

## DEVELOPMENT OF HYDROGEN LEAKAGE MEASUREMENT DEVICES BASED ON WIRELESS SENSOR NETWORKS

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**Abstract:** This paper describes the wireless sensor network based measurement devices for hydrogen leakage detection and monitoring. The hydrogen is gaining much attention as a possible future substitute for fossil fuel in the transport sector but hydrogen energy should be used with caution and always involves the safety management devices. We suggest the measurement devices for hydrogen leakage based on the wireless sensor networks (WSNs). Our proposed device model supports the measurement of hydrogen leakage quantities and mobility by wireless communications.

**Keywords:** Hydrogen Energy, Measurement Devices, Hydrogen Safety

### 1. INTRODUCTION

Hydrogen energy offers the highest potential benefits in terms of diversified supply and reduced emissions of pollutants and greenhouse gases. Moreover hydrogen energy can realize the ideal fuel inexhaustibility, cleanliness, convenience. Similar to electricity, hydrogen is a high-quality energy carrier, which can be used with a high efficiency and zero or near-zero emissions at the point of use. It has been technically demonstrated that hydrogen can be used for transportations, heating, and power generation, and could replace current fuels [1]. Although hydrogen has many advantages, it should be used with caution. Hydrogen gas is combustible which has wide explosive and very fast propagation speed. For the reason, hydrogen gas has some risk which includes leakage, diffusion, ignition, and explosion in the whole process - production, transportation, and storage, thereby needs the safety device and systems.

Hydrogen sensor for leakage detection limit of the gas explosion in the concentration range of skills required to accurately detecting and works in conjunction with safety devices must be able to take immediate action.

In this paper, we describe the wireless sensor networks based devices for hydrogen leakage measuring and monitoring services.

### 2. RELATED WORKS - HYDROGEN SENSORS

A typical method of measuring the hydrogen leakage is using the detection sensor. Several types of hydrogen

sensors are in use depending on the operating conditions. Electrochemical, catalytic and thermal conductivity sensors are mainly used in industries where hydrogen risk is present [2-4]. Hydrogen detection devices themselves should not be a source of ignition and the response times of these devices should be as rapid as possible. The important performance factors that should be considered when selecting a hydrogen sensor for a specific application include the following [4]:

- *Response Time, Detection Range, Durability/Lifetime.*
- *Calibration/Maintenance, Cross sensitivity/specificity.*
- *Area coverage.*

The correct location of reliable sensors is crucial for the timely detection and warning of hydrogen leaks before an explosive mixture is formed. Recommended locations (ISO/TR 15916, 2004) for sensors include the following [6]:

- *Locations where hydrogen leaks or spills are possible.*
- *At hydrogen connections that are routinely separated.*
- *Locations where hydrogen could accumulate.*
- *In building air intake ducts, if hydrogen could be carried into the building.*
- *In building exhaust ducts, if hydrogen could be released inside of the building.*

A generally accepted and commonly used concentration level for alarm activation is 1% hydrogen (volume fraction) in the air, which is equivalent to 25 % of the lower flammability limit. This level usually provides adequate time to respond in an appropriate manner, such as system shutdown, evacuation of personnel, or other measures as necessary. For designing reliable hydrogen detection and monitoring system, the following recommendations have been made by NASA [6]:

- *Evaluate and list all possible sources to be monitored (e.g., valves, flanges, connections, and bellows) and provide valid justification for sources not monitored.*
- *Evaluate the expected response time of the leak detection system to ensure compatibility with the responding safety system.*
- *Provide visual and audible alarms as necessary when the worst allowable condition is exceeded. The*

allowable condition must still be in the safe range, but a warning indicates a problem.

- Provide portable detectors for field operations or isolated areas and permanently installed detectors for remote-automated operations.
- Utilize a program to maintain and periodically recalibrate detectors to ensure acceptable performance
- Determine the number and distribution of sampling points in the hydrogen detection system based on the possible leak rate, the ventilation amount, and the area size. Consideration should be given to methods for routing hydrogen to the detector.

### 3. DESIGN THE SENSOR CONTROLLER

The leakage detection of hydrogen is most important mechanism for its safety. Hydrogen is likely to be leaked in all process such as valves, regulators, pipelines, etc. The way of solving the hydrogen leakage problem needs various mechanisms and measure devices. First of all, the mechanism based on sensor is basic but very important. We proposes the new model of hydrogen sensor has smaller size based on CNTs has wide surface area can absorbs numbers of hydrogen for new mechanism of hydrogen detection sensor. Besides, we have been tasked the design, implementation and testing it versus the existing hydrogen sensor. Sensor types to detect the hydrogen are of various forms and are used for specific purposes. However, the existing sensors have a relatively high latency (response time, measurement time), febricity by internal heating module, and a short lifetime.

