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Design Concept of Dynamic-Adaptive Reconfigurable Wireless Sensor Node (DARWiSeN)

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Abstract

This paper describe the proposed design concept of wireless sensor node named Dynamic-Adaptive Reconfigurable Wireless Sensor Node (DARWiSeN), with special emphasis on the design principles and functionality. The design concept is targeted to a wireless sensor node prototype that has ability to adapt various applications and situation with a minimal redesign effort through concept of reconfigurable hardware and modularity approach. Both the hardware and software components are detailed, together with experimental evaluation. The experimental evaluation revealed that this approach is not only capable to show rapid prototype of wireless sensor application design, but it can also be used as a generic wireless node platform design in dynamic-adaptive reconfigurable feature, flexible, and greatly extending its applicability.

Keywords*: wireless sensor node, dynamic recofigurable, adaptability, flexibility*

1. Introduction

Wireless sensor networks (WSNs) have been used in wide areas of application and become an attractive area for researchers in recent years. It has great potential for many applications and some already exists in scenarios such as military target tracking and surveillance [1], natural disaster relief [2], biomedical health monitoring [3], agriculture, environment monitoring, habitat monitoring [4], structure health monitoring [5], hazardous environment exploration, and seismic sensing [6]. Other possible fields include home/office automation, education [7], inventory monitoring, intrusion detection, motion tracking [8], machine malfunctions, toys and many others [9],[10].

A WSN consists of a large number of tiny sensor nodes deployed over a geographical area also referred as sensing field; each node is a low-power device that integrates computing, wireless communication and sensing abilities. Nodes organize themselves in clusters and networks, and cooperate to perform an assigned monitoring (and/or control) task without any human intervention at scales (both spatial and temporal) and resolutions that are difficult, if not impossible, to achieve with traditional techniques. Sensor nodes are thus able to sense physical environmental information (e.g., temperature, humidity, vibration, acceleration or whatever required), process locally the acquired data both at unit and cluster level, and send the outcome -or aggregated features- to the cluster and/or one or more collection points, named sinks or base stations. Even though WSNs has some advantages compare than traditional techniques, their applicability is often reduced by the limitations of the sensor nodes on the system platform requirements. Real-world wireless sensing applications are quite diverse, and they impose a wide range of constraints on the system platforms, including power availability, the size, cost, wireless connectivity, memory, storage, performance, compactness, high integration of the sensor, and flexibility.

1.1. Reconfigurable Wireless Sensor Node State of the Art

Recently, few wireless sensor node platforms integrate with the concepts of reconfigurable in the WSNs research fields, such as ***The Tyndall25 Mote*** that was developed at *Tyndall National Institute,* Ireland as part of the D-Systems project investigating the development of distributed intelligent systems. The Tyndall mote is a miniaturised, programmable, modular system designed to meet the requirements of various wireless sensor

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networks of different types. It uses the original 25mm micro controller transceiver layer, incorporating an Atmel ATmega 128 micro controller and Nordic VLSI (Very-large-scale integration) nrf2401 2.4GHz transceiver incorporating Shock burst technology [11]. The Nomad Mobile Research Centre, (NMRC), has designed Field Programmable Modular Wireless Sensor Network nodes. It called ***NMRC node***. In these motes, selected *processing* and *sensor signal filters* are synthesized, as hardware, on an FPGA. It is based on reconfiguring the processing and sensor signal filtering according to the application and the environmental requirements [12]. ***PicoRadio*** is mote concepts presented by the University of California, Berkeley right after the development of the MICA2 motes. The PicoRadio is a meso-scale low cost radio designed for ubiquitous data acquisition. The PicoRadio integrates the concepts of reconfigurable state machines and FPGAs. [13],[14]. At CEI (Centro de Electronica Industrial), Universidad Politecnica de Madrid, a modular HW reconfigurable platform has been developed, called ***Cookie***. This platform includes an uC and a FPGA as processing elements. HW reconfiguration features *improve node flexibility and computation performance*, and opens the possibility of remote HW reconfiguration, which can be very useful to tune node performance with new actualizations, to debug on-line (commissioning) the WSN, and make the node smarter [15]. The Hogthrob project was aiming to develop a sensor network infrastructure for sow monitoring. A part of the project consists of developing sensor nodes that can be tagged onto the sows (in replacement of the RFID tags they wear today), called the ***Hogthrob*** platform. A key component of that sensor node development platform is an FPGA which has *enabled us to explore various hardware/software tradeoffs*. All the application functionality has been placed on the embedded processor and is gradually being moved to the FPGA. [16]. ***mPlatform***, a new reconfigurable modular sensor net platform that enables real-time processing on multiple heterogeneous processors. At the heart of the mPlatform is a scalable high performance communication bus connecting the different modules of a node, allowing time-critical data to be shared without delay and supporting re-configurability at the hardware level. mPlatform addresses this problem by introducing *a new flexible, efficient* and *reconfigurable communication channel architecture* that better fits the needs of modular sensor network platforms [17].

