Wireless Sensor Prototype for Industrial Harsh Environments

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ABSTRACT: *The overall goal of the ECSEL project MANTIS is to provide a proactive maintenance service platform architecture based on Cyber Physical Systems. Proactive maintenance can be regarded as upgrade of conventional preventive and predictive maintenance and goes further by focusing on problem causes. In this way, problems are settled before they actually occur. The MANTIS project comprises eleven distinct industrial partners and deals with maintenance use cases in different environments (e.g., industrial machines, vehicles, renewable energy assets). An important issue of the MANTIS project is provision of reliable communication. In this paper we present a solution of wireless pressure sensor developed for possible replacement of the existing cable-connected sensors in a harsh industrial environment.*

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1. Introduction

Cyber-Physical Systems (CPS), which represent the next generation embedded intelligent ICT systems, are characterized by large numbers of tightly integrated heterogeneous components, which may dynamically expand and contract with each other. Multiple sensors and actuation units that gather, process, exchange and use information bring together the world of computing and communications with the physical and biological worlds [1]. CPS components are collaborative, autonomous and provide computing and communication, monitoring/control of physical components/processes in various applications. The concept of CPS is being widely applied in industry, energy economy, health care, to mention just the few most prominent examples.

While CPS are known to be difficult to analyze due to their increasing complexity, the maintenance of CPS-based industrial systems represents a great challenge. In the near future, maintenance of industrial systems will change from traditional monitoring, based on the detection of malfunctions, to advanced techniques that prevent malfunctions by predicting the faults. To this day, four different maintenance plans are used: reactive maintenance, preventive maintenance, predictive maintenance and proactive maintenance [2].

In the case of reactive maintenance, the equipment is replaced or repaired only after it breaks. This approach has the advantage of minimizing the manpower to keep things running. Disadvantages are unpredictable production capacity and high overall maintenance costs.

In preventive maintenance, maintenance tasks are performed periodically, based on specific time period or the amount of working hours of machine use. The drawback is that the production is stopped during the maintenance. On the other hand, the equipment lifetime is prolonged and the probability of malfunction is reduced [3].

Predictive maintenance or condition-based maintenance, relies on physical measurements of the equipment conditions, such as temperature, vibration, noise, lubrication and corrosion [4]. When these measures reach a certain threshold, preventive maintenance task is applied.

Proactive maintenance benefits from the preventive and prediction methods and goes further by focusing on problem causes. In this way, problems are settled before they actually occur. Proactive maintenance is a constant process of operation improvement that starts at the early design phase and comprises the whole periodic life cycle analysis. By employing prediction methods it relies on constant condition monitoring and evaluation to avoid machine failures. Condition monitoring is achieved through extensive sensor data collection and analysis [5].

The overall goal of the MANTIS project (http://www.mantisproject. eu/) is building a maintenance service platform that will enable proactive maintenance strategies in different environments (e.g., industrial machines, vehicles, renewable energy assets). For this purpose, advanced data monitoring, communication and analytics is required. Since the maintenance service platform will operate in different environments including harsh conditions, ensuring reliable communication is one of the major issues. In the following we present a solution of wireless pressure sensor developed for possible replacement of the existing cable connected sensors in a harsh industrial environment.

2. Wireless Sensor Prototype

2.1 Sensor

Sensor prototype is based on HYB pressure transducer for differential wet-wet applications. It is a new generation of ceramic pressure sensors made with low temperature cofired ceramic (LTCC) technology using piezo-resistive principle to detect the pressure. The LTCC material is compatible with many types of aggressive media like water, hydraulic oils, diesel and others, which makes the sensor suitable for pressure measurements in harsh environments. Special protection of the piezo-resistors also makes this sensor suitable for wet-wet applications. High performance and accuracy are achieved with the special sensor construction, which allows this sensor to be used in many applications, and with its compact and convenient design it is very suitable for OEM users requiring use in harsh environment. The output signal from the sensor is analog and digital. The HPSD 7000 analog output signal is amplified and temperature compensated from 0 to 70°C with signal conditioning electronics.

Figure 1. HPSD 7000 pressure sensor

The digital output signal is available via standard I2C communication with default slave address 0x78 (1111000b). Pressure and temperature output signals form HPSD7000 pressure sensors are 15 bit values from the data acquisition output register. Data transfer is initiated by I2C master with the start condition. followed by 7 bit slave address (factory default is 0x78) and data direction bit R/W (for read data R/W=”1”). Slave confirms this address with acknowledge (A) bit followed by pressure data as 2 byte value, MSB first and temperature data as 2 byte value, MSB first. Master must confirm each received byte with acknowledge bit and terminate the data transfer by sending the stop condition.

