An IoT Node with Organic Pressure Sensor for Structural Health Monitoring System

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***Abstract*—In this paper, we develop an IoT node with an organic pressure sensor for structural health monitoring (SHM) system. A 100μm-thick polyurethane film was sandwiched by top/bottom electrodes to complete the flexible pressure sensor fabrication. IoT sensor nodes using available low-cost components in the market were designed for the SHM system. Sensors collect data about the state of structural infrastructures and send information to a virtual private server through a network gateway. We also built a website on the hosting server for the purpose of SHM including monitoring signals, storing data and other administration tools. Experiment results show that the IoT node with organic pressure sensors has high potential in SHM application. The organic pressure sensor manufacturing steps and the SHM system will be described in detail in this paper.**

Keywords: IoT node, organic pressure sensor, structural health monitoring

I. INTRODUCTION

In recent years, a pressure sensor using polymer materials has received much attention among academics and industry due to its unique advantages, including low-temperature processing, low manufacturing costs, mechanical flexibility, and the potential to work in a large area [1-6]. These characteristics indicate the potential to construct the next generation of Internet of Things (IoT) sensing nodes, where sensors are required to not only be low-power and low-cost, but also, be compatible with many surface types.

Meanwhile, IoT-oriented wireless networks using the Wi-Fi, Zigbee and LoRa have achieved promising results [7, 8]. However, the disadvantages in the above works are often limited in transmission distance due to the availability of internet connection at the deployment location of the devices.

Therefore, in this paper, we present an IoT node with organic pressure sensors for the structural health monitoring system. The capacitive pressure sensor was made of a polyurethane film sandwiched by top/bottom electrodes by lamination. Data from sensors is collected by the DAQ module and transmitted to users via the internet. We have also built a website to store sensed data, display real-time results, and perform other administrative tasks. Users can access this website to track the results at any location with the Internet connection. Initial testing shows that the system has a high potential for tracking the health of buildings. Moreover, the system can be easily modified and supplemented for other tasks such as health care and environment monitoring.

The remainder of this paper is organized as follows. Section II presents the experiment procedure of the proposed organic pressure sensor for SHM IoT node. Then, Section III shows the results and discussions. Finally, the conclusion and future plan are included in Section IV.

II. EXPERIMENT PROCEDURE

Firstly, Fig. 1 shows the illustration of the structure of the capacitive pressure sensor and its photo in both normal mode and flexible mode. The construction steps of the sensor were presented in our recent work [9].

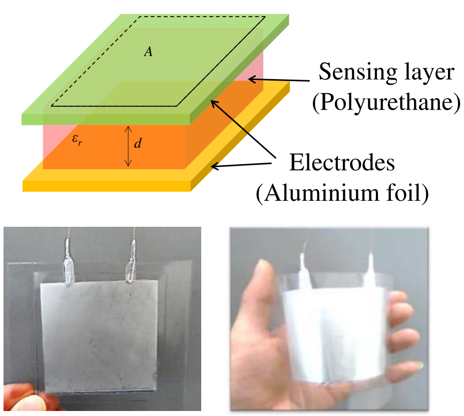

Fig. 1. Structure (the above) and photos of the capacitive pressure sensor in the normal mode (the below left) and flexible mode (the below right).

In short, a sensing material of Polyurethane (Takeda Sangyo) with 100 μm thickness was sandwiched between two electrodes of Aluminum foil, following by laminating at 80°C for twice. The sensor size is 70 × 70 mm^2. For protection, the sensor was also covered with a plastic film by the lamination method at 80°C. Finally, copper wires were attached to electrodes to form the connecting leads of the sensor. The sensor characterization was performed using a universal compression testing machine (UH 500-kN, SHIMADZU) and a capacitance meter (YF-150) at room temperature. A wide working range of the sensor to 0.65 Mpa and the best sensitivity of 8.10^{-2} kPa^{-1} were recorded. The capacitance-pressure characteristic of the sensor was present in Fig. 2. At the beginning of the characteristic curve from 0 to 0.1 N/mm^2 with the high

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slope, the sensor can be used for applications that require high sensitivity such as in the SHM system. On the contrary, the back part of the curve has low sensitivity but wide working range, the sensor can be used for applications with extensive pressure up to 0.65 N/mm^2, and car detection could be a good application [9].

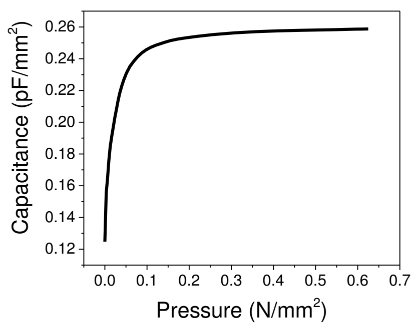

Fig. 2. The capacitance-pressure characteristic of the sensor.