In the recent literature, several approaches address optimization of the wireless sensor networks by using reconfigurable technical approach. To avoid the waste of energy for the periodic tasks of CPU wireless sensor node, *Glaser, J., et al*. [18] propose a reconfigurable hardware blocks to a WSN SoC (single on chip) which independently conduct simple sub-tasks instead of the CPU. The CPU is only activated if any further (more complex) processing is required. Therefore these logic blocks act as a “filter” for these events. *Garcia, R., et al*. [19] proposes a methodology and modular architectural framework for situation-based reconfiguration in WSNs using partial reconfiguration (PR)-capable field programmable gate arrays (FPGAs). To address the performance improvement in Wireless Sensor Networks (WSNs) in order to reduce the processing overhead, *S. Commuri, et al*. [20] implement dynamic data aggregation using reconfigurable cluster heads (RCHs) based on Field Programmable Gate Arrays (FPGAs). Such an implementation provides the necessary flexibility in data aggregation techniques demanded by real-time applications, while resulting in significant reduction in the query processing time and the overall power consumption in the network. *Muralidhar, P. and Rao, C.B.R*. [21] propose a new HW/SW interface synthesis design method aiming at the Nios-based system on programable chip (SOPC) platform with a dynamically reconfigurable functional unit. One of the design goals is to implement a dynamic reconfigurable sensor node for energy efficient computational intensive tasks to minimize the energy required for the communication.

1.2. The Proposed Design Concept

Develop a system for wireless sensor node, which provides some requirements is a complex task, and a pragmatic ’real-world’ approach is chosen. Proposed methods and design approaches are tested by experiments. Some of fitur on the developed wireless sensor node platform are energy-efficient, flexibility and adaptability, reconfigurable/re-programming, low cost, and sufficient performance (self calibration, self diagnostic and self monitoring). Thus the fiturs shall be to find a suitable compromise of those requirements by the approach based on the combination of a processor with dynamically reconfigurable/re-programming hardware. Moreover all the components on wireless sensor node build based on COTS (Commercial, off-the-shelf) components. However, a system composed of readily available COTS components can reduce design cycle time, and an important design consideration while designing the sensor node development platform, has been to reduce the overall cost of prototyping by using COTS components.

Nowadays, most of wireless sensor node was developed based on fixed and specialized low-power hardware, ASICs (application-specific integrated circuit), and specialized energy efficiency protocol. ASICs shows best performance and energy-efficiency but provide hardly any flexibility. To implement several different functions on a chip, one ASIC block for each function must be created, which leads to increasing area consumption the more functions are implemented. Thus, chip area can be traded off for some flexibility. The other sensor node was built base on microprocessors. Microprocessors are most flexible, small enough and could usually even deliver an acceptable performance (if it is too low, the clock frequency could be raised). Their main disadvantage lies in their inefficiency, which is the price paid for high flexibility.

Furthermore, those methods would *result in time-consuming, very expensive,* and *need complex design cycles,* and thus it demand *highly complex algorithms* and *technologies*. Nodes built using ASIC or SOC (System on-chip) technologies can outperform COTS (Commercial, off-the-shelf) based nodes in terms of power consumption, price, and size, but they have longer design cycles and higher development costs.

The proposed wireless sensor node platform architecture for experiment consists of four closely-interacting subsystems as shown in Figure 1. These subsystems are: the sensor and sensor interface subsystem, the processing unit subsystem, the communication subsystem, and the power-supply subsystem. The platform design using a modular and reconfigurable development approach. Moreover, researching using this platform turns open, due to the node flexibility, which makes possible the proof of several concepts minimizing the effort.

