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Measurement System Based on Arduino for Biogas Sensing: Development Considerations and Laboratory Scale Approach

Short Paper

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***Abstract*—Measurement systems are used in every scientific and technological process to measure and monitor a number of magnitudes. During last years, open source technology and, concretely, open source hardware devices are being introduced in different R&D projects due to their advantages of low cost, easy development, shared information in the Internet and so on. Arduino microcontroller is the most illustrative example of this kind of devices. This paper presents a measurement system based on Arduino board to perform biogas sensing. A set of sensors are responsible of measuring the gases that compose the biogas (hydrogen, methane, ammonia and carbon monoxide) and the results are displayed to the user via a small graphical monitoring interface. The development of the system is reported and initial results are provided to demonstrate the suitability of the microcontroller.**

Keywords- measurement system; Arduino; open source; monitoring; biogas.

I. INTRODUCTION

Every scientific and technological process requires to measure and monitor variables of different nature (analog/digital) that inform about the behavior or state of such process. To this aim, measurement systems follow the common architecture depicted in Fig. 1. A physical process needs to be monitored and/or controlled, so a set of sensors measure the representative magnitudes. These sensors are linked to a microprocessor or microcontroller-based board, which is responsible of acquiring and processing their signals. In Fig. 1, both the sensors and the board are considered into the block named Measurement Acquisition System (MAS) for a higher level of generality. A Monitoring Interface (MI) exchanges data with the microcontroller in order to provide useful information, by means of numerical or graphical displays, to the user.

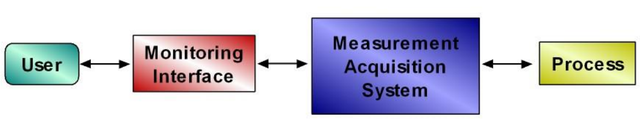

Figure 1. General diagram of measurement systems.

The present paper reports the development of a measuring system for biogas sensing using a development board called Arduino, which is based on a microcontroller. This board is commonly referred to as Arduino microcontroller. Diverse considerations about the proposed system as well as initial results are also provided. Particularly, an Arduino Mega board and a set of four sensors (methane, ammonia, carbon monoxide and hydrogen) constitute the MAS; whereas a LCD screen plays the role of MI. This manuscript is an extended version of the congress contribution in [1].

A scientific domain where measurement systems are profusely applied is that related to Renewable Energy Sources (RES), which gains increasing attention both from governments and R&D initiatives around the world. As it well-known, the dependency on fossil fuels needs to be decreased so RES are progressively being introduced in the energetic scenario. Within RES, photovoltaic and wind energies are the most exploited due to their availability. Nonetheless, other important source is available as a result of the human activities, namely biogas. Biogas is a combustible fuel generated by the disposal of waste, and composed by a variable mixture of methane (50-70%) and carbon dioxide (30-50%), and also minimal quantities of nitrogen, hydrogen and water vapor (Fig. 2). Biogas can be produced in natural means or in a sealed, oxygen-free container named anaerobic digester, from the reactions of biodegradation of the organic matter, by the action of microorganisms in the absence of oxygen [2].

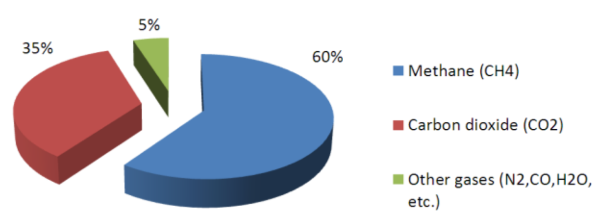

Figure 2. Composition of biogas.

Arduino microcontroller is nowadays the maximum representative of the open source hardware trend. Given its versatility and widespread application for diverse scopes, in the authors' humble opinion, it is suitable to act as the core of a measurement system to determine the composition of biogas. In this sense, the main contribution of this work is the development of a fully functional measurement system for biogas using such an inexpensive open source microcontroller. This paper is envisioned to provide useful insights about the implementation of such system, which can be a valuable resource for scientists and scholars involved in R&D activities related to biogas fuel.

