Survey about the Utilization of Open Source Arduino for Control and Measurement Systems in Advanced Scenarios. Application to Smart Micro-Grid and Its Digital Replica

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Abstract: The advantages of open source technology have led to their ever-growing utilization in advanced scenarios like the Industry 4.0, the Industrial Cyber-Physical Systems (ICPSs) and Smart Grids, among others. Concerning open source hardware, the platform Arduino receives great attention from academicians, hobbyists and even industrial practitioners. This paper aims at providing a panoramic overview of recent scientific literature reporting the use of Arduino in such challenging scenarios, proving its validity for control and measurement purposes. In addition, the application of such device as part of the equipment to monitor the operation and development of a Smart Micro-Grid and its digital replica is expounded.

1 INTRODUCTION

The digital transformation that is taking place in different technological domains is derived from the penetration and expansion of the Information and Communication Technologies (ICTs) (Calderón et al., 2018; González et al., 2019). In the industrial environment, the Industry 4.0 is a concept of integration of industry automation, data exchange, and modern manufacturing technologies (Babiceanu and Seker, 2016). It is also commonly referred to as the fourth industrial revolution, as a consequence of an initiative of the German government (Industrie 4.0 homepage), the Industrie 4.0. The Industry 4.0 era is envisioned to be implemented through the so-called Industrial Cyber-Physical Systems (ICPSs), which enable monitoring and control of industrial physical processes and bridge the cyber and virtual worlds (Colombo et al., 2017).

The paradigm of Industry 4.0 involves various challenging frameworks like the aforementioned ICPSs, the Industrial Internet-of-Things (IIoT), Big Data, Cloud Computing, Smart Grids, Smart Cities, cyber-security, digital replicas and open-source technology.

The latter one involves the utilization of hardware and software with complete availability of schematics, code, etc., so the user can develop and customize the solution at deep level. This information is publicly shared through the Internet and there are thousands of hobbyists and professionals sharing their projects. Moreover, commonly open source systems have low-cost nature. For instance, there are various single-board micro-controllers available for less than 20 €. Indeed, most of the open source software packages are free, promoting their usage.

Hence, open source technology is receiving increasing attention in last years from scientists and practitioners in a multitude of different domains. For instance, the amount of devices within the IoT can be increased thanks to this type of technology (Fisher et al., 2015) and open source projects are key accelerators for the industry adoption of IoT (Martinez et al., 2017).

At the hardware level, according to Thames and Schaefer (Thames and Schaefer, 2016), open source

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hardware (and its associated open source software) is envisioned to lead to fast and incremental updates to hardware platforms in future manufacturing processes. There are various devices of this type like Raspberry Pi, BeagleBone, Phidget, Intel Edison and Arduino. The latter one is an inexpensive single-board micro-controller (Arduino online) and is considered as the flagship open source hardware. In fact, it is a powerful tool to develop different applications in the arenas of data acquisition, automation and engineering in general (Calderón et al., 2016).

Concerning the power scenario, renewable energy sources are expected to play a vital role in the mitigation of the greenhouse emissions effects and of the global warming. Even more, their hybridization with hydrogen generation and consumption constitutes an important research field (González et al., 2017). In particular, Smart Grids (SGs) are the next generation of power grids, emerging as the digital transformation applied to the energy industry, and being an important component of the Industry 4.0 paradigm (Batista et al., 2017). SGs are defined as a modern electric power grid infrastructure for improved efficiency, reliability, and safety with smooth integration of renewable and distributed energy sources, through automated and distributed controls and modern communication and sensing technologies (Kilic and Gungor, 2013). These power grids are a worthy domain where to apply open source technology (González et al., 2017).

This paper aims at providing a panoramic survey of recent scientific literature reporting the use of open source hardware, namely Arduino, in advanced technological scenarios, proving its validity for control and measurement purposes. Indeed, as a consequence of the benefits associated to open source technology, its inclusion in Research and Development (R&D) projects flows in a natural manner. In this sense, Arduino is being incorporated within a project dealing with the deployment and operation of a Smart Micro-Grid and its digital replica. This will be further commented in section 4.