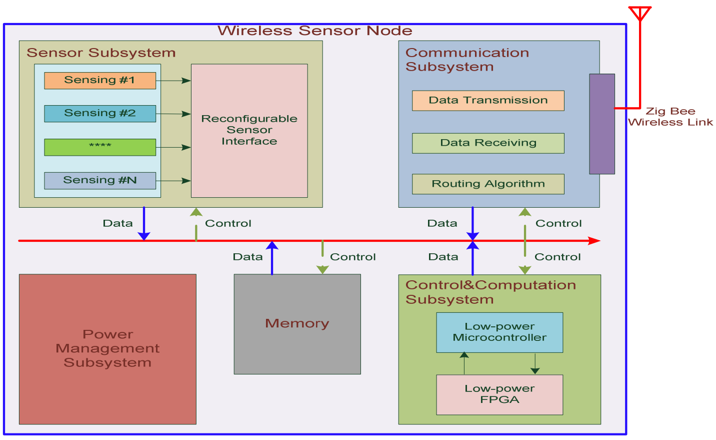


Figure 1. Proposed Reconfigurable wireless sensor node prototype architecture

2. Experiment Design

2.1. Hardware

The design method is implemented in some algorithms based on reprogramming/ reconfiguration approach which will be applied on sensor node level of wireless sensor node. The experiment environment will be built using some moduls according to the proposed architecture of wireless sensor node.

The current wireless sensor node prototype implemented called **D**ynamic-**A**daptive **R**econfigurable **Wi**reless **Se**nsor **N**ode (DARWiSeN) as shown in Figure 2. DARWiSeN is the first sensor node prototype that targeted to adapt various applications and situation with a minimal redesign effort through concept of reconfigurable hardware and modularity approach.

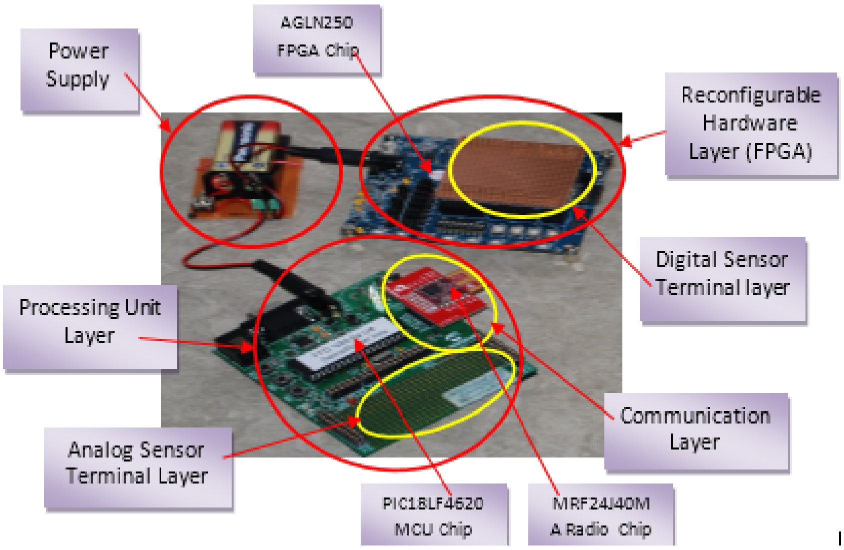


Figure 2. The Current Wireless Sensor Node Platform Prototype

DARWiSeN platform prototype uses the Microchip PCI18LF6420 microcontroller, and Actel's IGLOO nano AGLN250 FPGA as processing unit. FPGA also dedicated to manage various reconfigurable digital sensor interface. The communication channel uses the Microchip's MRF24J40 transceiver for IEEE 802.15.4 application designers, and the ZigBee protocol stack. Sensor interface layer allows attaching the sensors with both analog and digital interfaces. It was desirable to design a sensor node that could be expandable to support a variety of applications. Since DARWiSeN is a prototype, it uses a 9V Ni-MH size battery as an external power supply, and an internal voltage regulator DC-to-DC was added.

2.2. Software

The software design for DARWiSeN platform prototype includes the algorithms for the monitor station, the transmit-receive node, and base station node. The describing the data flow that begins at the monitor station. This is a custom application running on a personal computer and is responsible for displaying data from base station node to graphical user interface.

