Sensors & Transducers, Vol. 197, Issue 2, February 2016, pp. 28-33

Sensors & Transducers

http://www.sensorsportal.com

Enhanced Environment Interaction with Use of RFID Smart Labels

Nejc SUHADOLNIK, Tilen SVETE and Anton PLETERSEK
ams R&D, Tehnološki park 21, 1000 Ljubljana, Slovenia
Tel.: +386 1 7772770, fax: +386 1 281 1184
E-mail: nejc.suhadolnik@ams.com

Received: 30 December 2015 /Accepted: 29 January 2016 /Published: 29 February 2016

Abstract: Smart labels are devices with sensors which can interact with existing RIFD (radio frequency identification) infrastructure. Sensors can be integrated in tag chips or can be connected externally. Smart labels have been used in numerous applications to improve transportation and product control. In this work we have summarized some of our applications in which smart tags are used to enhance interaction with environment. Smart labels can be used to control temperature in fish supply cold chain, control fruit ripening process in plantation, control medical staff disinfection in hospitals or be used to measure sweat contents on a patch worn on human skin. We presented a smart tag with digital sensor interface and two example sensor nodes. First with 4 environmental sensors and second with accelerometer and gyroscope. The sensor nodes have been used for wireless data collection. *Copyright © 2016 IFSA Publishing, S. L.*

Keywords: RFID, Smart tag, Contactless sensors, Data logging, Energy harvesting.

1. Introduction

Integrated functions in a single chip tag enables contactless measuring, logging of transport conditions, and verification of the environmental impacts on items. Thus, physical parameters like temperature, light, time stamp, humidity, chemicals, pressure, stress, etc. can be successfully acquired and stored in a so-called - Smart Active Label (SAL), also named a smart tag, which is mounted as a label on palettes, items, etc. It enables contact-free communication with the readers of different producers, as a whole - either UHF RFID (Ultra High Frequency RFID) infrastructure that is conformable with the international standards EPC Gen2 and ISO18000-6c or HF RFID (high frequency RFID) that is compatible to ISO 14443A/B, ISO 15693 or FeliCa standards. All these are standards which describe the signals, commands and communication protocols that are built into the RFID infrastructure reader and tag chips.

With integration of RFID readers into smart phones use cases for smart labels have extended from transportation business environment to everyday life. Smart tags with various sensors can be used in passive i.e. battery-less mode to wirelessly measure different environmental quantities. Measured values can give user additional information about things equipped with smart labels. This information can be used to enhance user interaction with things and environment. Smart label with logging functionality can give user even the information about the past of an item with the attached smart label.

Work in this paper has been partly presented at International Conference on Sensors Engineering and Electronics Instrumental Advances (SEIA) in Dubai on 21st and 22nd November 2015 in presentation entitled 'RFID Smart Sensors for Enhanced Interaction with Environment' [1].

Paper is organized in four sections. Section 1 is introduction in Section 2 some use cases for smart tags are described, in Section 3 an example smart tag with environmental sensors is presented and accompanying measurements are shown. In Section 4 second example with accelerometer and gyroscope is presented. Section 5 is conclusion.

2. Use Cases for Smart Tags

Smart tags with logging functionality can be used to control temperature in cold or hot supply chain. With built in threshold function the smart label can deliver simple information weather temperature was below or above a preset threshold. Temperature plots are also available for whole duration of transportation but are limited by sample time and tag's internal memory size. It has been shown that smart tags can be used for monitoring temperature of fish supply cold chain [2].

In another example a smart tag was used to monitor apple ripening process. During the ripening process, the starch in the fruit is being decomposed into sugars, and parallel flavors and other substances are formed, which causes the firmness of the fruit and the acid content to drop [3]. In plantation of apple-trees temperature, light and relative air humidity was logged with SL900A [4]. The components were combined in a sensor node shown in Fig. 1. Each sensor node was logging data which was collected wirelessly with appropriate UHF reader.

Fig. 1. UHF RFID sensor node with logging functionality composed of SL900A with integrated temperature sensor and external light and humidity sensors [3].

Work [5] demonstrates the developed application for disinfection control by the sensing of chemical agents. The objective was to develop an Automatic Disinfectant Tracker (ADT) that would verify the disinfection of the hands of nurses, doctors, staff, patients, and visitors in hospitals within a required time frame. Two approaches were demonstrated, both based on the wireless Ultra-High-Frequency-based Radio-Frequency Identification (UHF-RFID) technology using ams AG's UHF RFID infrastructure [4]. In the application smart tag was meant to be used instead of normal identification badge. Capacitive alcohol sensor would detect alcohol presence during hands disinfection. Example of application is shown in Fig. 2.

