Industrial WSN node extension and measurement systems for air, water and environmental monitoring

IoT enabled environment monitoring using NI WSN nodes

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***Abstract*—Air and Water are the most important resources of the planet that we use daily for sustaining life. Air quality affects all living creatures, from trees and plants to animals and people. Air quality, especially in the trend of more industrialized cities and with a rapid growing population of cars, is degrading. Continuous monitoring allows the national administrations to take measures in order to reduce pollution and toxic compounds in the air and prevent further degrading of the air quality. From drinking and producing electricity in hydroelectric power plants to cooling nuclear reactors, water is one of the most common substances that we must manage. In flood management applications, hydroelectric dams, city water infrastructure, and other environmental monitoring applications the high distance between measurement points determine engineers and scientists to use autonomous low power wireless data acquisition systems that are independent on a permanent power supply. In this paper the authors present a flexible low power extension board designed around NI WSN analog input nodes that allows connection of different output type sensors (even digital sensors) to be monitored with one WSN node.**

Keywords—WSN, data acquisition, sensors, nodes, IoT, industrial

I. INTRODUCTION

In recent times, wireless sensor networks and data acquisition systems evolved rapidly, the new circuits allowing more computational power, higher transmission distances, higher precision measurements with lower power consumptions. Above all, standardized intercommunication between devices and the rising need of remote access accelerated the integration of wireless networks and wireless nodes in the evolving world of Internet of Things(IoT). IoT defines a world of devices - form DYI projects to industrial controllers – that are connected and present in the Internet. Applications of IoT enabled devices to vary from environmental monitoring, home automation to energy efficiency measurements, building automations and smart cities.

One of the most interesting applications of IoT and WSN is environmental parameters monitoring of water and air.

The field of water parameters monitoring is of high interest nowadays. Research activities generate new optimizations, solutions and methods to increase reliability, simplicity and energy efficiency. In [1] the authors present a WSN based water environment monitoring system dedicated for water quality measurements. The system consists of WSN sensors, routing nodes, base stations, remote monitoring center and SMS alarms. The hardware design of sensor nodes consists of measurement transducers (pH, temperature and dissolved oxygen), an MSP430 controller as a processor module and a CC2530 radio processor. Routing nodes contain CC2530 radio controllers for 3G and inter-node communication and an ARM32 processor for processing the routes of messages. In [2] the authors present a WSN system dedicate for troughs water level measurements based on Raspberry Pi, Atmega328 and RFM95 RF transceiver. The Raspberry Pi is used for gateway building and the Atmega328 as the node controller. In [3], A.N.Parsad et al present a smart water quality monitoring system based on IoT devices. The device presented measures the pH, oxidation and reduction potential, conductivity and temperature. The built system comprises of sensors, an ADC, microcontroller, SD storage and GSM module. Another approach for building an energy efficient WSN for urban water level monitoring is described by T, Nguyen in [4]. The system is based on CC1110 hardware from Texas Instruments and uses polar power supplies and according to the results the energy efficiency design is concluded. In [5] S. Yang and Y. Pan present an application of WSN in a monitoring application of Fushun Reach River in China. The goal of their application is to measure the pollution degree of the water using sensors to detect petroleum pollutants, volatile phenols, sulfide, discharge volume, etc.

Besides water monitoring with a great field of applications, environmental measurements imply also air quality monitoring.

In [6] D. Marquez-Viloria et al show that in developing countries have urban areas without air-pollution monitoring systems. Based on their premises they propose a low-cost air pollution system monitoring system that are dedicated for indoor and outdoor air quality measurement. The product is based on ESP8266 WIFI chip with microcontroller include, GUVA ultraviolet photodiode, DHT22 for temperature and relative humidity measurement, CO MQ7 sensor, MQ131 Ozone Sensor. The platform is connecter to the internet and the data is sent through ThingSpeak IoT enabling platform. The authors show the results of measurements using the proposed system. In [7] Chien-Hao Wang et al describe the result of their research in developing a self-sustainable WSN air quality monitoring system. Sensor nodes are built with Octopus II platform, based on the ultra-low power MSP430 microcontroller from Texas Instruments. The radio chip used is CC2420 that implements IEEE802.15.4 protocol over a carrier frequency of 2.4GHz. MiCS-5521 sensor for CO concentration, and DSM501A dust and Particulate matter-PM concentration sensor are attached to the device. The energy source consists of a 12V Lead-Acid Battery, a solar panel and a charge controller. The energy harvesting solution implemented assures an energetic independency of the product.