2.2.1. Base Station Algorithm

Figure 3 describes the algorithm applied by the base station node. Firstly, varying parameters are initialized including the communication of the microcontroller with Zigbee modul, and the adjustment of serial communication parameters. Subsequently, the base station node seeks for end-devices (transmir-receive node) to be added to the network. The base station node can recognize all end-devices of the network using their node ID., it given during the programming process. Subsequently, it will check whether all nodes have sent their data packets at the pre-set time points.

The base station node records which node was the one that has failed to transmit a data packet and asks the node to re-send it, assuming that the packet had not been sent in the expected allocated time slot. The node that had failed to transmit the packet receives the base station node's message and transmits the data packet again. This happens in every cycle and the base station node expects from the failing node to re-send the missing packet. If for some reason the node fails to send the specific packet over a relatively long period of time, it would mean that the system is facing a problem and water resource is terminated for the particular node.

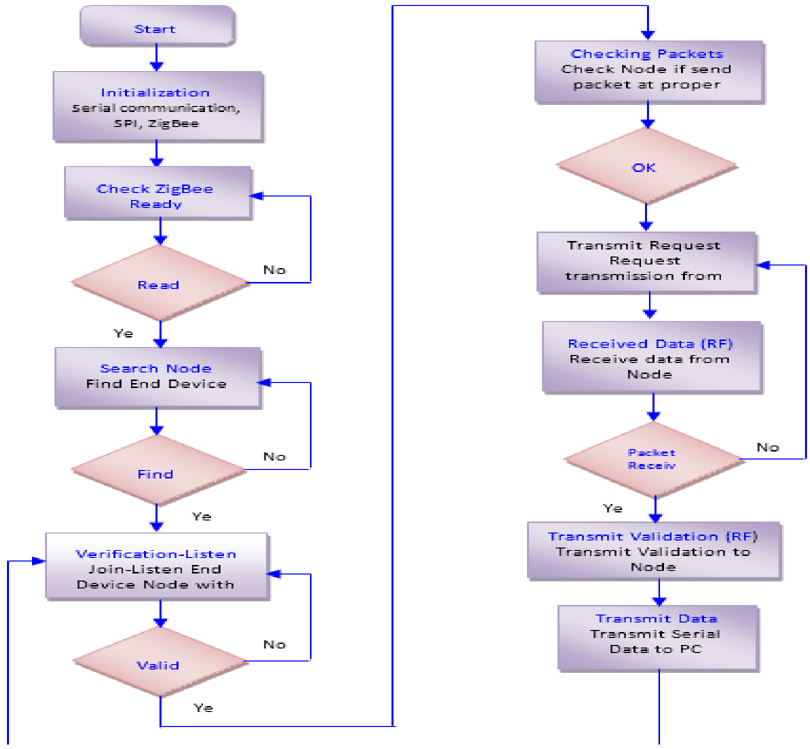


Figure 3. Flowchart model to illustration of base station node algorithm

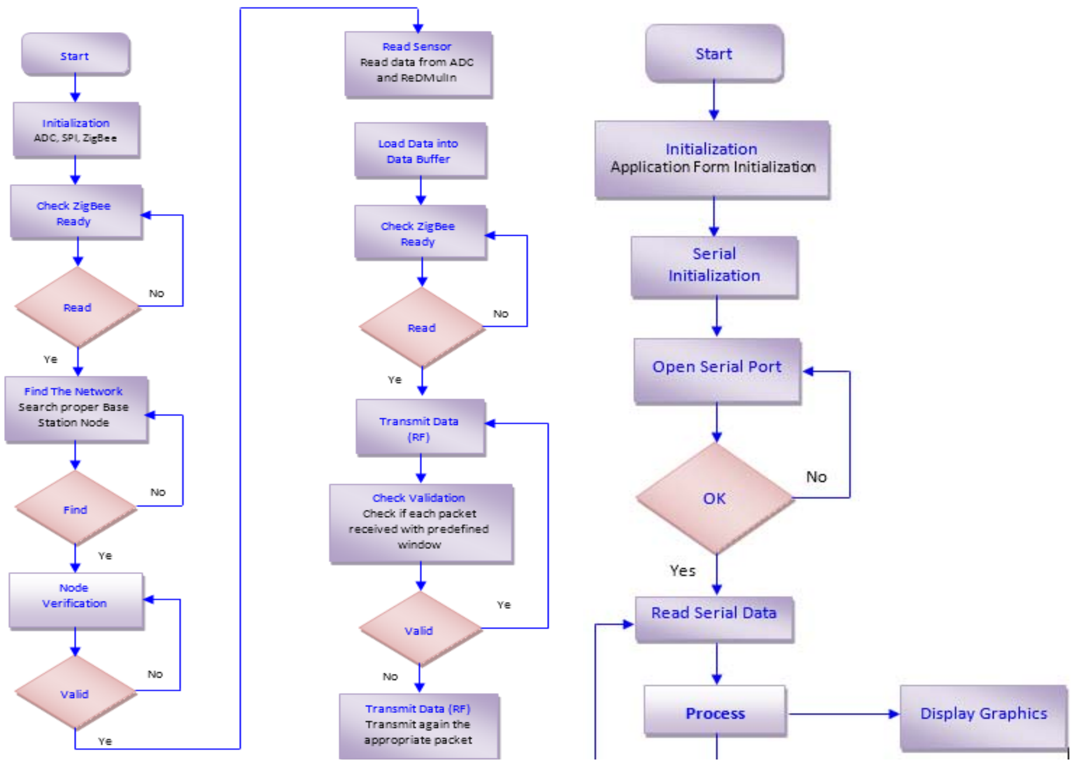
2.2.2. End Device Algorithm

The algorithm used by each end device (transmit-receive) node as illustrated in Figure 4.a. At the beginning, the appropriate initializations is performed. The key points during this process is the initialization of the analog to digital converter and the communication to the multisensor interface (ReDMulIn). Afterwards, node seeks a base station node, depending on the way they have been designed to get connected. Following confirmation, the node may join the network using the identical key. Afterwards, the data from the sensors are being "read". Finally, the data is being send through wireless transmission to the base station node.