The remainder of the paper is as follows. Section II is devoted to provide a brief review of measuring systems and Arduino microcontroller applications in order to highlight the relevance of our proposal. Section III deals with the description of the developed system, both hardware and software approaches. Finally, main conclusions and further works are outlined in Section IV.

II. Brief review about measuring systems and Arduino

This section provides a background about the utilization of Arduino platforms, mainly in the context of measuring systems.

A noteworthy remark is that open source technology, comprising both hardware and software, constitutes an ever-growing trend during last years [3]. The open source tools provide the developer with the ability to perform in-depth configurations since the source code, schematics and documentation are available. As a consequence, these means offer serious advantages regarding low, or even inexistent, economic costs and custom-designed approaches.

On the contrary, the main drawback is that programming and/or hardware related skills are commonly required. In addition, there is no customer support, which can be an important boundary for professional solutions. This kind of tools is achieving increasing presence in different technological and scientific scenarios. For instance, modern paradigms like the global pervasive network of interconnected devices known as the Internet of Things (IoT) will take advantage of open source hardware and software projects [4, 5].

Regarding open source hardware, Raspberry Pi, BeagleBone, Phidget, OpenDAQ, Intel Edison and Arduino boards are devices of this nature that are being more and more exploited. Low-cost, ease of use and wide availability have opened a new door to democratize electronics [6]. Open source philosophy implies that a great variety of information, examples and tutorials are shared by a collaborative community through the Internet, embracing development based on this type of devices.

Arduino is a low-cost single-board microcontroller [7] and is the prevalent open source hardware device. Concerning R&D and Academia activities, Arduino constitutes a merging trend, which has become a powerful tool to develop different applications in the fields of data acquisition, automation and engineering in general [8].

The versatility of this microcontroller is validated by the numerous applications reported. Out of the measurement systems sphere, it has been used for humanoid robotic [9], greenhouse control [10], fuzzy cognitive maps [11], remote laboratories for engineering education [12-15], ZigBee-based communication [16], cyber-physical systems [17, 18] and as electronic interface between Programmable Logic Controllers (PLCs) and sensors [19-21].

Concerning measurement-centered approaches, recent works report Arduino applications for agricultural instrumentation [22, 23], monitoring of photovoltaic systems [24-27], environmental monitoring [28, 29], Wireless Sensor Networks (WSNs) implementation [30], air quality monitoring [31], sensors deployment in Unmanned Aircraft Vehicles (UAVs) [32] or for monitoring hydrogen fuel cells [8, 33].

There is a wide diversity of Arduino boards with different sizes and resources. For instance, Uno, Yun, Mini, Nano, Mega, Duemilanove, Extreme, Lilypad, etc., so the developer can choose the model that fits better the application to implement. In the present case, the Mega 2560 R3 board has been chosen.

The developed system corresponds to the block diagram shown in Fig. 1. The functions of the MI as well as a further connectivity link are provided by the so-called shields. They are expansion cards with additional features that can be directly coupled on the main board. There are an increasing number of shields devoted to diverse tasks: data visualization, motor control, sensors connection, data storage, etc. Therefore, these cards facilitate the developments using Arduino, for instance, in the proposed approach; a display is used to provide information to the user as described in the next section.

Some advantages of the Arduino boards are now listed in order to emphasize the suitability of such a device for the purpose of the present work:

- Low cost. The cost of an Arduino Mega board is around 40€ whereas a commercial data acquisition board costs about 450€.
- Open hardware. All the schematics and documentation related to the Arduino microcontroller as well as to the shields are freely available in the Internet.
- Availability of expansion cards. The shields constitute an important advantage to promote the applications of Arduino since they facilitate the connection and configuration of additional features or devices.
- Great information shared by the community. Tutorials, forums and videos offer knowledge freely available that contribute to develop Arduino-based projects.
- Rapid development. As a result of the previous consideration, the time and effort required to design and implement systems including Arduino are shorten.
- Continuous improvements. The open source community continuously enhances the Arduino resources like libraries and shields, helping to

improve already existent systems or to design new approaches.

- Increasing application in R&D domain. As it has been expounded, Arduino is widely used as tool to develop a multiplicity of R&D applications.