The rest of the paper is organized as follows. The second section provides an overview of the main characteristics of the open source Arduino. Section 3 presents a survey about literature dealing with Arduino in a number of advanced scenarios. The application of Arduino for data sensing and acquisition in the context of research about a Smart Micro-Grid is reported in the fourth section. Finally, the main conclusions of the work are addressed.

2 OVERVIEW OF ARDUINO CHARACTERISTICS

This section is devoted to overview in a brief manner the most relevant features of the Arduino platform. Evidently, there is a great amount of information available in the Internet in this regard, following the principles of the open source philosophy.

Arduino is essentially a micro-controller mounted on a board with the circuitry required to connect sensors and actuators in an easy manner. In other words, it is an embedded prototyping board designed for electronics projects that demand repeated execution of some tasks (Costa and Duran-Faundez, 2018). It must be noted that Arduino is not a micro-processor/computer like for example Raspberry Pi, therefore, it has not embedded operating system.

Arduino chips are based on micro-controllers manufactured by Atmel, mainly of the family ATmega. It was originally designed and manufactured in Italy, in a project that started in 2005. The GNU General Public License (GPL) allows the manufacture of Arduino boards and software distribution by anyone.

Some popular models are: Uno, Mega, Yun, Due, Nano, Duemilanove, Extreme, Lilypad, just to name a few. Hence, the developer is able to select the model that fits better the application to deploy. In (Costa and Duran-Faundez, 2018) a detailed overview and comparison of different open source platforms, including Arduino, can be found.

The expansion boards, called shields, provide a number of enhancements of the Arduino functionalities and resources. Some examples of shields are those devoted to data storage through Secure Digital (SD) cards, Global Positioning System (GPS) functionality, direct connection of sensors/actuators, etc. About connectivity options, there are diverse shields to support communication means both wired and wireless. Some examples or wired links are RS-232, RS-485, and Ethernet. Available wireless means are Bluetooth, WiFi, ZigBee, Global System for Mobile communications (GSM), General Packet Radio Service (GPRS), or Radio Frequency IDentification (RFID). Figure 1 shows the aspect of an Arduino Mega and an Ethernet shield.

Concerning the software, to program and configure Arduino chips the open source Integrated Development Environment (IDE) is freely available. IDE uses a programming language based on a simplified version of the C++ language. It runs in a computer to which the board must be connected via Universal Serial Bus (USB) communication. This software allows designing the code for Arduino as well as to monitor its operation through the serial port of the computer. It includes a number of in-built programs to facilitate the learning and development of the applications.

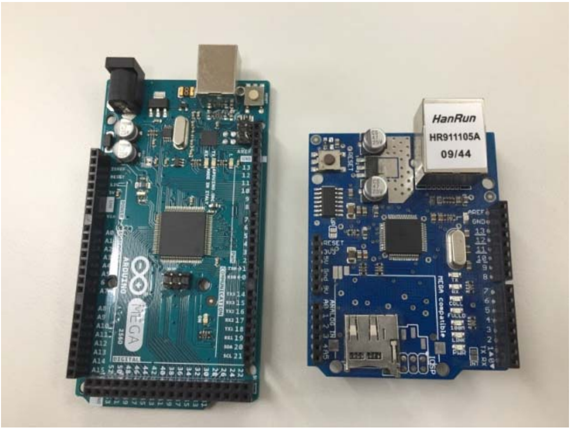

Figure 1: Physical aspect of an Arduino Mega board and an Ethernet shield.

Figure 2 shows a screenshot of the IDE with the code to conduct reading of analogue input signals. Apart from the IDE, there is an immense amount of libraries in the Internet that can be used for different purposes, from configuring an Ethernet connection to implement fuzzy control algorithms.

Figure 2: Screenshot of the Arduino IDE.

Additionally, some software packages widely used in scientific and industrial environments like Matlab or LabVIEW already include communication options to exchange data with Arduino boards. For instance, the LabVIEW Interface for Arduino (LIFA) toolkit enabled the data sharing between a virtual instrument of LabVIEW and an Arduino board through an USB connection.

There also exist web pages devoted to store, visualize and analyse data gathered by Arduino boards like thingspeak.com, facilitating and promoting the integration of these boards with cloud and IoT resources.