As mentioned above, in the algorithm of the base station node, the end-device is awaiting for the base station node to confirm receipt of the packets, within a certain time frame. In case no confirmation is received, the end-device re-sends the packet that has been placed in a stack. Each node uses interrupt for the receipt of data from the base station node without continuously occupying the microcontroller. Upon receipt of a data packet it checks which process the packet is referred to. One of these processes is the parameter adjustment, such as controlling the sampling rate. Moreover, it checks whether the packets awaiting confirmation in the stack have received their confirmation. Finally, it checks whether the base station node asks for re-transmission. Subsequently it completes the circle by checking once again its status within the network and proceeds repeating the above process.

2.2.3- Computer Algorithm

Figure 4.b illustrates the algorithm of the program running on the PC. At the beginning, the graphical user interface window, where all measurements will be illustrated, is initialized. Following that, the serial communication with the base station node is initialized, too.



(a) (b)

Figure 4. (a) Flowchart model to illustration of end-device algorithm
(b) Flowchart model to illustration of PC-running algorithm

3. Development Environment Testbed Setup for The Proposed Platform and Discussion

The testbed was comprised of a base station that collects the data sent by the wireless sensor node platform protoype. The application testbed was used for integrating the new platform for a real-life application development environment. Figure 5 depicts the architecture of the proposed testbed integration.

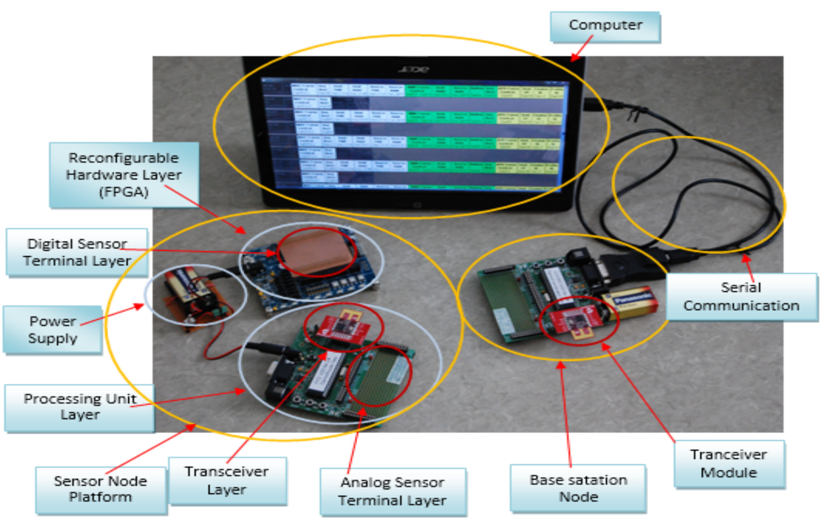
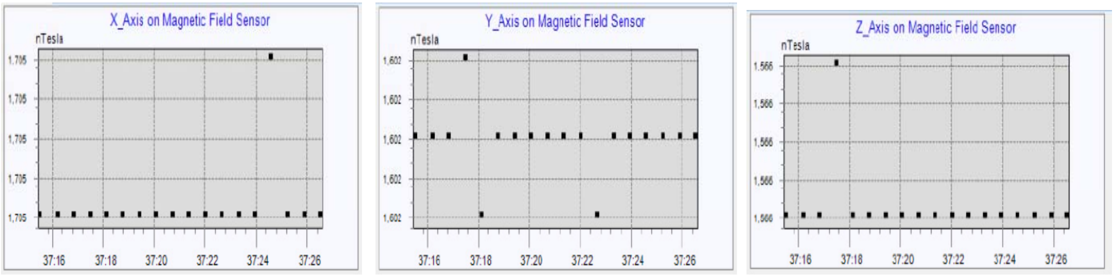