III. Development of the Measurement System

This section deals with the description of the main features of the elements that compose the presented measurement system as well as their interconnection and configuration. For a better comprehension of the proposal, a block diagram of the whole system is provided in Fig. 3.

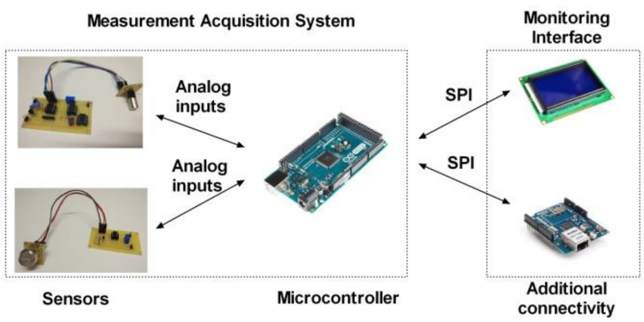

Figure 3. Diagram of the implemented prototype of measurement system.

A. Arduino microcontroller

The measurement system developed in this work is based on the open source hardware Arduino microcontroller, model Mega 2560 R3. Through this microcontroller we can read the data, display them on a screen and share them with other devices via Modbus.

The hardware consists of a printed circuit board with an ATmega2560 microcontroller. It includes 54 digital input/output ports, 16 analog inputs, 4 UARTs, a 16 MHz crystal oscillator, a power jack, an In Chip Serial Programmer (ICSP) header and a reset button. It also includes a USB connection port from where it is possible to power the board and establish communication with the computer.

In order to visualize the concentrations of the different gases that make up the biogas, an LCD graphic display will be used, which in fact acts as MI. It has been opted for a graphic LCD of 128x64 points with an ST7920 controller. For the connection of the LCD screen with Arduino, it has been decided to use the serial communication under the Serial Peripheral Interface (SPI) protocol.

The SPI bus is a communications standard, used mainly for the transfer of information between integrated circuits. It includes a line of clock, incoming data, outgoing data and a select chip pin, which connects or disconnects the operation of the device with which one wishes to communicate. In this way, this standard allows multiplexing the clock lines. Fig. 4 depicts the SPI bus scheme.

On the Arduino Mega 2560, the SPI port is located on pins 50 to 53.

The connection between the MI and the Arduino Mega are as shown below (Fig. 5).

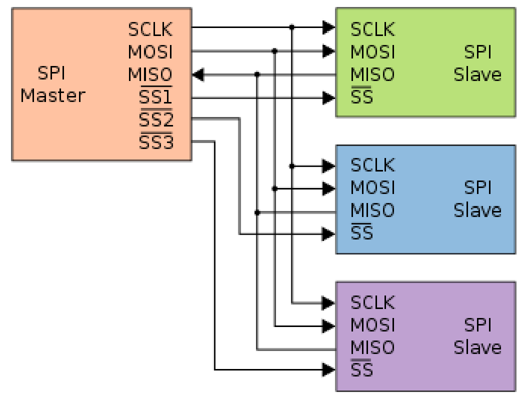

Figure 4. SPI bus scheme of connections.

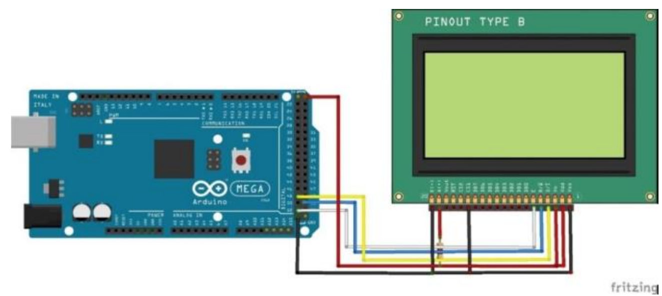

Figure 5. Connection between the MI and Arduino.

In order to use the Modbus TCP/IP protocol to access the sensor readings an Ethernet port must be added to the Arduino Mega. For this purpose, an Ethernet shield that fits perfectly with this version of Arduino will be used. Specifically, the Hanrun HR911105A Ethernet shield model was chosen, which uses the Wiznet W5100 Ethernet chip to allow Internet connection.