Research work extends further and combine water and air parameters monitoring in more complex solutions. In their paper [8], Liang-Ying et al, reunite air temperature and humidity, soil temperature and humidity, light intensity and CO2 concentration under one solution for greenhouse environment monitoring. The solution is based on NRF51822 embedded ANT on-chip system with integrated 32 ARM cortex processor, compatible with Bluetooth Low Energy and ANT protocol agreement. The network sensor terminal, part of the wireless network reports the data through GPRS powered by SIM900A GSM module.

Air monitoring using WSN systems include other applications such as dangerous and hazardous situations prevention in mining zones. In [9], U.I.Minhas et al present a monitoring and event reporting WSN based solution for underground mine environments. The paper targets optimum solution for individual aspects, studies dependencies and based on the studies the proposed architecture is proposed. In the process of constructing the system design the authors take in consideration several aspects such as economical hardware design, reliable RF propagation, communication scheme for energy efficiency.

Dependent on the hardware requirements for water and air parameter monitoring, the solution can be either developing a custom build hardware platform, either using off the shelf WSN nodes with analog inputs and attaching different type of sensors. It is not easy to find nodes that can accept all types of sensors or a certain type of sensor.

In this paper, the authors present a solution to solve incompatibility between the inputs of the node and the output of the sensor. In chapter II we will show different off the shelf available programmable industrial nodes that can be included in WSN based solutions. In chapter III we will present the hardware high level architecture of an interface and signal conditioning board that is controlled by the wireless node and allows connecting multiple type of sensors (voltage output, current output, resistance output and digital sensors) to a node with one type of input. The software protocol used for controlling the extension board is presented and explained in the same chapter. In chapter IV we will present the results, intercommunication procedures at simulated hardware level and possible improvements. In chapter V we will discuss future possibilities of improvement of the architecture and the device.

II. STATE OF THE ART

From the programmability and flexibility of the nodes program, current solutions on the market of wireless nodes can be split in two main sections:

- Non-programmable sensor nodes – the nodes that have a fixed input configuration, a fixed sample rate and cannot interpret data or run complex algorithms
- Programmable sensor nodes – the nodes that have a flexible input configuration, a flexible sample rate and can run algorithms and basic mathematic functions. Besides the inputs, in the communication between with other nodes or gateways the node frame format and contents can be custom defined

Libelium [10] provides of the shelf WSN solution that contain nodes, gateways and sensors. The Waspmote plug and sense node can integrate more than 120 sensor types., has the capability of Over the Air Programming and allows the usage of external solar panel for autonomy. The Waspmote allows customization of the inputs integrating 7 Analog Inputs, SPI, UART and I2C.

The producers offer an API for developers, examples and case studies and address applications from Smart Cities and Smart Environment to Smart Metering and eHealth[10].

Another industrial WSN solution is provided by National Instruments and consists of nodes and gateways. NI offers either programable nodes that can run programs and interpret data locally, either non-programmable nodes that read the data from the inputs and forward it to the gateway. The WSN nodes are certified for industrial rating -40 to 70 °C operating temperature, 50 g shock and 5 g vibration. In this article we will focus on NI WSN-3226 4 Ch, 20-Bit, Programmable Voltage/RTD Combination Node (Fig. 1) that has four analog inputs (±10V 20 bit) and two Digital I/O channels configurable for input, sinking or sourcing output.

Fig. 1. NI Wireless Node [11]

The NI nodes can be configured to act as end nodes or routers and can work together to form a mesh network structure, allowing higher transmission distances and a more efficient usage of the resources. Programming the WSN nodes as well as collecting the data is done through the NI 9792 WSN Real-Time Ethernet Gateway (Fig. 2) that allows running complex control algorithms and integrating the data in LabVIEW projects [12].