Fig. 2. Application with smart tag used in place of identification badge. Capacitive alcohol sensor is read with UHF reader to verify wearer's hand disinfection [5].

In yet another example [6] an RFID tag was made on a patch to be worn on human skin. The patch had a sensor for measuring NaCl concentration in sweat. The measurement system was completed with a smart phone to read and display measurements.

Application, described here uses the humidity sensor presented in [7]. It is a passive UHF RFID humidity sensor tag fabricated using inkjet technology. Vimax (recycled paper) printing substrate was printed using SC-CRSN2442 SunTronic 280 Thermal Drying Silver Conductive Ink.

The wireless sensor application that provides tracking capability is shown in Fig. 3. The same screen printing technique was used for printing the humidity sensor and for the UHF antenna [8]. Reference and measured capacitive sensor are AC supplied. The SL900A is an EPC Class 3 tag chip enabling affordable RFID automatic data logging applications with sensor functions. The SL900A works in semi-passive (battery-assisted) mode as well as in fully passive mode. Battery support enables data logging and burst communication range with reader. Sensor data readout is also possible in fully passive operating mode – without battery.

Corresponding temperature and humidity measurements are shown in Fig. 4. Data was taken once every hour (x-axis), for 7 days, and was stored in the SL900A's memory. The application was placed in the open air, where conditions during the day and night are clearly recognized. Sensors were exposed to direct sun in the middle of the day (measured in May 2014).

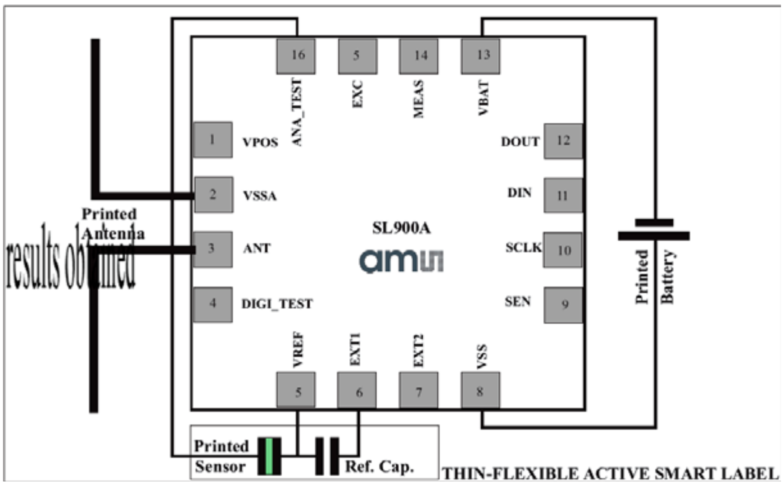

Fig. 3. Practical-sensory tag application, based on SL900A smart label with integrated temperature sensor, real time shelf-life calculation and data logging capability, combined with external screen printed humidity sensor, and screen printed UHF antenna [8].

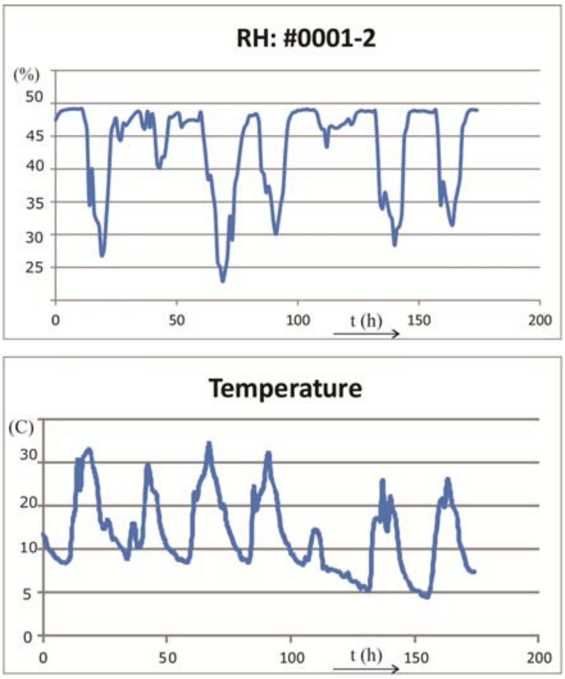

Fig. 4. Measured relative humidity using the printed sensor and on board integrated temperature sensor [8].