This Ethernet shield uses the SPI protocol to share the information with the Arduino board. Exactly, it uses the pins of the ICSP Port of the Arduino Mega for the connection. As can be seen in the Arduino Mega port scheme, the ICSP Port also allows connection with the SPI protocol. The physical assembly of this shield is very simple, it simply has to be inserted in the Mega Arduino and it will be connected and fixed.

Four already available commercial sensors of the manufacturer Figaro [34] are used to measure methane (model TGS3870), ammonia (model TGS2444), carbon monoxide (model TGS5042) and hydrogen (model TGS821). For further details about the features of theses sensors and the auxiliary electronic circuitry, see reference [35].

Furthermore, apart from the Arduino board and the Ethernet shield and the LCD screen, to develop this prototype, a series of auxiliary electronic circuits are needed to operate the sensors. These auxiliary circuits are responsible for generating pulses, amplifying signals and sampling them.

B. *Software implementation*

For the implementation of the microcontroller script, known as sketch, the software consists of the Integrated Development Environment (IDE) based on the Processing environment and a programming language, a simplified version of the C++ language, as well as on the bootloader that is executed on the board. The Arduino IDE is a free software package that allows programming all Arduino boards. The microcontroller is programmed by a computer via the IDE and using serial communication via a RS-232 to TTL serial level converter. Moreover, open source libraries are used to configure the additional modules, in the present case, the Ethernet shield and the LCD screen.

The developed software consists on the programming of the data acquisition from the sensors, the conditioning and scaling of the measured signals and the presentation of the results in the LCD screen.

To control the graphic display, the U8g2 library has been chosen, a library that allows the use of a large number of monochrome displays with different controllers, including the one used in this work (ST 7920).

For the ModBus TCP/IP protocol, three libraries have been used; two of them are specific to Arduino IDE, such as SPI.h and Ethernet.h, which allow us to use the Ethernet protocol in this project. And the third one is Modbus Library for Arduino. This library implements the industrial communication protocol ModBus in Arduino, allowing the use of the Series physical layer (RS232 or RS485) or Ethernet (TCP/IP). Fig. 6 shows the beginning of the Arduino sketch where the libraries are included.

```
 // Librerías utilizadas
/////////////////////////////////////////
#include <SPI.h>
#include <Ethernet.h>


#include <Modbus.h>
#include <ModbusIP.h>

#include <U8g2lib.h>

/////////////////////////////////////////
```

Figure 6. Libraries included in the sketch.

1) Library U8g2: Next, the operation of the U8g2 library will be briefly described. First, an object is defined to select the type of display, the size and type of buffer used. It is defined that the controller of the graphic LCD screen is the ST920: the screen resolution chosen has been 128 x 64 pixels. In addition, to remove load from the CPU, the hardware buffer that incorporates the controller has been used. The SPI port is used for the LCD communication and the Arduino pin 48 is defined as chip select line to enable the SPI slave. Once the library is configured, the *Starting_Screen ()* function will be executed within the program's *void setup ()*.This function is responsible for starting the screen and displaying an initial animation every time the Arduino is started. Fig. 7 shows the corresponding code.

```
// FUNCIÓN DE ANIMACIÓN INICIAL. PANTALLA DE INICIO.

void Pantalla_Inicio (){

    u8g2.begin();
    u8g2.enableUTF8Print();



     u8g2.clearBuffer();
     u8g2.setFont(u8g2_font_10x20_tf);
     u8g2.drawFrame(0,0,128,63);
     u8g2.drawBox(0,60,128,3);
     u8g2.drawBox(125,0,3,63);
     u8g2.drawStr(12,17,"Analizador");
     u8g2.drawStr(50,35,"de");
     u8g2.drawStr(35,52,"Biogas");
     u8g2.sendBuffer();
     delay(1000);

  }
```

Figure 7. Starting screen funtion of the U8g2 library.