Fig. 2. Programable Ethernet Gateway [11]

III. ARCHITECTURE AND IMPLEMENTATION

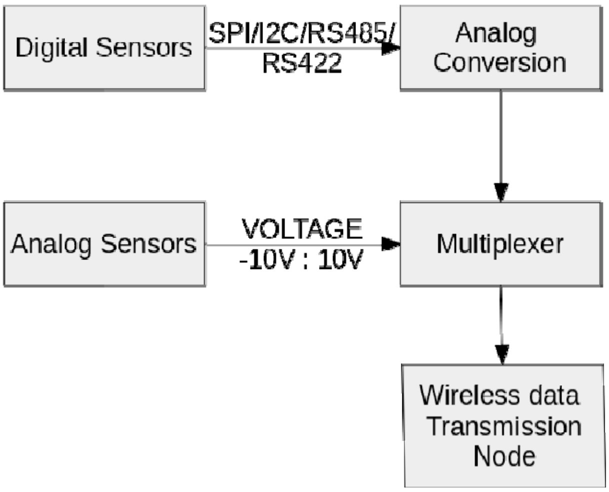


Fig. 3. Hardware Architecture

In Fig. 3 we present the overall hardware architecture that will be further detailed in this section. The Wireless Node has four analog input channels with a ±10V full scale range and a resolution of 20 bits and two digital Input/output that can be configured in either TTL mode output/input, or source/sink mode. Communication with the extension board is done through the digital channels in a request/response mode – one line acts as a CLK line and one is dedicated for data. It is designed as a low baud rate communication interface. Initially the extension board is configured as a listener, and the wireless node generates the communication frame. The data is read on the rising edge of the simulated CLK signal. Considering that both the extension board and the node implement the correct framework, the possibility of both being configured as output in the same time is low. In the case that both Wireless Node and extension board have the I/O configured as digital outputs, the entities have short circuit protection. The command communication frame states what analog inputs will be coupled to the WSN node through low impedance (100-ohm RDSon), or what digital sensors need to be read by the microcontroller and on what output will the Digital to Analog Converters will be coupled.

The extension board is battery powered from one cell LI-Po battery. The circuit allows charging the battery while the board is in operation. The first power supply generates 5V (Fig. 4) for the internal microcontroller and DAC circuit. From the 5V rail we obtain 12V through a second boost power supply and a -12V using an isolated DC to DC module. The +12V and -12V are necessary for the multiplexers to allow negative voltages down to -10V to be coupled to the WSN node.

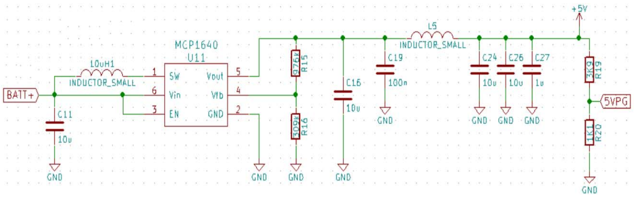


Fig. 4. 5V Boost power supply

For the conversion of the data coming from the digital sensors to an analog value that can be read by the WSN node we have used a 12-bit resolution buffered and filtered dual Digital to Analog Converter (MCP4822 – Fig. 5) circuit capable of generating voltages from 0 to 4.096V. Whenever the extension board processes and generates new date it sends a signal to the WSN to confirm the signals are steady and the outputs of the DACs are latched and have settled.

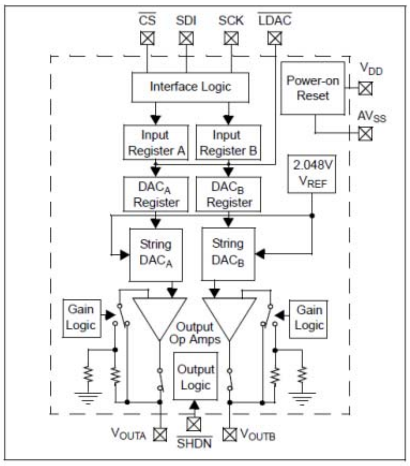


Fig. 5. MCP4822 block diagram [13]

The software implementation is based on two Finite State Machines that cycle through all the preconfigured inputs and generate the communication signals. A command is generated for the next set of inputs that need to be coupled/generated by the extension board. The command is sent to the communication board, and when the outputs are steady a confirmation signal is transmitted to the node. The FSM is represented in Fig. 6.

