM7	LPC1768 CORTEX M3	MPC82G516A (Megawin)	ARDUINO ATmega 328p
MEMORY SIZE	FLASH	32 kB	512 kB	14 kB	64kB	32kB
	DATA	8kB	64kB	64kB	1024B	2kB
OPERATING VOLTAGES		1.8V – 3.6V	2.6V – 3.6V	2.4V – 3.6V	2.5V – 5V	5V
TRANSCEIVER		RF2500/ CC2500	MC13192	Xbee	nRF24L01	Xbee
COMMUNICATION DISTANCE		<20m [3]	10m [6]	30m-90m [23]	30m-100m [12]	30m-90m [23]
SIMILARITIES		Sensors, low-power microcontroller, transceiver and power supply.				
DIFFERENCES		-Noise Cancellation -Amplifier	-Alarm circuit -button -LCD	-	- RS232 - TB88-30 - PIC12F629 (timer)	LEDs indication system

These sensor nodes are different from each other based on other additional devices used such as the use of a level converter to avoid the connected chip or microcontroller IO pin from being damaged, for example the RS232 is used to connect between Zigbee module and the microcontroller. While the use of amplifier and noise cancellations are depicted in [3]. Others, the use of alarm circuit is shown in [6] to alert doctor or the caregiver . The use of these devices depends on the output signal produced by the sensor. If the sensors are in direct use, the sensor node would be as simple as in architecture in [8], where the microcontroller has a built in ADC for analog data conversion which reduced the external devices usage in one sensor node. In [10], the use of LEDs as a control display that give warning when the threshold value not met.

IV. THE PROPOSED DESIGN OF WIRELESS SENSOR NODE

For a wireless sensor node design, there are 4 essential devices need to be considered which are the sensor, microcontroller, power supply and the wireless module as discussed in previous section. These devices are chosen based on the comparison given in section III. The general block diagram of proposed wireless sensor node as illustrated in Figure 8.

The sensor used is DHT 11 which is a temperature and humidity sensor for environmental data acquisition, an ARM microcontroller for data pre-processing and nRF24L01 transceiver for wireless communication between the sensor node and base station. The use of signal conditioning as in [13] depends on sensor used in the node, since the microcontroller already have built in ADC, the signal conditioning circuit can be stashed out from the system. Finally, 3V power supply is supplied to the sensor node given the requirement voltage of microcontroller and transceiver in [14] and [12].

The LPC2103FBD48 microcontroller, an ARM7 based architecture is chosen for its simple size memory, 32kB Flash and 8kB RAM, high performance and low power consumption from 1.65V to 3.6V of 32-bit RISC processor useful for real time data monitoring and as addition for the variable peripheral interfaces option which incorporate of 2 UARTs, 2 fast I2C buses, an SPI and SSP. A 10-bit built-in ADC reduces the need of external ADC and hence, minimizes the design cost and size. Meanwhile, the Real Time Clock (RTC) provides a simple way to program the clock for display purpose [14][15].

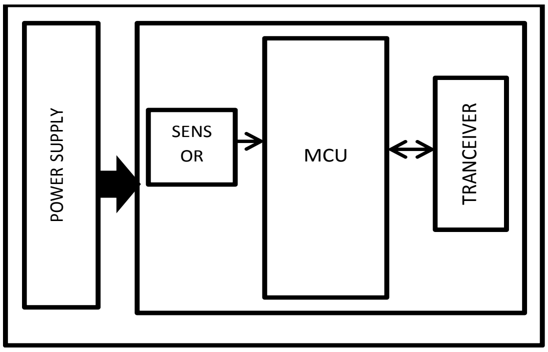


Fig. 7. Show the propose block diagram of the sensor nodese design

TABLE II. SHOW THE TYPE OF HARDWARE TO BE USED FOR THE PROPOSE DESIGN

Hardware	Type	Manufacturer	Price range
Microcontroller	LPC2103FBD48	NXP Semiconductor	\$2-\$6
Transceiver	nRF24L01	Nordic Semiconductor ASA	\$1-\$6
Temperature and Humidity Sensor	DHT11	Ada fruit Industries LLC	\$3-\$4
Power supply	AA Alkaline battery	Any type	\$2- \$3

Meanwhile, the wireless communication on the sensor nodes, Nordic RF module labelled nRF24L01 is chosen from the basic feature mentioned in [12]. The ideal current usage for this Nordic RF in transmit, receive, power down and idle mode are 11.3mA,12.3mA, 900nA and 22µA respectively as yielded in [12] which currently better than Zigbee, Xbee also other transceiver mentioned in Table 1. The transceiver's effective communication distance ranged from 30m to 100m on open space as experimented in [16] and [17] . The distance can be extended if using an operational amplifier circuit as in [18] and [19]. The results in [19] shows the distance achieved by the transceiver using different value of the op- amplifier.

This sensor node can be powered by harvesting energy from solar energy such as in [20] or even an electrostatic kinetic energy in [21] or simply battery usage in [22] are optional for powering the wireless sensor node. The proposed node will be supplied with power from AA alkaline battery based on the environmental conditions.