2) Modbus Library: The operation of the Modbus library is concisely explained hereafter. First of all a ModbusIP object will be defined. This object will contain all the configuration and data registers. To make better use of the memory, the analog readings are scaled and transferred directly to the corresponding Modbus register. Once transferred to the Modbus registers, they will already be accessible from a remote master. Fig. 8 shows the corresponding code.

```
//// MODBUS
// Configuración de la conexión Ethernet
    byte mac[] = { 0xDE, 0xAD, 0xBE, 0xEF, 0xFE, 0xED };

    byte ip[] = { 192, 168, 1, 10 };


    mb.config(mac, ip);


    //TIPOS DE REGISTROS DISPONIBLES EN MB Y SUS CARACTERISTICAS

    //mb.addCoil(x);   // Reg "Coil" Digital out R/W
    //mb.addHreg(x);   // Reg "Holding" Analog out R/W
    //mb.addIsts(x);   // Reg "Input Status" Digital In R
    //mb.addIreg(x);   // Reg "Input Reg" Analog in R

    for(int i=0;i<4;i++){
    mb.addIreg(i);
    }
```

Figure 8. Modbus library configuration.

IV. INITIAL OUTCOMES

The prototype is within a testing phase in order to evaluate its behavior and to detect improvements or corrections to carry out. In this sense, diverse experiments are being accomplished; some of them devoted to check the sensors' measurements whereas other trials are focused on the microcontroller performance. For instance, in the first group of experimentations, the repeatability of the measurements is being studied. On the other hand, some delays are introduced into the Arduino sketch in order to establish the optimal sampling time.

A. Final assembly

In Fig. 9, the diagram of the final assembly is shown. The central element of this prototype is the Arduino Mega, with which all the peripherals communicate.

- LCD screen: Communicates with Arduino through the SPI bus.
- Ethernet Shield: Communicates with Arduino through the SPI bus.
- Gas sensors: Communicates with Arduino through analog signals between 0 and 5V.

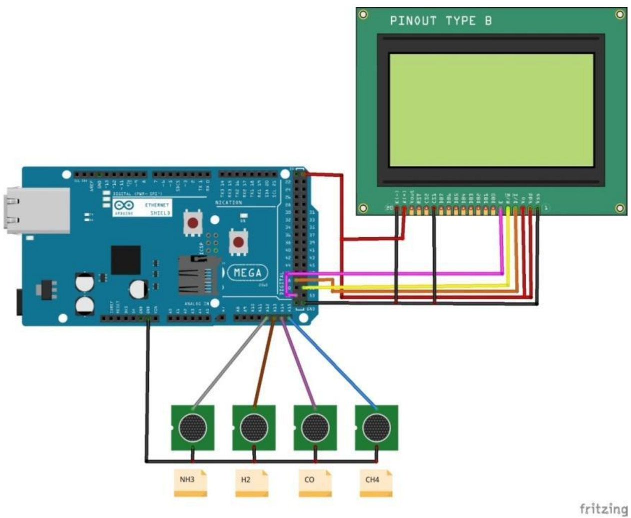

Figure 9. Diagram of the final assembly of the measurement system.

Fig. 10 contains a snapshot of the experimental measurement system once assembled in the laboratory approach.

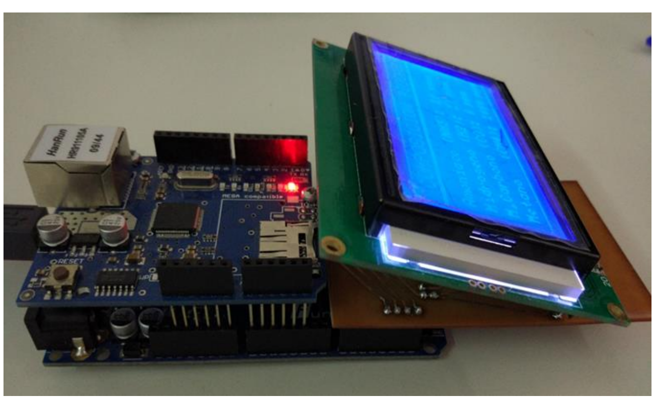

Figure 10. Final assembly of the experimental measurement system.