Among the advantages of the Arduino, the most relevant ones are now listed:

- Open source nature. Schematics, code and documentation related to Arduino and to the associated shields are available in the Internet.
- Low-cost components. The boards of Arduino as well as the shields and sensors/actuators are inexpensive.
- Easy-to-use. The time and effort required to develop and deploy Arduino-based systems are shorten due to the abovementioned availability of information.
- Community support. A large amount of tutorials, forums and videos supports knowledge sharing, facilitating Arduino-based projects.
- New products and software continuously released. The open source community constantly increases resources like libraries and shields, contributing to enhance existent arrangements or to design novel systems.

3 LITERATURE SURVEY ABOUT ARDUINO IN ADVANCED SCENARIOS

In this section, among the ever-increasing literature dealing with Arduino-based developments, recent publications devoted to advanced trends like Industry 4.0, cyber-physical approaches and so forth have been reviewed in order to illustrate the importance and suitability of Arduino.

In industrial environments, diverse paradigms are involved, like Industry 4.0, ICPSs, or cyber-manufacturing, therefore, Arduino boards have been widely reported as part of these scenarios. To begin with, it must be noted that Arduino has been identified as technology for Industry 4.0 and smart manufacturing by different publications (Trappey et al., 2017; Akerman et al., 2018; Chiarello et al., 2018). In (Pisching et al., 2018) an architecture for Industry 4.0-enabled factories is developed, where Arduino chips are used in a TCP/IP network. A fog computing framework for process monitoring and prognostics in cyber manufacturing systems is proposed in (Wu et al., 2017), measuring the vibrations of rotating machinery through Arduino. Another case of usage of Arduino for machine status prediction in the Industry 4.0 era is found in (Kuo et al., 2017).

Examples of Arduino utilization for ICPSs have been reported in (García et al., 2016; González-Nalda et al., 2017; Müller et al., 2017). About robotics, interesting works dealing with robotics and Arduino can be found in (Cela et al., 2013; Santos et al., 2016; Tejado et al., 2016; Lupetti, 2017).

Concerning facilities integrating Renewable Energy Sources (RES), a number of publications report the successful applications of Arduino. For instance, it has been used for data acquisition and monitoring of hydrogen fuel cells in (Calderón et al., 2016; Segura et al., 2017; Vivas et al., 2019), of photovoltaic systems in (Fuentes et al., 2014; Gad and Gad, 2015; Rahman et al., 2018), for weather sensing (Morón et al., 2018) or as part of simulation frameworks (Pagola et al., 2019). A special mention is devoted to Smart Grids, where Arduino devices have been used to perform measurement/sensing tasks (Batista et al., 2014; Pereira et al., 2015; Paul et al., 2016; Oprea et al., 2018, Raju et al., 2018).

Scenarios closely related to Smart Grids are Smart Cities and Smart Buildings. In this context, Arduino has been pointed out as an enabling technology for developments in Smart Cities (Costa and Duran-Faundez, 2018), used for the deployment of sensors in (Trilles et al., 2017). Regarding Smart Buildings, Arduino has been reported as means for smart energy metering in (Viciana et al., 2018).

The impact of ICT has enabled the development of systems that are remotely accessed and managed through the network. An important example of this trend is represented by remote laboratories where a user can visualize and/or operate a physically distant facility. A number of publications address the utilization of Arduino boards to implement this type of laboratories with engineering education orientation (Prada et al., 2016; Chacón et al., 2017; Heradio et al., 2019) or for general purposes (Mejías et al., 2017).

Cyber-security is of the utmost importance in the advanced hyper-connected setups, from modern manufacturing facilities to smart cities passing through critical infrastructures like power plants. In this sense, Arduino chips have been used to study cyber-security issues for industrial control systems in (Janicke et al., 2015; Bernieri et al., 2016; Alberca et al., 2016; Sasaki et al., 2017).

In the context of the so-called digital replicas (a virtual representation of physical assets), Arduino has been reported as part of the physical counterpart to perform measurement of different magnitudes in (Wei et al., 2017; Choi et al., 2018; Liu et al., 2018; Vrabic et al., 2018).