Figure 5. Testbed for Integrating the Proposed Reconfigurable Platform

The simple experiment was done where a magnetic field sensor attached to the wireless node. The sensor acquired experiment data (magnetic fields), and send data processing to the computer monitor over radio frequency communication. The received data appear on 3 windows on the computer screen. The first window is the magnetic field on X-axis, second window is the magnetic field on Y-axis, and the next is the magnetic field on Z-axis. The graphs of measurement result are show in Figure 6. The result of simple experiment show that the developed wireless sensor node can read the magnetic fields around 1.5 – 1.7 nTesla, and sending them to the terminal monitor (computer) wirelessly.



(a) (b) (c)

Figure 6. (a) X-Axis sensor data on screen window (b) Y-Axis sensor data on screen window (c) Z-Axis sensor data on screen window

The magnetic sensor field which is attached on the developed wireless sensor node is one of simple application example. In order to change the wireless sensor node application, it can be done by replacing the sensor with others sensor suitable with the application, and make a little reconfigurable of sensor node hardware. The proposed design concept use approach that has overcome the trade-off methods and technology as already stated before is using a reconfigurable hardware. Even though is impossible to optimize the combination of all requirements of wireless sensor node at the same time, but this approach has the potential to offer a much better than the approach which are found in most state of-the-art sensor nodes in order to find and to achieve a suitable compromise of wireless sensor node requirements. State of the art sensor nodes usually do not use the potential of reconfigurable hardware. In most cases, a microprocessor is used as computing core. It is not sufficient due to the requirements that a sensor node’s hardware platform must meet are precise.

4. Conclusion

In the normal (generic) wireless sensor node, some of application requirements is often reduced by node ability which is due to design method and technology. Dynamic-adaptive reconfigurable is an emerging feature in the wireless sensor node paltform development. This feature is affecting various adaptation situation of wireless sensor node in the wireless sensor network application. The advantages of this approach are that it allows to develop a node at rapid prototyping because of reconfigurable system, based on low-power and COTS components, and opening the possibility to make a node with sufficient performance with integration x-self feature (self calibration, self diagnostic and self monitoring).

References

[1] Yick JB., Mukherjee D., Ghosal. *Analysis of a Prediction-based Mobility Adaptive Tracking Algorithm*. In Proceedings of the IEEE Second International Conference on Broadband Networks (BROADNETS), Boston. 2005.

[2] Hariyawan MY., Gunawan A., Putra EH. Wireless Sensor Network for Forest Fire Detection. *TELKOMNIKA*. 2013;11(3): 563-574.

[3] Gao T., Greenspan D., M. Welsh, RR. Juang, A. Alm. *Vital signs monitoring and patient tracking over a wireless network.* In Proceedings of the 27th IEEE EMBS Annual International Conference. 2005.

[4] Szewczyk R., Mainwaring A., Polastre J., Anderson J., Culler D. *An analysis of a large scale habitat monitoring application*. In Proceedings of the 2nd International Conference on Embedded Networked Sensor Systems (SenSys 2004), Baltimore, MD, USA, November. 2004: 214–226.

[5] Widodo A., Rozaqi L., Haryanto I., Satrijo D. Development of Wireless Smart Sensor for Structure and Machine Monitoring. *TELKOMNIKA*. 2013; 11(2): 417-424.