The physical assembling of the gas sensors is enabled by means of a custom-designed methacrylate box (Fig. 11), which hosts the sensors and makes the gas to circulate for being measured.

Figure 11. Custom-designed methacrylate box to host the gas sensors.

As a proof of concept, Fig. 12 shows a photograph of the prototype working, where can be appreciated that the MI provides real time data about the biogas composition.

Figure 12. Measurement system based on Arduino working.

B. Discussion and considerations

Once the prototype has been described, some considerations from the authors' perspective are commented below.

- Biogas sensing can be effectively solved using the open source microcontroller Arduino.
- The instrumentation required is already available but must be interfaced with the Arduino board with custom designed circuitry. The availability of shields devoted to connect sensors for gas measurement would reduce the time and effort of development.
- The wide range of connectivity interfaces provided by Arduino allows an easy development of networked communication.
- As a consequence of the available information about Arduino-related projects, the effort necessary to become familiar with the microcontroller resources has been relatively short. In fact, the time devoted to

configure the Arduino board has been shorter than that required to configure the sensors.

- Further improvements of Arduino libraries and/or shields will enrich the proposed system.
- Some minor drawbacks have been found during the development such as a weak physical connection between the GLCD and the main board, as well as inaccuracy of the sample time achieved by the microcontroller.
- The prototype must be assessed under real operation conditions in order to check its robustness.
- Reliability and repeatability of the measurements must be studied before an intensive utilization of the prototype.

V. Conclusions

A measurement system based on the Arduino microcontroller devoted to biogas sensing has been presented. A set of sensors are responsible of measuring four gases, namely hydrogen, methane, ammonia and carbon monoxide. On the other hand, the Arduino board performs the signal processing of the acquired data and establishes the percentage of each gas, displaying such information by means of a small screen, which acts as MI.

This system is still under development and validation; nonetheless, initial outcomes at laboratory scale demonstrate the suitability of Arduino microcontroller for biogas sensing.

Arduino acts as the core of the developed measurement system, providing important advantages like low cost, open source hardware, great amount of information available in the Internet and easy configuration, just to name a few. As it is evident, this device also presents some drawbacks, being the main one the inaccuracy of the sampling time.

Further works are focused on integrating the proposed approach with a monitoring and supervisory system in order to enable real time visualization of the biogas composition. In addition, the networked operation to provide cloud-enabled measurements storage is also being considered.

Acknowledgment

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References

[1] A.J. Calderón and I. González, “Design and Implementation of a Low Cost System to Determine the Composition of Biogas,” Proc. Eighth International Conference on Sensor Device Technologies and Applications (SENSORDEVICES 2017), IARIA, Sep. 2017, pp. 76-77, ISBN: 978-1-61208-581-4.

[2] D. Deublein and A. Steinhauser, Biogas from Waste and Renewable Resources: An Introduction, Wiley-VCH, 2011.

[3] I. González, A.J. Calderón, J.M. Andújar, “Novel Remote Monitoring Platform for RES-Hydrogen based Smart Microgrid,” Energy Conversion and Management, vol. 148, pp. 489-505, 2017, doi: 10.1016/j.enconman.2017.06.031.

[4] R. Fisher, L. Ledwaba, G. Hancke, C. Kruger, “Open Hardware: A Role to Play in Wireless Sensor Networks?,” Sensors, vol. 15, pp. 6818-6844, 2015, doi: 10.3390/s150306818.

[5] B. Martinez, X. Vilajosana, I.H. Kim, J. Zhou, P. Tuset-Peiró, A. Xhafa, “I3Mote: An Open Development Platform for the Intelligent Industrial Internet,” Sensors, vol. 17, pp. 986, 2017, doi: 10.3390/s17050986.

[6] A. Garrigós, D. Marroquí, J.M. Blanes, R. Gutiérrez, I. Blanquer, M. Cantó, “Designing Arduino electronic shields: experiences from secondary and university courses,” Proc. IEEE Global Engineering Education Conference (EDUCON), April 2017, doi: 10.1109/EDUCON.2017.7942960.