Master receives pressure data as a 15 bit values which can be converted to actual pressure value with pressure units in mbar using simple linear transformation using data from the datasheet for Pmin, Pmax, Dmin and Dmax, where values are min pressure (mbar), max pressure (mbar), max digital pressure (counts) and min digital pressure (counts), respectively.

$$S = \frac{Dmax - Dmin}{Pmax - Pmin}$$

$$P = \frac{D - Dmin}{S} + Pmin$$

2.2 Power Management

Sensor is powered by small Lithium battery charged via standard USB connector, commonly used as a mobile phone charging device. The electronics is supplied at 3,3V. The Lithium battery has own protection circuit to avoid over-charge, over-discharge, over-current and short circuit conditions which may permanently damage the battery cell. The cell voltage could be over 3,3V and below 3,3V during the discharge cycle. This requires Buck-Boost DCDC converter. Due to low power overall consumption, the synchronous buck boost converter was selected with maximum efficiency 97% at lower currents in the range of 100mA. The device operates from 0.65V to 4.5V input supplying max. 200mA of current from single battery cell. No other power management was implemented on the prototype. The power switching was done with usual mechanical SPST switch.

2.3 Wireless Interface

The wireless part of the sensor is based on ESP8266 from Espresiff in the form factor of small WiFi Module. It is a self contained SOC with integrated TCP/IP protocol stack with additional interfaces to give the device access to WiFi network. The module has a powerful enough on-board processing and storage capability that allows it to be integrated with the HPSD7000 sensor through its GPIOs. Its high degree of on-chip integration allows for minimal external circuitry and occupying minimal PCB area.

2.4 Software

WiFi module operates as an Access Point by setting up a network of its own, allowing other devices to connect directly to the sensor. The WiFi client connects to the SOC and exchange packets via User Datagram Protocol (UDP). This represents lowest possible load to the sensor, client and allows low latency. The drawback is lack of control mechanisms when packets are not delivered. The tradeoff between data loss and latency seems to be optimal for such short range peer-to-peer communication.

Prototype was tested using smart phone with installed “UDP terminal” application. First, the phone is connected to the access point using default password.

Then UDP terminal application is started. Packets are sent from phone to sensor on port 4096 and received by phone on port 11000.

When the letter “P” is sent with UDP packet on port 4096, the sensor returns pressure readout on port 11000. It is up to the client application to calculate the pressure from the readout.

2.5 Hardware prototype

The prototype was developed and tested using multi-module stack shown in Figure 5.