The general configuration of an IoT node is presented in Fig. 3 [10], data from sensors is collected and sent to users via the internet. But in some IoT nodes, for example, when Wi-Fi, LoRa and Zigbee are used, the communication range between IoT nodes and users depends on the availability of Internet connection [7, 8]. This problem can be tackled by using the Universal Mobile Telecommunication System (UMTS)/3G unit as a gateway connection. Since UMTS signals are almost ubiquitous today, the communication distance is theoretically unlimited. Moreover, when the sensed signal is digitized and transmitted over the Internet, one can easily add data management programs as well as other administration tools. Fig. 4 illustrates our structural health monitoring system.

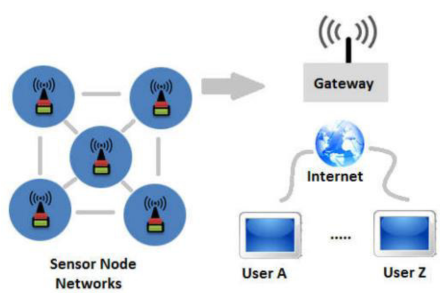

Fig. 3. The general structure of the wireless sensor networks toward the Internet of Things [10].

In our proposed system, data from sensors is collected by the data acquisition module (DAQ) and sent to users via the internet thanks to the UMTS/3G unit. We also built a website to save sensor data, live-monitoring and fulfill other administration tools.

The DAQ module was constructed basically on the STM32 chipset family (AMR Cortex-M3) with integrated analog to digital converter. STM32 chipset can support up to 9 sensors per node and easy to upgrade the node capacity. UMTS/3G unit plays as a gateway to provide a connection to the internet. We choose the integrated circuit board Sim5320E as the UMTS/3G unit. Sim5320E board is flexible in connection, GPS support for position location and efficiently compatible with telecommunication service providers.

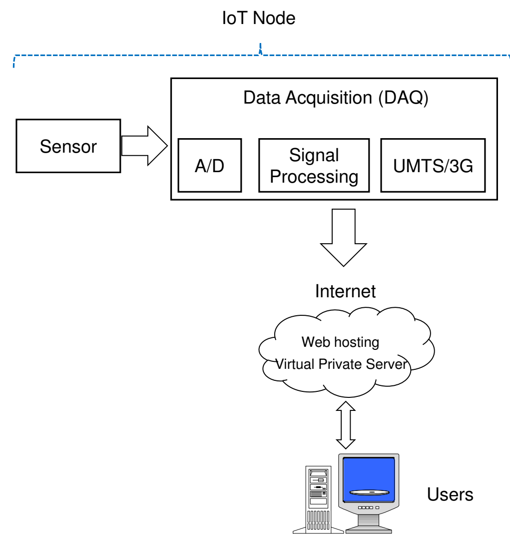

Fig. 4. Structural health monitoring system with IoT nodes.

III. RESULTS AND DISCUSSION

For the purpose of the field test with the proposed IoT node using the flexible pressure sensor, a completed structural health monitoring system using the sensor and a wireless DAQ was designed with a circuit diagram presented in Fig. 5. In addition, a website was built to store information from sensors and perform user's interaction. It can be seen from the diagram that the NE555-based oscillator is utilized to convert the sensing capacitance to a pulse train. The capacitance of the sensor is computed from the frequency value of the pulse train with a microcontroller of STM32F103C8T6 and sent to the website via a UMTS/3G module of Sim5320E. A constructed website allows real-time display of the sensed signal and saves data in a virtual private server for further analyses.

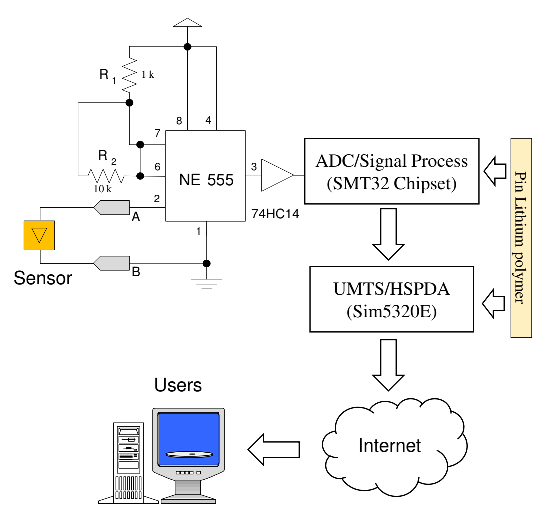

Fig. 5. DAQ's circuit diagram of the SHM system.