[7] Arduino homepage. Available from: https://www.arduino.cc/ (last accessed February 2018)

[8] A.J. Calderón, I. González, M. Calderón, F. Segura, J.M. Andújar, “A New, Scalable and Low Cost Multi-Channel Monitoring System for Polymer Electrolyte Fuel Cells,” Sensors, vol. 16, pp. 349, 2016, doi: 10.3390/s16030349.

[9] A. Cela, J.J. Yebes, R. Arroyo, L.M. Bergasa, R. Barea, E. López, “Complete low-cost implementation of a teleoperated control system for a humanoid robot,” Sensors, vol. 13(2), pp. 1385-1401, 2013, doi:10.3390/s130201385.

[10] C. Robles, J. Callejas, A. Polo, “A. Low-Cost Fuzzy Logic Control for Greenhouse Environments with Web Monitoring,” Electronics, vol. 6, pp. 71, 2017, doi: 10.3390/electronics6040071.

[11] L.B. Souza, P.P. Soares, R.V. Duarte, M. Mendonça, E.I. Papageorgiou, “Dynamic Fuzzy Cognitive Maps Embedded and Intelligent Controllers Applied in Industrial Mixer Process,” International Journal On Advances in Systems and Measurements, vol. 10, numbers 3 and 4, pp. 222-233, 2017.

[12] M.A. Prada, P. Reguera, S. Alonso, A. Morán, J.J. Fuertes, M. Domíngez, “Communication with resource-constrained devices through MQTT for control education,” IFAC-PapersOnLine, vol. 49(6), pp. 150-155, 2016, doi: 10.1016/j.ifacol.2016.07.169.

[13] I. Tejado, J. Serrano, E. Pérez, D. Torres, B. Vinagre, “Low-cost Hardware-in-the-loop Testbed of a Mobile Robot to Support Learning in Automatic Control and Robotics,” IFAC-PapersOnLine, vol. 49(6), pp. 242-247, 2016, doi: 10.1016/j.ifacol.2016.07.184.

[14] A. Mejías, M. Reyes, M.A. Márquez, A.J. Calderón, I. González, J.M. Andújar, “Easy handling of sensors and actuators over TCP/IP Networks by Open Source Hardware/Software,” Sensors, vol. 17, pp. 94, 2017, doi: 10.3390/s17010094.

[15] J. Chacón, J. Saenz, L. de la Torre, J.M. Diaz, F. Esquembre, “Design of a Low-Cost Air Levitation System for Teaching Control Engineering,” Sensors, vol. 17, pp. 2321, 2017, doi: 10.3390/s17102321.

[16] R. Pereira, J. Figueiredo, R. Melicio, V.M.F. Mendes, J. Martins, J.C. Quadrado, “Consumer energy management system with integration of smart meters,” Energy Reports, vol. 1, pp. 22-29, 2015, doi:10.1016/j.egyr.2014.10.001.

[17] M.V. García, E. Irisarri, F. Pérez, E. Estévez, M. Marcos, “OPC-UA Communications Integration using a CPPS architecture,” Proc. Ecuador Technical Chapters Meeting (ETCM), Oct. 2016, doi: 10.1109/ETCM.2016.7750838.

[18] M. Müller, E. Wings, L. Bergmann, “Developing open source cyber-physical systems for service-oriented architectures using OPC UA”, Proc. IEEE 15th International Conference on Industrial Informatics (INDIN), Jul. 2017, doi: 10.1109/INDIN.2017.8104751.

[19] M. Kajan, J. Sovcik, F. Duchon, L. Mrafko, M. Florek, P. Beño,” Sensoric subsystem of automated guided vehicle: TCP communication between SIMATIC S7 PLC and Arduino,” Proc. 23rd International Conference on Robotics in Alpe-

Adria-Danube Region (RAAD), Sep. 2014, doi: 10.1109/RAAD.2014.7002258.

[20] H. Rahadian, W. Nugroho, D.Nurual, “Siemens CPU1215C Input Expansion and Remote Monitoring with Arduino Bridge,” Proc. 6th International Annual Engineering Seminar (InAES), Aug. 2016, doi: 10.1109/INAES.2016.7821926.