3. Smart Label with Energy Harvesting and Digital Interface

The passive smart tag AS39514 [4] is compliant with FeliCa and ISO 15693 protocols. It has a digital interface and capability to interact with 4 digital sensors over I^2C (Inter-Integrated Circuit) protocol [9]. It can operate in master mode and control sensors directly without the need of an external microcontroller. This reduces required power for tag operation and tag complexity. Instead of sensors AS39514 can control external EEPROM (Electrically Erasable Programmable Read-Only Memory) over SPI (Serial Peripheral Interface) bus to extend internal memory.

As a slave device it can be accessed over SPI or I^2C bus and can be used for bridge connection between microcontroller and reader. In master mode operation tag can control 4 digital sensors over I^2C bus or it can control external EEPROM over SPI. The smart tag has integrated battery charger with selectable voltage output. Battery charger has functionality of harvesting energy from RF (Radio Frequency) field and use it to charge battery or capacitor. Stored energy can be used for short time data acquisition with higher current consumption sensor.

3.1. I2C Master Mode Micro Code

Smart tag can control I2C bus as master. In this mode the tag can execute micro code commands to control the bus and manipulate data. Micro code can be send from reader directly over RF field. More convenient way is to store micro code in internal EEPROM. In this way access to micro code can be protected with password and only code execution is controlled over RF field. Micro code is composed of following commands: enable and disable output driver, I2C start sequence and I2C stop sequence, read n number of bytes, write n number of bytes, and wait for. Additional to read and write there are complex read and write commands, which are intended to write or read only one bite of full byte.

With combination of these simple commands sensor's internal registers can be accessed, data conversion can be triggered and results can be read. Values read from sensors' registers are stored in 16 byte FIFO and can be accessed from reader over RF field. For reading sensor AD7150 [11] only 5 commands are sufficient and are shown in Table 1.

Table 1. Micro code for reading sensor AD7510.

No.	Code (hexadecimal)	Command
1.	0x01	Enable output driver
2.	0xE3	Read 3 bytes
3.	0xC3	I^2C stop sequence
4.	0x00	Disable output driver
5.	0xFF	End of sequence

3.2. Wireless Sensor Node with Environmental Sensors

In our measurement system the sensory tag AS39514 was used together with four digital interface sensors. We used temperature and relative air humidity sensor SHT21 [12], ambient light sensor TSL2572 [4], air pressure sensor LPS331AP [13] and capacitance converter AD7150 for proximity sensing. Complete micro code for controlling sensors is stored in internal EEPROM and is only 57 bytes long.

The complete tag was implemented on a PCB together with an antenna and is shown in Fig. 5. Capacitive proximity sensors are implemented with two metal strips.

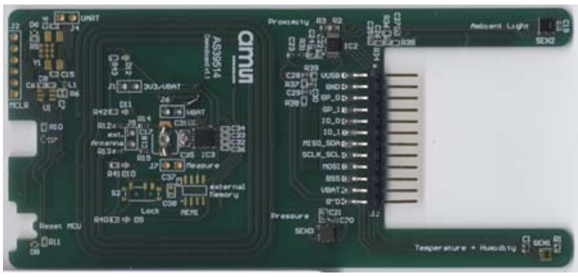

Fig. 5. AS39514 smart tag demo PCB. 4 sensors with digital interface are positioned on right side, AS39514 IC is on the middle with antenna turns around it.

The tag was placed on a reader and was supplied from the reader's field. Communication between reader and tag was done with FeliCa protocol. A computer connected to the reader was reading and storing measurements each half an hour. Reader and tag were placed outside to measure data.

Measurements of one rainy autumn day are shown in Fig. 6. From the measurements a peak in daylight intensity is visible. The temperature also increased and air humidity decreased during day time. Proximity sensor's capacitance was low and changed slowly meaning that smart tag was not touched or covered during the measurements.