V. CONCLUSION

In this paper, a sensor node design is discussed based on five different wireless sensor nodes as depicted in Section III. All of these nodes cover wide range of its application from medical, structure to agriculture. Based on these designs, we found that 4 important devices are needed to design a node which can be found in Section 4 alongside with our proposed design. Besides, we managed to accumulate the differences and similarities of these sensor nodes as in Section III The proposed design consist of an ARM7 based processor, LPC2103 controller, Nordic radio frequency transceiver, nRF24L01 for communication purpose, a temperature and humidity sensor, a single DHT11 and battery for voltage supply.

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VI. REFERENCES

[1] S. M. R. Islam, D. Kwak, and H. Kabir, "The Internet of Things for Health Care : A Comprehensive Survey," vol. 3, 2015.
[2] J. M. G. Duarte, E. Cerqueira, and L. A. Villas, "Indoor patient monitoring through Wi-Fi and mobile computing," in *2015 7th International Conference on New Technologies, Mobility and Security (NTMS)*, 2015, pp. 1–5.
[3] R. S. Dilmaghani, H. Bobarshad, M. Ghavami, S. Choobkar, and C. Wolfe, "Wireless sensor networks for monitoring physiological signals of multiple patients," *IEEE Trans. Biomed. Circuits Syst.*, vol. 5, no. 4, pp. 347–356, 2011.
[4] S. Macis, D. Loi, D. Pani, L. Raffo, S. La Manna, V. Cestone, D. Guerri, and S. A. Dedalus, "Home Telemonitoring of Vital Signs Through a TV-based Application for Elderly Patients," 2015.
[5] P. S. Purnima, "Zigbee and Gsm Based Patient," pp. 6664–6669, 2014.
[6] Q. Huang, F. Zhang, and W. Chen, "Research and Realization of Blood Pressure Monitoring System Based on ZigBee Wireless Sensor Network," pp. 205–211, 2012.
[7] S. Jiang, W. Wang, G. Xiao, and Z. Li, "Design of wireless sensor node for drought monitoring in tea plantation," *2011 Int. Conf. Electr. Inf. Control Eng.*, pp. 1328–1332, 2011.
[8] C. Selvi, C. Ahuja, and E. Sivasankar, "Intelligent Computing and Applications," *Adv. Intell. Syst. Comput.*, vol. 343, pp. 367–379, 2015.
[9] W.-Y. Chung, C.-L. Chen, and J. Chen, "Design and Implementation of Low Power Wireless Sensor System for Water Quality Monitoring," *2011 5th Int. Conf. Bioinforma. Biomed. Eng.*, vol. 30, pp. 1–4, 2011.
[10] S. K. Nagpal, S. Sudha, and E. Engineering, "Design and Development of a Sensor Node to Monitor and Detect Change in Internal Parameters of a Cold Storage System," no. Gcct, pp. 745–748, 2015.
[11] E. Hopkin, "TI's MSP430 vs. ST Microelectronics' ARM Cortex-based processor for battery-powered apps | Embedded," 2008. [Online]. Available: http://www.embedded.com/electronics-blogs/industry-comment/4026838/TI-s-MSP430-vs-ST-Microelectronics-ARM-Cortex-based-processor-for-battery-powered-apps. [Accessed: 22-Dec-2015].
[12] "Single Chip 2 . 4GHz Transceiver Product Specification," no. July. 2007.
[13] K. Mundada, P. Kanjalkar, and J. Kulkarni, "CCIS 269 - Development of Sensor Node to Measure Soil Moisture," pp. 628–636, 2012.
[14] "Lpc2101/02/03," no. June. 2009.
[15] "Volume 1: LPC2101/02/03 User Manual," vol. 1, no. January, 2006.
[16] Y. Wang, C. Hu, Z. Feng, and Y. Ren, "Wireless transmission module comparison," *2014 IEEE Int. Conf. Inf. Autom. ICIA 2014*, no. July, pp. 902–907, 2014.
[17] Y. Huang, X. Huang, Q. Sun, A. K. Issues, and R. System, "The Design of the Management System for Parking lot Based on 2 . 45GHz Active RFID," pp. 850–853, 2011.
[18] B. Li and J. Zou, "The design of oil drilling wireless data acquisition system," *2011 Int. Conf. Electr. Control Eng.*, pp. 1810–1813, 2011.
[19] S. Chen, Y. J. Yuan, and S. Member, "Wireless electronic tourist guide system based on microcontroller."
[20] G. Nisha and J. Megala, "Wireless sensor network based automated

irrigation and crop field monitoring system," 2014.
[21] Y. Lu, F. Cottone, S. Boisseau, F. Marty, D. Galayko, and P. Basset, "A nonlinear MEMS electrostatic kinetic energy harvester for human-powered biomedical devices," *Appl. Phys. Lett.*, vol. 107, no. 25, 2015.
[22] G. Feltrin, N. Popovic, K. Flouri, and P. Pietrzak, "A Wireless Sensor Network with Enhanced Power Efficiency and Embedded Strain Cycle Identification for Fatigue Monitoring of Railway Bridges," vol. 2016, 2016.
[23] Digi International, "XBee ® /XBee-PRO ® RF Modules." 2009.