[21] U. B. Kayande, P. Jaspreetkaur, R. M. Kulkarni, S. B. Mahajan, P. Sanjeevikumar, “Digitally Controlled Hybrid Liquid Level Detection System Using Programmable Logic Controller and Microcontroller,” Lecture Notes in Electrical Engineering, vol. 442, pp. 365-374, 2018 doi: 10.1007/978-981-10-4762-6_35.

[22] B.D. Lampson, Y.J. Han, A. Khalilian, J.K. Greene, D.C. Degenhardt, J.O. Hallstrom, “Development of a portable electronic nose for detection of pests and plant damage,” Computers and Electronics in Agriculture, vol. 108, pp. 87-94, 2014, doi: /10.1016/j.compag.2014.07.002.

[23] D. Piromalis, K. Arvanitis, “SensoTube: A scalable hardware design architectures for wireless sensors and actuators network nodes in the agricultural domain,” Sensors, vol. 16, pp. 1227, 2016, doi: 10.3390/s16081227.

[24] N.C. Batista, R. Melício, J.C.O. Matias, J.P.S. Catalão, “Photovoltaic and wind energy systems monitoring and building/home energy management using ZigBee devices within a smart grid,” Energy, vol. 49, pp. 306–315, 2013, doi: /10.1016/j.energy.2012.11.002.

[25] P. Papageorgas, D. Piromalis, K. Antonakoglou, G. Vokas, D. Tseles, K.G. Arvanitis, “Smart Solar Panels: In-situ monitoring of photovoltaic panels based on wired and wireless sensor networks,” Energy Procedia, vol. 36, pp. 535-545, 2013.

[26] H.E. Gad and H.E. Gad, “Development of a new temperature data acquisition system for solar energy applications,” Renewable Energy, vol. 74, pp. 337-343, 2015, doiI: 10.1016/j.renene.2014.08.006.

[27] M.M. Rahman, J. Selvaraj, N.A. Rahim, M. Hasanuzzaman, “Global modern monitoring systems for PV based power generation: A review,” Renewable and Sustainable Energy Reviews, vol. 82(3), pp. 4142-4158, 2018, doi: 10.1016/j.rser.2017.10.111.

[28] J. Carland, M. Umeda, T. Wilkey, A. Oberbeck, J. Cumming, N. Parks, “Meteorological Wireless Sensor Networks,” Sensors & Transducers, vol. 160, pp. 118-124, 2013.

[29] S. Ferdoush and X. Li, “Wireless Sensor Network System Design Using Raspberry Pi and Arduino for Environmental Monitoring Applications,” Procedia Computer Science, vol. 34, pp. 103–110, 2014.

[30] S. Trilles, A. Calia, O. Belmonte, J. Torres-Sospedra, R. Montoliu, J. Huerta, “Deployment of an open sensorized platform in a smart city context,” Future Generation Computer Systems vol. 76, pp. 221-233, 2017, doi: 10.1016/j.future.2016.11.005.

[31] P. Arroyo, J. Lozano, J.I. Suarez, J.L. Herrero, P. Carmona, “Wireless Sensor Network for Air Quality Monitoring and Control,” Chemical Engineering Transactions, vol. 54, pp. 217-222, 2016.

[32] A. Arenal, J. Pascual, R. González, S. Ríos, “Platform for controlling and getting data from network connected drones in indoor environments,” Future Generation Computer Systems, 2018, In press, doi: 10.1016/j.future.2018.01.011.

[33] F. Segura, V. Bartolucci, J.M. Andújar, “Hardware/Software Data Acquisition System for Real Time Cell Temperature Monitoring in Air-Cooled Polymer Electrolyte Fuel Cells,” Sensors, vol. 17, pp. 1600, 2017, doi: 10.3390/s17071600.

[34] FIGARO ENGINEERING INC. homepage. Available from: http://www.figaro.co.jp/en/product/ (last accessed April 2018)

[35] A.J. Calderón and I. González, “Biogas analyzer based on Open Source Hardware: Design and Prototype Implementation,” Sensors & Transducers, vol. 220, pp. 31-36, 2017.