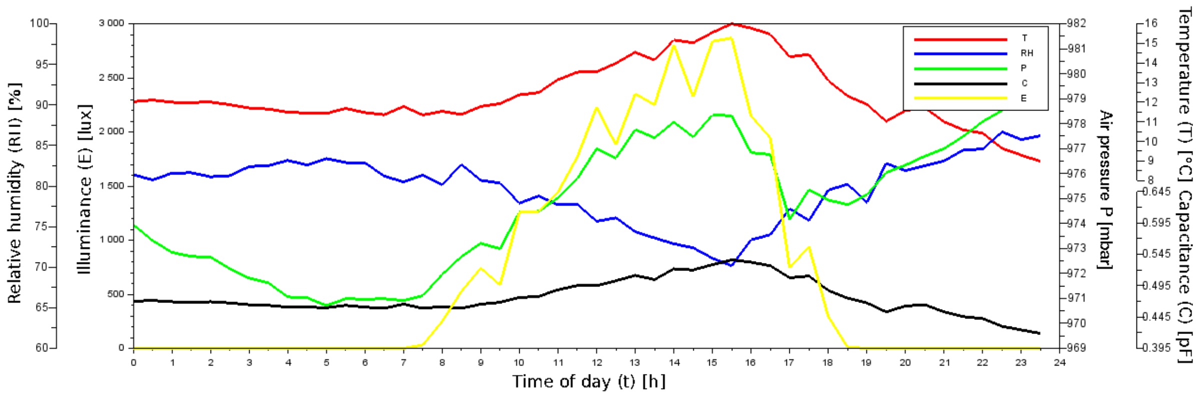

Fig. 6. Results of 1 day measurements with sensor node. Temperature, relative air humidity, air pressure, and light show dependence of hour with peaks at middle of the day. Capacity of proximity sensor was low and changed slowly, meaning that sensor node was not touched during measurements.

4. Example of Wireless Accelerometer and Gyroscope

In another application, the AS39514 passive tag was used to provide power and to transfer data to and from a MEMS (Micro Electro-Mechanical Structure) sensor. The RF field was provided by the AS3911 RFID and NFC reader. The main goal of the application was to sample and save sensor data with a PC, with the reader and tag acting as a short range wireless bridge. Further processing of the data was done on the PC using a Kalman filter to remove gyroscope drift.

The MEMS sensor, MPU-6050, contains a 3-axis accelerometer and 3-axis gyroscope, which consume a relatively large amount of power during operation; 3.8 mA typical [10] when all 3 axes of the gyroscope and all 3 axes of the accelerometer are enabled. The sensor can act as an I2C master for other slave sensors and also houses a Digital Motion Processor [10] for advanced data processing.

The sensor's gyroscope has a user-programmable full scale range of ±250, ±500, ±1000 and ±2000°/sec. The accelerometer also has a user-programmable full scale range of ±2 g, ±4 g, ±8 g and ±16 g. Each axis of the gyroscope and accelerometer has its own 16-bit analog-to-digital converter (ADC), for a total of 6 ADCs for the gyroscope and accelerator. Communication to and from the sensor was via I2C at 400 kHz.

Because of the large power consumption of the sensor, the range of NFC communication was very short, 1 cm at best, with the reader and tag both configured to provide good power transfer to the sensor. The sensor has an operating voltage range from 2.375 V to 3.46 V, with the AS39514 delivering almost 4 mA and 3 V to the sensor when both reader and tag antennas were at a vertical distance of 2 mm (one printed circuit board - PCB thickness). Both antennas were in a concentric orientation to one another.

The dimensions of the reader antenna were 65 mm×65 mm with 2 coil turns. The tag antenna was a standard Class 1 antenna, as defined by ISO/IEC 10373-6, which measures 71.5 mm×41.5 mm with 4 coil turns. Communication between the reader and tag was with the FeliCa RFID protocol, at a data rate of 424 kbit/s.

The reader was controlled by a PC via USB to collect sensor data from the reader memory for evaluation and further processing using a Kalman filter on the accelerometer and gyroscope results to remove gyroscope drift. Gyroscope drift is caused by a small offset in the angular velocity measured by the gyroscope, which when integrated over time, causes the angle data to drift. Sensor calibration prior to measurements can greatly reduce drift, however it can never truly eliminate it. Gyroscope angle data is thus unreliable in the long term without proper filtering and merging with accelerometer data, which is reliable in the long term.

Prior to measurements, the sensor was not calibrated, so that any offset and corresponding drift produced by integrating the gyroscope data was large. Fig. 7 shows the difference between the raw integrated gyroscope data and data after Kalman filtering. One of the advantages of using a Kalman filter is the ability to modify the filter constants to configure it for any application, be it fast, slow or noisy.