Thus, we propose a new model for hydrogen detecting sensor device in this dissertation. The main concepts of the solution the proposed sensor core are as follows:

- *Rapid absorb*: Rapid absorb is related to the response time and overall performance. The existing hydrogen sensor can detect gas within 1~3 second.
- *Quick response*: Quick response depends on the response of the first absorption. Hydrogen can affect the system with a small amount of volume (4 vol. %) and is an important measure.
- *High density*: a sensor with a high density is able to make a smaller size through turning up the absorption volume per unit of extent and making it efficient.
- *Low Power Profile*: most of the existing sensors are operated at a relatively high voltage, such as DC 12~24V. Moreover, several sensor types, such as heat conduction sensors, have a short lifetime.

To make a full functioning device that runs independently, a sensor controller that gathers data and controls itself or another actuator device by electric signals such as voltage and current is needed. Existing measuring devices for hydrogen detection are relatively large in size and are installed in a fixed area. These devices are not easy to install with respect to small mechanical components such as valves or gas regulators. Therefore, the development of a hydrogen measuring machine is required. For solving these

problems, we are approaching some suggestion with micro-controller based control mechanism.

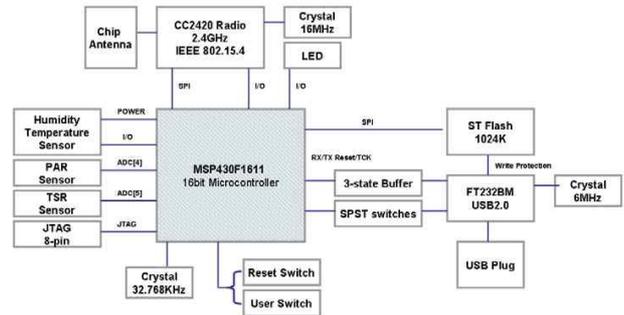


Figure 1. Block diagram – MSP430 [7]

First, we have been approaching the signal processing from analogue output signal of proposed sensor core. The challenge in designing the interface between a sensor and the analogue-to-digital (A/D) converter of a system was to obtain an accurate real world signal with the limitations of low power and reduced voltage swings. Given that the sensor-core's initial response to any exposure of hydrogen was distinct and immediate, this intrinsic characteristic served as an ally for the successful detection of hydrogen. Since the sensor-core's resistance changed with respect to how much and how long the device has been exposed to hydrogen, the most popular and accurate way of detecting resistance changes was through the use of Wheatstone Resistive Bridges, as illustrated in Figure 2.

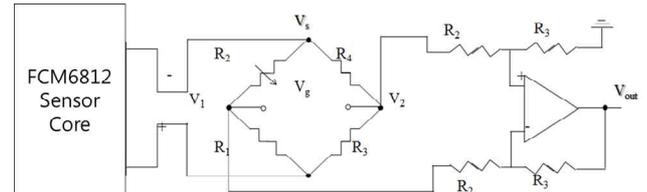


Figure 2. Sensor controller

With no hydrogen present, the passivated and exposed sensor-core were similar in resistance, and the output voltage of our sensor to A/D converter interface was approximately 0 V, which is very close to the ideal condition. Using the combination of a Wheatstone Resistive Bridge, and a difference amplifier as shown in Figure 2 an extremely low power and portable interface for the detection of hydrogen was designed. The Wheatstone Resistive Bridge and the Difference Amplifier were combined through an additional non-inverting gain amplifier stage to buffer, amplify, and provide a high impedance input to the Wheatstone bridge before the signal from the resistive bridge was processed by the difference amplifier. This topology of amplifiers is also known as an instrumentation amplifier. MAX4289 Op-Amps from Maxim-IC were used as the instrumentation amplifier. These Op-Amps were chosen due to their low power requirements (1.0 V/9 IA) and for their typical low input offset voltage of 200 IV. By applying a reference voltage of 2 V on the supply voltage, and using the on-board 10-bit A/D converter of a low power micro-controller, the MSP430, the A/D converter had a

resolution of about 2 mV, with 1024 digitized voltage levels between 0 and 2 V. The output of the interface met this requirement and provided at least a 2 mV/X output. Given the A/D resolution of 2 mV, the sensor and sensor interface were capable of detecting the presence of at least 10 ppm of hydrogen.