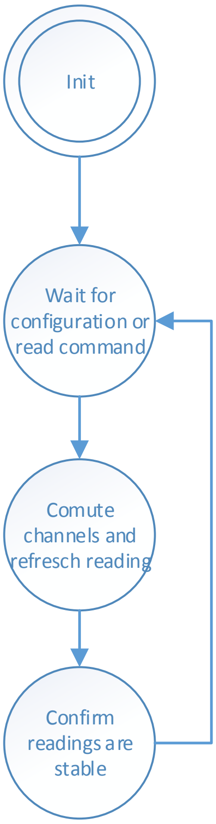


Fig. 6. Firmware state machine

IV. RESULTS AND CONCLUSIONS

We have obtained an extendible architecture that allow reading digital sensors and transducers using a node with analog input capabilities. The implementation (Fig. 7) based on the proposed architecture has been tested and we have validated the functionality of the design. The 100-ohm RDSon coupling resistance is negligible compared to the input impedance of the WSN node (1 MOhm).

For the test we have used one analog temperature sensor – LM35 [15] and one digital sensors (the extension of DST800 NMEA 0183 Depth sensor [16]) that generated through RS485 a string containing the temperature reading)

A. Case study and results

We have implemented a program for measuring using our device the depth and temperature of water using a DST800 NMEA0183 digital sensor.

Since the onboard DAC had a resolution of 12 bits, it can generate 4096 voltage values (in the range of 0 to 4.096 V). We have made a simple correlation of the range of the temperature sensor (-10 to 40 °C) with the output voltage of the DAC. In this situation, we can obtain a resolution of measurement in temperature of ±0.012 °C, below the precision of the digital value. The error introduced by converting the value from a digital representation, to a voltage and back to a digital representation is less than 5% of the accuracy. The sensor has an accuracy of ±0.5 °C and our method of data conversion generates an accuracy of ±0,512 °C.

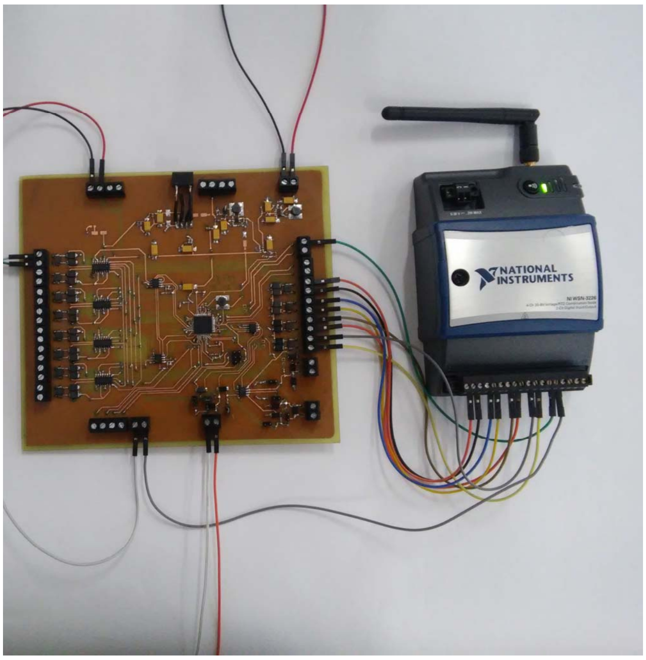
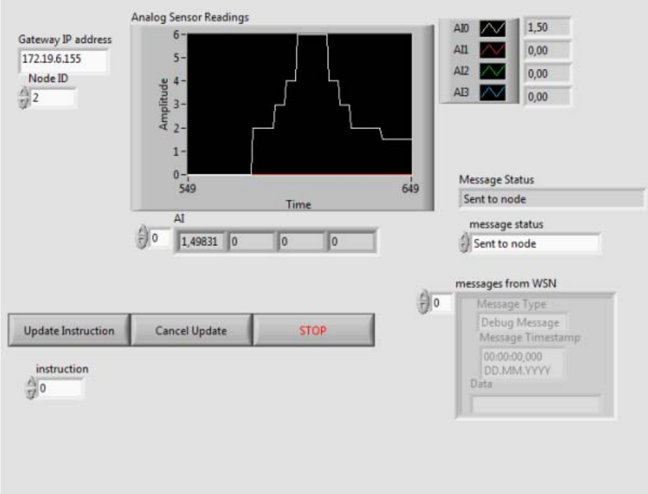