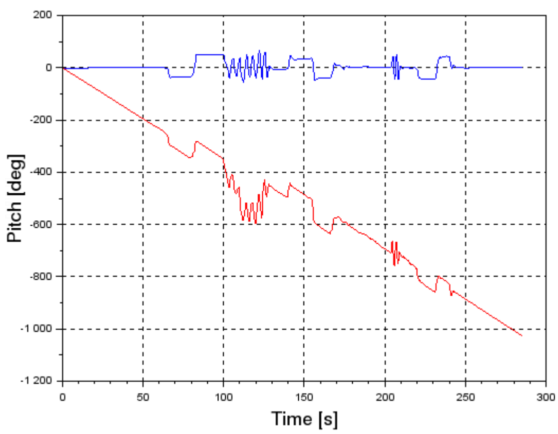

Fig. 7. Integrated raw gyroscope data in red and the Kalman filter output in blue. A large drift can be seen on the gyroscope data, while the filter response shows no drift.

7. Conclusions

We have shown the possibility to use RFID infrastructure in different live environmental conditions for various purposes like optimization and prediction of optimal deadlines for harvesting in different agriculture branches, to control disinfection and to establish an efficient smart sensors network to track environmental conditions in cold chain and track the transportation conditions. We have presented two examples for wireless sensor nodes with different sensors and shown results obtained with the sensor nodes.

Acknowledgements

We would like to thank ams staff members for support and help with development of demonstrated examples.

References

[1]. N. Suhadolnik, T. Svete, A. Pleteršek, RFID Smart Labels for Enhanced Interaction with Environment, in *Proceedings of the International Conference on Sensors Engineering and Electronic Instrumental Advances*, Dubai, UAE, 2015, pp. 12-15.

[2]. M. Trebar, M. Lotrič, I. Fonda, A. Pleteršek, K.Kovačič, RFID Data Loggers in Fish Supply Chain Traceability, *International Journal of Antennas and Propagation*, Vol. 2013, 2013, pp. 1-9.

[3]. B. Germšek, A. Pleteršek, Radio frequency identification (RFID) in agriculture-food safety and traceability, in *Proceedings of the International Conference on agriculture and animal sciences (AgriAnimal'13),* Thalangama North: International Center for Research and Development, 2013, pp. 30-41.

[4]. ams web page: (www.ams.com).

[5]. A. Pleteršek, *et al.*, Monitoring, control and diagnostics using RFID infrastructure, *Journal of Medical Systems*, Vol. 36, No. 6, 2012, pp. 3733-3739.

[6]. D. P. Rose, *et al.*, Adhesive RFID Sensor Patch for Monitoring of Sweat Electrolytes, in *Proceedings of the* IEEE Transactions in Biomedical Engineering, Vol. 62, No. 6, 2015, pp. 1457-1465.

[7]. M. Mraović, A. Pleteršek, T. Muck, U. Kavčič, M. Đokić, Performances of the Screen printed capacitive humidity sensors on recycled paper and cardboard, in *Proceedings of the 49th International Conference on Microelectronics, Devices and Materials & the Workshop on Digital Electronic Systems*, Kranjska Gora, Slovenia, 25-27 September, 2013, pp. 155-159.

[8]. U. Kavčič, L. Pavlovič, M. Pivar, M. Đokić, B Batagelj, T. Muck, Printed electronics on recycled paper and cardboards, *Informacije MIDEM*, Vol. 43, No. 1, 2013, pp. 50-57.

[9]. NXP, I2C-bus specification and user manual, 2014. (http://www.nxp.com/documents/user_manual/UM10204.pdf).

[10]. InvenSense Inc., MPU-6000 and MPU-6050 Product Specification Revision 3.4, 2014.

(http://www.invensense.com/products/motion-tracking/6-axis/mpu-6050/)
[11]. Analog Devices, AD7150 Datasheet. (http://www.analog.com/media/en/technical-documentation/data-sheets/AD7150.pdf)
[12]. Sensirion, Datasheet SHT21. (https://www.sensirion.com/fileadmin/user_upload/customers/sensirion/Dokumente/Humidity_and_Temperature_Sensors/Sensirion_Humidity_and_Temperature_Sensors_SHT21_Datasheet_V4.pdf)
[13]. ST, LPS331AP Datasheet (http://www.st.com / st-web-ui/static/active/en/resource/technical/document /datasheet/DM00036196.pdf