The micro-controller was programmed to run as a state machine, and had two different re-programmable modes of operation. In each mode of operation, the micro-controller operated within the following states: initialize, collect data, transmit data, and sleep. The first mode of operation was for the level monitoring of hydrogen. This mode ran through each state until a discernable threshold of hydrogen was detected. This threshold was set at a level that hydrogen concentration would be high enough to pose serious danger. Once this level of hydrogen concentration was detected, the micro-controller forced the RF front end to transmit an emergency pulse to the central monitoring station. The second mode of operation was for data transmission. In this mode, the micro-controller collected data from the sensor interface, and queued this data to the RF front end to be transmitted to the central monitoring station. This mode was for a constant tracking of hydrogen levels, while the level monitoring mode was to alert the end user that hydrogen has indeed been detected. The state flow diagrams for the level monitoring mode, and data transmission mode are shown in Figure 3.

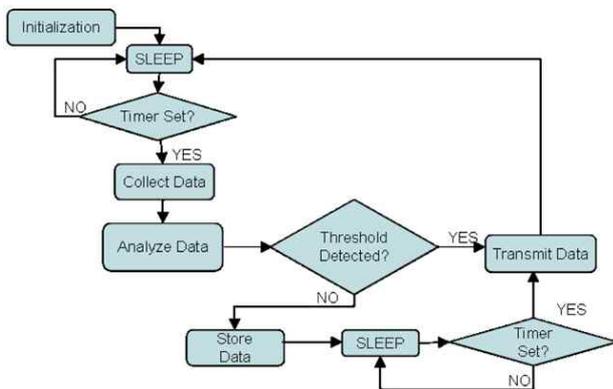


Figure 3. Operation algorithm

#### 4. WIRELESS BASED MEASUREMENT

The aim of using sensor network is to implement a real-time monitoring and control system for hydrogen leakage. Our proposed sensor network model that supports the real-time leakage monitoring is based on some sensor devices and gateways by running peer to peer network. In this experiment, our measuring point is the real-time processing such as detection the gas, determine the dangerous situation, running to actuator like valves, alarms when hydrogen is leaked. For implementation, we made a Telos-B wireless sensor device include TI-MSP430 and CC2420 (2.4Ghz Zigbee support). Figure 4 shows the prototype devices of wireless based measurement.