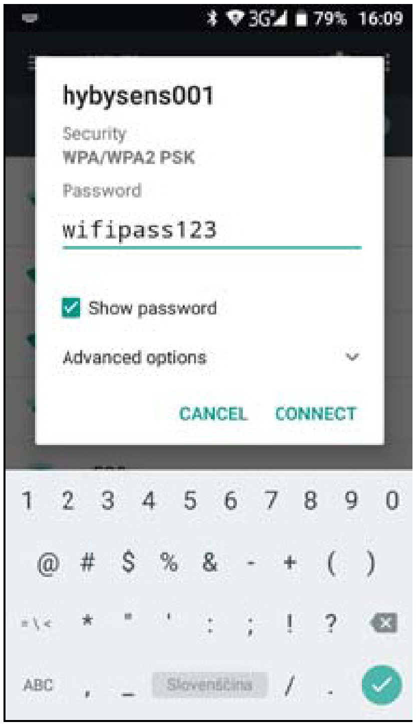

Figure 2. Communication start dialog

Figure 3. UDP terminal application

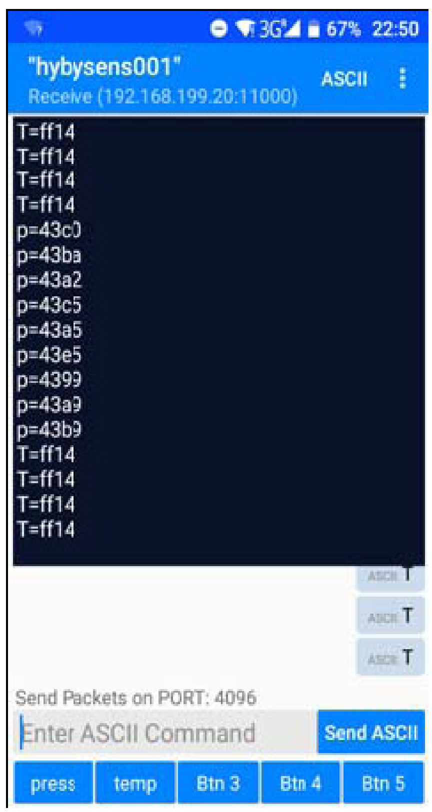

Figure 4. Pressure sensor readouts

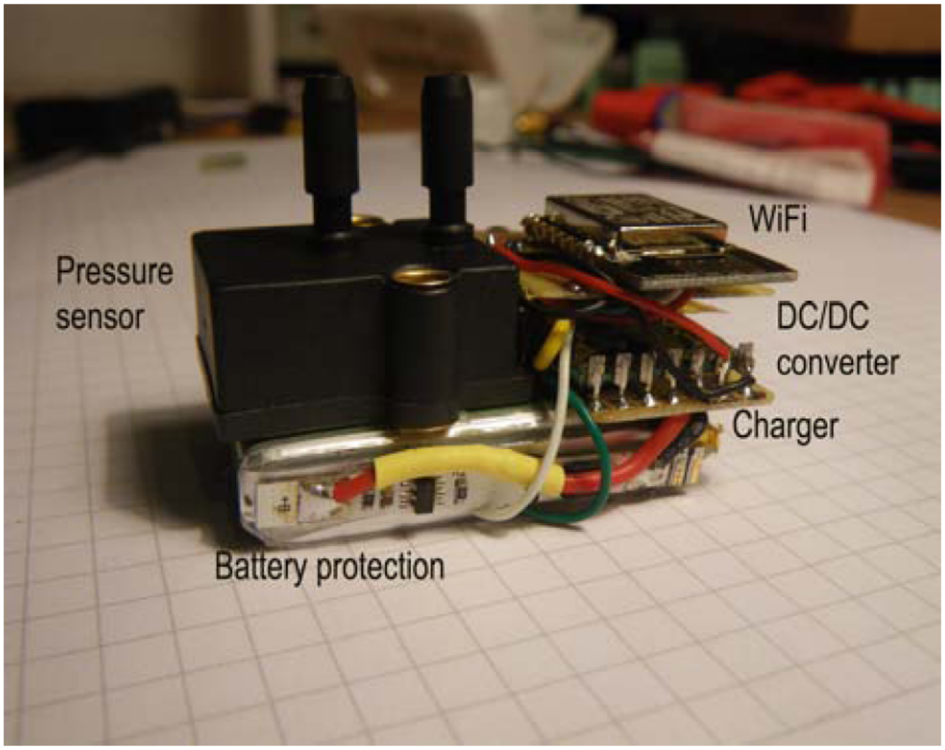

Figure 5: Wireless pressure sensor prototype

Preliminary prototype was assembled inside 3D-printed plastic housing as shown in Figure 6.

Figure 6. 3D model of the housing, which was printed using 3D printer and PLA plastic material

2.6 Extending the Range of the Wireless Module

The on-board antenna has potentially low range, especially indoors. Some preliminary experiments have shown the indoor range of about 20m when sensor and client were placed in the same room. When obstacles, like human body, wall, doors or other objects were placed in the signal propagation path, the range was significantly lower.

Possible improvement is additional antenna. The module used in the prototype was ESP8266-12E with PIFA (Planar Inverted »F« Antenna) integrated on the module itself. Modules with the same functionality and connector for external antenna exist. Most widely used is module ESP8266-05, which has »u.Fl« type of antenna connector. Such small connector is not suitable for direct antenna connection and requires some adapter. The adapter has u.Fl connector on one side and SMA or similar connector on the other side of the coaxial cable. The SMA connector is more suitable for integration on the sensor housing and sealed against external environment.

One example is shown in Figure 7. Advantage of such adapter is the possibility to attach external antenna for 2,4GHz or connect remote antenna with coaxial cable between SMA connector and antenna location.

Another option to improve the wireless sensor range is to use larger patch antenna, which is placed outside the housing. Advantage of this lies in easier sealing against environment (dust, moisture, water). The main disadvantage is larger dimension.

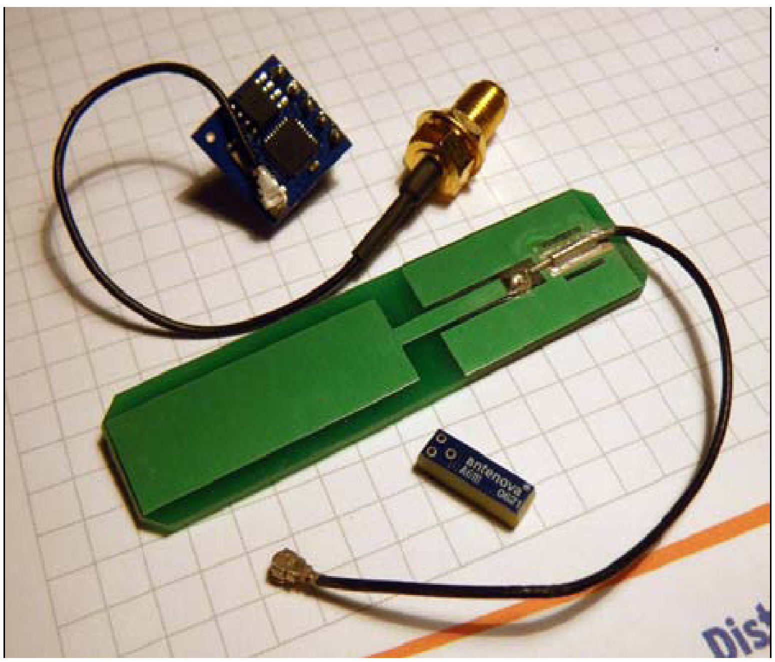

Figure 7. External antenna options: adapter cable (above), larger patch antenna (middle) and SMD solderable antenna (below)

3. Conclusions

The presented pressure sensor prototype has been developed for the proof of concept for possible replacement of wired sensors in existing industrial use case installations. Initial test is planned to be carried out at Philips shaver production plant.

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