In order to illustrate the existing literature dealing with Arduino utilization in advanced frameworks, Table 1 summarizes the abovementioned publications.

Table 1: Surveyed publications dealing with Arduino and advanced scenarios.

Scenario	Publications
Industry 4.0 and related trends (ICPS, Robotics, etc.)	Cela et al., 2013; García et al., 2016; Santos et al., 2016; Tejado et al., 2016, Kuo et al., 2017; González-Nalda et al., 2017, Müller et al., 2017; Lupetti et al., 2017; Trappey et al., 2017; Wu et al., 2017; Akerman et al., 2018, Chiarello et al., 2018; Pisching et al., 2018
RES and Smart Grids	Batista et al., 2014; Fuentes et al., 2014; Gad and Gad, 2015; Pereira et al., 2015; Calderón et al., 2016; Paul et al., 2016; Segura et al., 2017; Morón et al., 2018; Oprea et al., 2018; Rahman et al., 2018; Vivas et al., 2018; Pagola et al., 2019
Smart Cities	Trilles et al., 2017; Costa and Duran-Faundez, 2018; Viciana et al., 2018
Remote laboratories	Prada et al., 2016; Chacón et al., 2017; Mejías et al., 2017; Heradio et al., 2019
Cyber-security	Janicke et al., 2015; Alberca et al., 2016; Bernieri et al., 2016, Sasaki et al., 2017
Digital replica	Wei et al., 2017; Choi et al., 2018; Liu et al., 2018; Vrabic et al., 2018

On the view of the surveyed publications, it has been proven that Arduino constitutes a versatile tool very valuable even for challenging scenarios.

4 APPLICATION OF ARDUINO IN R&D PROJECT ABOUT SMART MICRO-GRID

The present work is framed in a research project to implement a Smart Micro-Grid (SMG) integrating renewable energy sources with hydrogen and to develop its digital replica.

SMGs can be defined as small scale SG which can be autonomous or grid-tied (Koohi-Kamali and Rahim, 2017). SMGs integrate physical elements in the power grid and cyber elements (sensor networks, communication networks, and computation core) to make the power grid operation effective (Yang et al., 2016).

The SMG of the aforementioned project combines photovoltaic energy and hydrogen generation/consumption to act as a self-sufficient eco-friendly energy system. A set of monocrystalline photovoltaic modules compose the Photovoltaic Subsystem (PVS). A Polymer Electrolyte Membrane Hydrogen Generator (PEM-HG) and a Polymer Electrolyte Membrane Hydrogen Fuel Cell (PEM-HFC) perform the generation and consumption of hydrogen respectively. The hydrogen is stored in a metal hydride tank whereas an electrochemical battery hosts the electrical flows, playing the role of DC Bus. Finally, DC and AC loads complete the micro-grid. A schematic diagram of the SMG is shown in Figure 3.

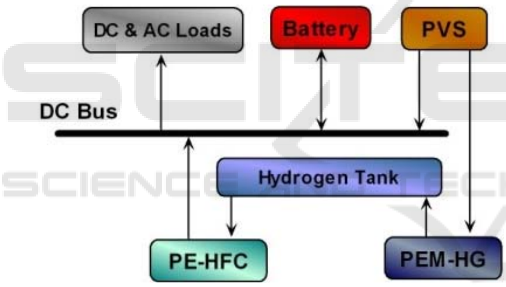

Figure 3: Scheme of the SMG.

An Automation and Monitoring System (AMS) carries out the management and surveillance of the energy flows and interactions between the nodes of the SMG. A Programmable Logic Controller (PLC) and a Supervisory Control and Data Acquisition (SCADA) system compose the AMS together with an Arduino board and a number of sensors (temperature, irradiance, current, voltage, etc.). The implemented energy control strategy aims to supply the loads and to produce hydrogen when a surplus of solar energy is available.

To build the digital replica of the SMG, massive data gathering is required, so Arduino boards are considered a valuable tool to implement cost-effective data acquisition equipment. Therefore, Arduino is being used to retrieve data which is considered non-critical for the automation/control tasks, namely environmental magnitudes like temperature and relative humidity. In the initial stage, it is being tested to measure the temperature of one of the photovoltaic modules through low-cost Lm35 sensors. In a previous stage, the retrieved data were validated through the comparison with those provided by a Pt-100 probe placed in the same module.