Fig. 7. WSN node and the extension board

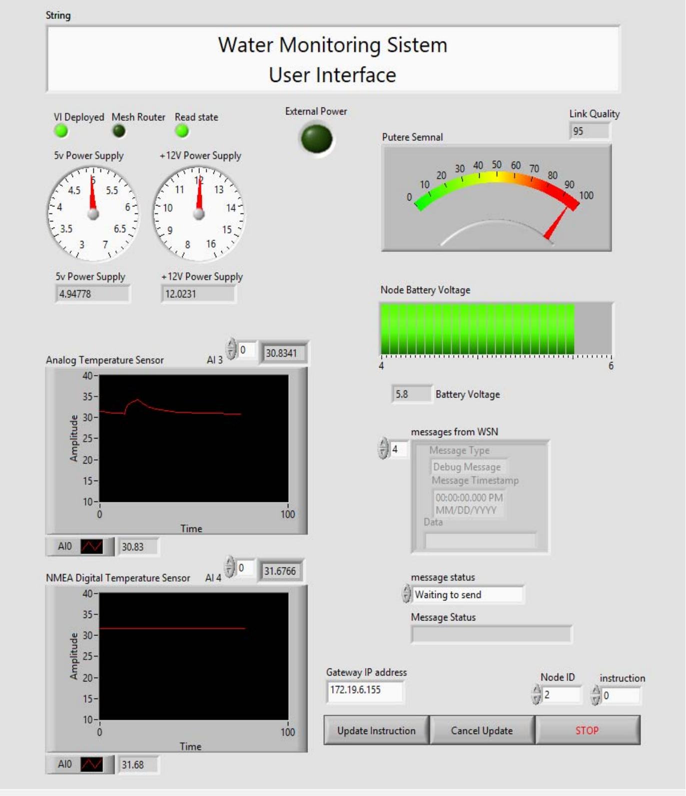
The analog data has been successfully transmitted to the WSN gateway. On the gateway and on the host computer we have presented the data in a graphical interface designed in LabVIEW [14] (Fig. 8).



Gateway IP address 172.19.6.155
Node ID 2
AI0 1,50
AI1 0,00
AI2 0,00
AI3 0,00
AI 0 1,49831 0 0 0
Message Status Sent to node
message status Sent to node
messages from WSN 0
Message Type Debug Message
Message Timestamp 00:00:00,000 DD.MM.YYYY
Data
instruction 0

Fig. 8. Basic Graphical Interface

We have further extended the application to interpret the received data and monitor all the parameters on the extension board. The user can see la feedbacks from the power supplies, if external power is applied, the state of the batteries, the signal power, link quality as well as the monitored parameters (Fig. 9)


String: Water Monitoring Sistem User Interface

5v Power Supply: 4.94778

+12V Power Supply: 12.0231

Link Quality: 95

Battery Voltage: 5.8

Analog Temperature Sensor AI 3: 0, 30.8341; AI0 30.83

NMEA Digital Temperature Sensor AI 4: 0, 31.6766; AI0 31.68

messages from WSN: 4

message status: Waiting to send

Gateway IP address: 172.19.6.155

Node ID: 2

instruction: 0

Fig. 9. Detailed user interface with all parameters

B. *Conclusions*

We have designed a low power flexible architecture that can be used for water, air and environmental parameters monitoring and allows the connection of different analog and digital transducers to analog input WSN. It can be further extended to allow more sensors and can be used in industrial environments, allowing Analog Input modules designed for PLCs to read data from digital sensors.

Thanks to the design of the power supply stage, the device can be powered by different types of batteries that are common in autonomous WSN systems – NiCad, NiMH, Li-Po, Li-Ion, Alkaline batteries and LiFePO4. With an average power consumption of less than 3mA, with a charging circuit based on a solar panel the device can operate on just 3 x R6 NiMH rechargeable batteries or one Li-Ion/Li-Po/LiFePO4 cell of at least 500mA – that can sustain the power consumption of the device during the night.

V. FUTURE DEVELOPMENT

We plan to extend the functionality and include software configurable charging circuits for the batteries. Also, we consider as a future development having a bootloader that allows different configurations on the board so that we can easily transfer the program through the WSN digital I/O lines.

ACKNOWLEDGMENT

This research is supported by the project clueFarm: Information system based on cloud services accessible through mobile devices, to increase product quality and business development farms - PN-II-PT-PCCA-2013-4-0870.

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