[6] Wener-Allen G., Lorincz K., Ruiz M., Marcillo O., Johnson J., Lees J., Walsh M. Deploying a wireless sensor network on an active volcano. Data-Driven Applications in Sensor Networks (Special Issue). *IEEE Internet Computing.* 2006.

[7] Srivastava M., Muntz R., Potkonjak M. *Smart kindergarten: sensor-based wireless networks for smart developmental problem solving environments*. In Proceedings of the 7th International Conference on Mobile Computing and Networking (MobiCom 2001), Rome, Italy, July. 2001: 132–138.

[8] Kuncoro C., Bambang D. *Development of Wireless Magnetic Field Sensor Node Based on Programmable System on Chip Microcontroller*. In Proceedings of 4th Industrial Research Workshop and National Seminar 2013 (IRWNS 2013). Politeknik Negeri Bandung. Indonesia. November. 2013: 129-135.

[9] Kuncoro C., Bambang D., Armansyah, Saad NH., Jaffar A., Low CY., Kasolang S. Wireless e-Nose Sensor Node: *State of the Art*. International Symposium on Robotics and Intelligent Sensors 2012 (IRIS 2012). *Elsevier Journal*. 2012.

[10] Kuncoro C., Bambang D. *Miniature and Low-Power Wireless Sensor Node Platform: State of the Art and Current Trends*. International Seminar on Applied Technology, Science, and Art (4th APTECS 2013). Surabaya. Indonesia. 2013.

[11] Barton J., Hynes G., O'Flynn B., Aherne K., Normana A., Morrissey A. A 25mm sensor–actuator layer: A miniature, highly adaptable interface layer. *Sensors and Actuators Journal*. 2006;132: 362–369.

[12] Bellis SJ., Delaney K., OFlynn B., Barton J., Razeeb KM., OMathuna C. *Development of Field Programmable Modular Wireless Sensor Network Nodes for Ambient Systems*. Proc. IEEE Computer Comm. Accepted for Special Issue on Wireless Sensor Networks. 2005.

[13] da Silva, JL. Jr., Shamberger J., Ammer MJ., Guo C., Li S., Shah R., Tuan M. Sheets, Rabaey JM., Nokolic B., Sangiovanni-Vincentelli A., Wright P. Design Methodology for PicoRadio Networks. *IEEE Computer Society*. 2001.

[14] Rabaey J. Picoradio Supports Ad Hoc Ultra-Low Power Wireless Networking. *IEEE Computer Magazine.* 2000; 33(7): 42–48.

[15] Krasteva YE., Portilla J., Carnicer JM., de la Torre E., Riesgo T. *Remote HW-SW Reconfigurable Wireless Sensor Nodes*. Centro de Electronica Industrial, Universidad Politecnica de Madrid. Conference of IEEE, Industrial Electronics, 2008. IECON 2008. 34th Annual.

[16] Virk K., Madsen J., Lorentzen AV., Leopold M., Bonnet P., Hansen M. *Design of a Development Platform for HW/SW Co-design of Wireless Integrated Sensor Nodes*. Proceedings of the 8th Euro-micro conference on Digital System Design (DSD'05). 2005.

[17] Lymberopoulos D., Priyantha NB., Feng Zhao. *mPlatform: A Reconfigurable Architecture and Efficient Data Sharing Mechanism for Modular Sensor Nodes*. 6th International Symposium on Information Processing in Sensor Networks, 2007. IPSN 2007.

[18] Glaser J., et al. A Novel Reconfigurable Architecture for Wireless Sensor Network Nodes. Informationstagung Mikroelektronik 10, Wien, Österreich; 07.04.2010 - 08.04.2010; in: "*Tagungsband zur Informationstagung Mikroelektronik 10.* 2010: S.284-288.

[19] Garcia R., at al. *Exploiting Partially Reconfigurable FPGAs for Situation-Based Reconfiguration in Wireless Sensor Networks*. 17th IEEE Symposium on Field Programmable Custom Computing Machines, 2009. FCCM '09.

[20] S. Commuri, et al. Reconfigurable Hardware Based Dynamic Data Aggregation in Wireless Sensor Networks. *International Journal of Distributed Sensor Networks*. ISSN: 1550-1329. 2008; 4: 194–212.

[21] Muralidhar P., Rao CBR. *Reconfigurable Wireless Sensor Network Node based on NIOS core*. Fourth International Conference on Wireless Communication and Sensor Networks, 2008. WCSN 2008.