Particularly, an Arduino MEGA 2560 has been chosen. It is based on a micro-controller ATmega2560 and has 54 digital I/O as well as 16 analogue inputs. An Ethernet shield provides Ethernet connectivity in order to share the sensor measurements with the monitoring system. Such a system is based in the package LabVIEW of National Instrument and is responsible of gathering, processing and representing the operational data of the SMG. The structure of the AMS is depicted in Figure 4.

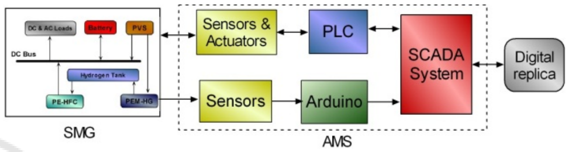

Figure 4: Block diagram of the AMS for the SMG.

5 CONCLUSIONS

The presence of open source systems in technological frameworks is growing day by day. In particular, open source hardware Arduino has become a powerful environment to accomplish control and measurement tasks. This paper has presented a literature survey about recent applications of this open source device in advanced scenarios like those related to Industry 4.0, ICPSs, and so forth, in order to show its suitability.

Regarding the digital transformation of the power grids, Smart Grids, Arduino is being also successfully used. Therefore, its inclusion in an on-going R&D project about a SMG and its digital replica has been expounded. Future guidelines aim to the development of a data acquisition system based on Arduino for massive data gathering in the SMG.

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REFERENCES

Akerman, M., Fast-Berglund, A., Halvordsson, E., Stahre, J. Modularized assembly system: A digital innovation hub for the Swedish Smart Industry. *Manufacturing Letters* 2018, 15, 143-146.

Alberca, C., Pastrana, S., Suarez-Tangil, G., Palmieri, P., 2016. Security analysis and exploitation of arduino devices in the internet of things. *ACM International Conference on Computing Frontiers*, Como, Italy.

Arduino Online. Available: www.arduino.cc (accessed on 30 January 2019)

Babiceanu, R.F., Seker, R., 2016. Big Data and virtualization for manufacturing cyber-physical systems: A survey on the current status and future work. *Computers in Industry*, vol. 81, pp. 128-137.

Batista N.C., Melício R, Mendes V.M.F., 2014. Layered Smart Grid architecture approach and field tests by ZigBee technology. *Energy Conversion and Management*, vol. 88, pp. 49–59.

Batista, N.C., Melício, R., Mendes, V.M.F., 2017. Services enabler architecture for smart grid and smart living services providers under industry 4.0. *Energy and Buildings*, vol. 141, pp. 16-27.

Bernieri, G., Del Moro, F., Faramondi, L., Pascucci, F., 2016. A testbed for integrated fault diagnosis and cyber security investigation. *International Conference on Control, Decision and Information Technologies (CoDIT)*, St. Julian's, Malta.

Calderón, A.J., González, I., Calderón, M., Segura, F., Andújar, J.M., 2016. A New, Scalable and Low Cost Multi-Channel Monitoring System for Polymer Electrolyte Fuel Cells. *Sensors*, vol. 16(3), pp. 349.

Calderón Godoy, A.J., González Pérez, I., 2018. Integration of Sensor and Actuator Networks and the SCADA System to Promote the Migration of the Legacy Flexible Manufacturing System towards the Industry 4.0 Concept. *Journal of Sensor and Actuator Networks*, vol. 7, pp. 23.

Cela, A., Yebes, J.J., Arroyo, R., Bergasa, L.M., Barea, R., López, E., 2013. Complete low-cost implementation of a teleoperated control system for a humanoid robot. *Sensors*, vol. 13(2), pp. 1385-1401.

Chacón, J., Saenz, J., de la Torre, L., Diaz, J.M., Esquembre, F., 2017. Design of a Low-Cost Air Levitation System for Teaching Control Engineering. *Sensors*, vol. 17, pp. 2321.