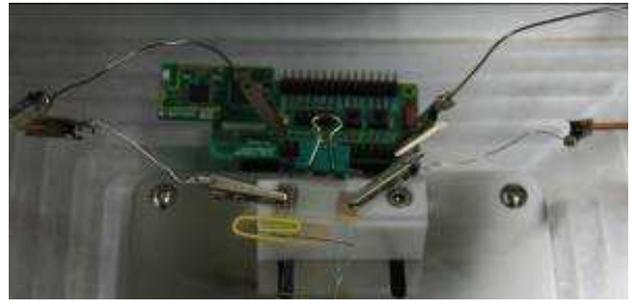


Figure 4. hydrogen leakage devices

We tested the hydrogen sensor networks to verify the performance through experiment of three issues. First issue is the sensor output, second is the network transmit, and last is the power consumption for supporting network lifetime. Figure 5 and 6 show the network packet monitoring and debugging screen.

```

$ java net/tingos/tools/Listen
serial@COM8:57600: resynchronising
7E 00 0A 7D 1A 01 00 72 01 01 00 AF 01 A8 01 B0 01 B0 01 A8 01 B0 01 B0 01 A9 01 B0 01 B0 01
7E 00 0A 7D 1A 01 00 7C 01 01 00 AA 01 AF 01 AF 01 AA 01 AE 01 AE 01 AA 01 AD 01 AE 01 AC 01
7E 00 0A 7D 1A 01 00 86 01 01 00 AD 01 AD 01 AD 01 AC 01 AD 01 AE 01 AA 01 AD 01 AD 01 A9 01
7E 00 0A 7D 1A 01 00 90 01 01 00 AE 01 AE 01 A8 01 AE 01 AE 01 A7 01 AF 01 AF 01 AC 01 B0 01
7E 00 0A 7D 1A 01 00 9A 01 01 00 AF 01 A8 01 B1 01 B0 01 A9 01 B0 01 B0 01 A9 01 B1 01 B1 01
7E 00 0A 7D 1A 01 00 A4 01 01 00 A9 01 AF 01 B0 01 AA 01 AE 01 AE 01 AC 01 AD 01 AD 01 AB 01
7E 00 0A 7D 1A 01 00 AE 01 01 00 AC 01 AD 01 AC 01 AA 01 AD 01 AC 01 A9 01 AE 01 AD 01 A8 01
  
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Figure 5. Data gathering by debug mode

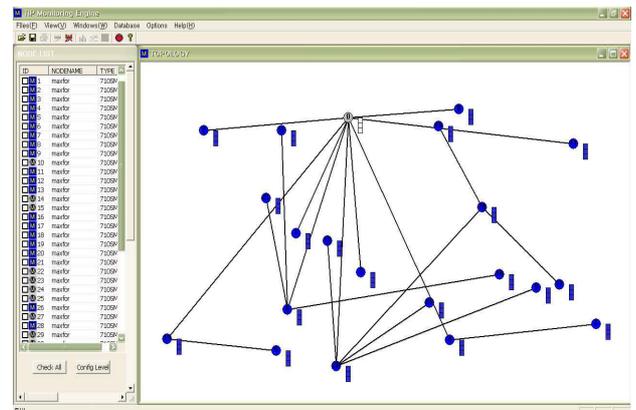


Figure 6. Network connection test

To verify its performance, we have tested the prototype sensor with the following steps:

- 1) Installation sensor and connect with electrode
- 2) Provide voltage source in chamber
- 3) Provide the pure hydrogen gas 10 ccm (99.9999 %) per unit by gas flow controller
- 4) Monitor and logging the data
- 5) Observing the variation with rising steps of voltage

Figure 7 presents hydrogen leakage monitoring results.

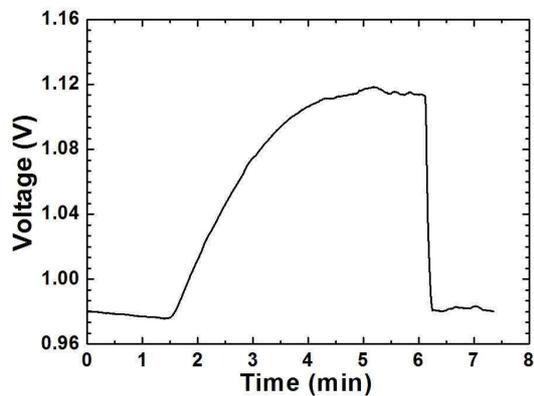


Figure 7. Leakage test results

## 5. CONCLUSION

Hydrogen energy systems is powerful and new energy source replacing with fossil energy. However, All hydrogen energy system includes producing, storage, transportation, usage always involves the safety technology with planning of policy. Hydrogen gas itself has flammability with 4 ~ 75 % concentration in air mixture. That kind of hazard starts at leakage problems in facilities system. Recently, research institute in developed country like DOE(Department of Energy), HYSAFE, NEDO has been developed the technical problems, hydrogen standard code and legal information of for the safety management. Existed monitoring system and safety management have many improvement focuses on information technology. For example, detector for high performance leakage, real-time monitoring system based on sensor network, and integrated safety management is needed.

In this paper, we proposed the hydrogen leakage measurement devices based on the wireless sensor networks. Our proposed model has some benefits than existing control system: First, the performance of our model has relatively rapid response time than existing sensors. Second, digital acquisition data enables to perform by signal processing through A/D conversion Third, it supports the wireless sensor network enabling to communicate with wireless devices for real-time processing.

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### References

- [1] A. Dicks, "Hydrogen Energy Research and Collaboration in Australia", Proceedings WHEC2010, Vol, 78, No.4, pp. 473-477, 2010.
- [2] P. K. Sekhar, E. L. Broshaa, M. A. Nelsona, T.L. Williamsona and F.H. Garzona, "Development and testing of a miniaturized hydrogen safety sensor prototype", Sensors and Actuators B: Chemical Vol. 148, Issue 2, pp. 469-477 , 2010.

- [3] W. Hoagland, D.K. Benson, R.D Smith, "Novel wide area hydrogen sensing technology", Second international conference on hydrogen safety, September 2007.
- [4] W.J. Buttner, M.B. Post, R.Burgess, C. Rivkin, "An overview of hydrogen safety sensors and requirements", International Journal of Hydrogen Energy, Vol. 36, Issue 3, pp. 2462-2470, 2011.
- [5] Hysafe, "Biennial Report on Hydrogen Safety", Retrieved on 25th, March 2011 from <http://www.hysafe.org/BRHS>.
- [6] U.S. Department of Energy. Safety planning guidance for hydrogen projects, Retrieved on 25th, March 2011 <http://www1.eere.energy.gov/hydrogenandfuelcells/codes/ovoversig.html>.
- [7] Texas Instrument, MSP430 Microcontroller, [http://www.ti.com/lscs/ti/microcontroller/16-bit\\_msp430/overview.page?DCMP=MCU\\_other&HQ=msp430](http://www.ti.com/lscs/ti/microcontroller/16-bit_msp430/overview.page?DCMP=MCU_other&HQ=msp430)