Figure 6 describes the DAQ in more detail after being designed. As can be seen in the figure, the printed circuit board of the STM32 chipset and Sim5320E integrated circuit are assembled into one block and placed in a protective case. As mentioned previously, the integrated circuit board Sim5320E with the built-in GPS function makes a very convenient for obtaining information about the location of the device. The DAQ blocks have compact dimensions of (6 × 10 × 4) cm^3.

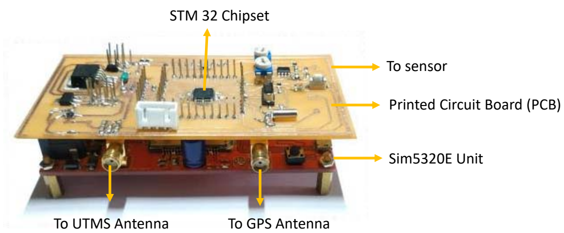

Fig. 6. Picture of the DAQ module with dimensions (6 × 10 × 4) cm^3.

The operation flow of the system in company with software is described in Fig. 7. When the system starts, the DAQ is configured and connected to the website. The signal from the sensor is continuously sent to the embedded processor where it is computed and then forwarded to the website through UTMS/3G unit. The website displays the signal and storage the sensed information. This loop ends when we stop the software. The website provides options consist of plot data, save data and open (previous) data. Sensed data can be export into Excel format for further analysis.

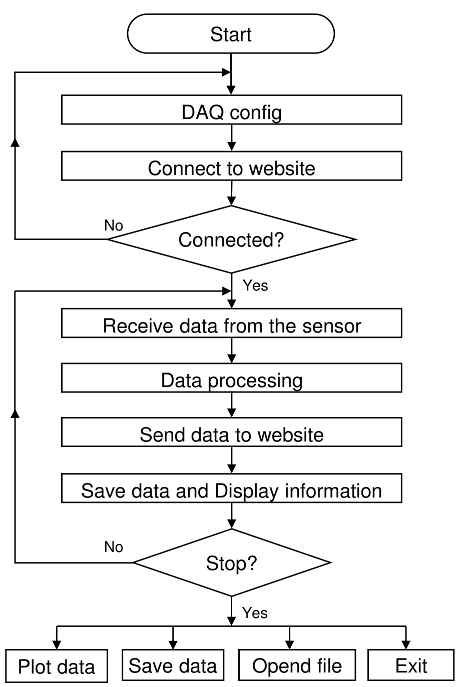

Fig. 7. The operation flow of the proposed system with the integrated software.

On the website, the menus to manage users, devices, and data were built. The highest-level admin account can create and provide access authority to other user accounts. Users can then connect to the website to inquire about the information on the structural health monitoring system. Figure 8 shows the sensed signal displayed on the website with two different monitoring times.

With the sensed information stored on the virtual system server, we easily develop flexible management tools such as setting alarm levels on the signal received from the sensor; automatically send warning email; or developing other applications in the future.

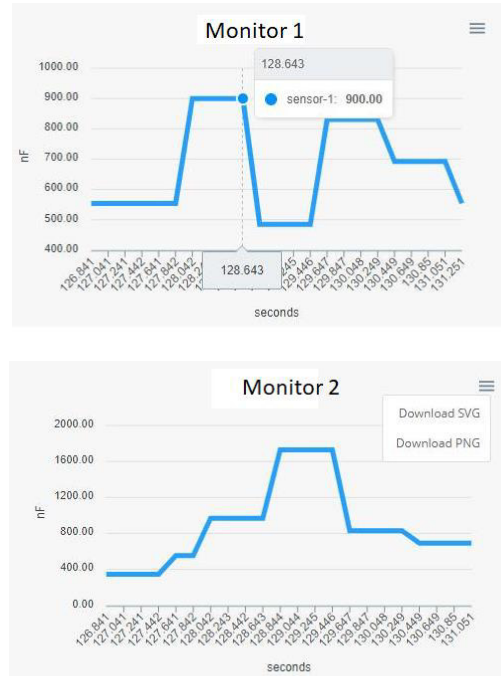

Fig. 8. Two different monitor signal display on the website.

IV. CONCLUSIONS

In this paper, we have demonstrated an IoT node with an organic pressure sensor for the structural health monitoring system. A 100µm-thick polyurethane film was sandwiched by top/bottom electrodes to complete the flexible pressure sensor fabrication. DAQ module has been designed to collect data from sensors, the sensed data is then transmitted to the internet via the UMTS/3G unit. We have developed a website to display real-time collected information and develop other administration tools. Data on the SHM system can be accessed by users at any location with an internet connection. The SHM system can be easily modified and supplemented for other tasks such as health care and environment monitoring.

ACKNOWLEDGEMENT

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