Chiarello, F., Trivelli, L., Bonaccorsi, A., Fantoni, G., 2018. Extracting and mapping industry 4.0 technologies using Wikipedia. *Computers in Industry*, 100, 244-257.

Choi, J., Jang, I., Lee, D., Son, Y., 2018. A virtual twinning system for user-centered eidetic human-object interaction. *IEEE International Conference on Consumer Electronics (ICCE)*, Las Vegas, NV, USA.

Colombo, A.W., Karnouskos, S., Kaynak, O., Shi, Y., Yin, S., 2017. Industrial Cyberphysical Systems. A Backbone of the Fourth Industrial Revolution. *IEEE Industrial Electronics Magazine*, vol. 11(1), pp. 6-16.

Costa, D.G., Duran-Faundez, C., 2018. Open-Source Electronics Platforms as Enabling Technologies for Smart Cities: Recent Developments and Perspectives. *Electronics*, vol. 7, pp. 404.

Fisher, R., Ledwaba, L., Hancke, G., Kruger, C., 2015. Open Hardware: A Role to Play in Wireless Sensor Networks? *Sensors*, vol. 15, pp. 6818-6844.

Fuentes, M., Vivar, M., Burgos, J.M., Aguilera, J., Vacas, J.A., 2014. Design of an accurate, low-cost autonomous data logger for PV system monitoring using Arduino™ that complies with IEC standards. *Solar Energy Materials & Solar Cells*, vol. 130, pp. 529-543.

Gad, H.E., Gad, H.E., 2015. Development of a new temperature data acquisition system for solar energy applications. *Renewable Energy*, vol. 74, pp. 337-343.

García, M.V., Irisarri, E., Pérez, F., Estévez, E., Marcos, M., 2016. OPC-UA Communications Integration using a CPPS architecture. *IEEE Ecuador Technical Chapters Meeting*, Guayaquil, Ecuador.

González, I., Calderón, A.J., Andújar, J.M., 2017. Novel Remote Monitoring Platform for RES-Hydrogen based Smart Microgrid. *Energy Conversion and Management*, vol. 148, pp. 489-505.

González, I., Calderón, A.J., Figueiredo, J., Sousa, J.M.C., 2019. A Literature Survey on Open Platform Communications (OPC) Applied to Advanced Industrial Environments. *Electronics*, vol. 8, pp. 510.

González-Nalda, P., Etxeberria-Agiriano, I., Calvo, I., Otero, M.C., 2017. A modular CPS architecture design based on ROS and Docker. *International Journal on Interactive Design and Manufacturing*, vol. 11(4), pp. 949-955.

Heradio, R., Chacón, J., Vargas, H., Galán, D., Saenz, J., De La Torre, L., Dormido, S., 2019. Open-Source Hardware in Education: a Systematic Mapping Study. *IEEE Access*, In press.

Industrie 4.0 homepage. Available: http://www.plattform-i40.de/I40/Navigation/EN/Home/home.html (accessed on 25 January 2019)

Janicke, H., Nicholson, A., Webber, S., Cau, A., 2015. Runtime-Monitoring for Industrial Control Systems. *Electronics*, vol. 4(4), pp. 995-1017.

Kilic, N., Gungor, V.C., 2013. Analysis of low power wireless links in smart grid environments. *Computer Networks*, vol. 57, pp. 1192–1203.

Koohi-Kamali, S., Rahim, N.A., 2017. Coordinated control of smart microgrid during and after islanding operation to prevent under frequency load shedding using energy storage system. *Energy Conversion and Management*, vol. 127, pp. 623–646.

Kuo, C.J., Ting, K.C., Chen, Y.C., Yang, D.L., Chen, H.M., 2017. Automatic machine status prediction in the era of Industry 4.0: Case study of machines in a spring factory. *Journal of Systems Architecture*, vol. 81, pp. 44-53.

Lupetti, M.L., 2017. Shybo. An open-source low-anthropomorphic robot for children. *HardwareX*, vol. 2, pp. 50-60.

Liu, C., Xu, X., Peng, Q., Zhou, Z., 2018. MTConnect-based Cyber-Physical Machine Tool: a case study. *Procedia CIRP*, vol. 72, pp. 492-497.

Martinez, B., Vilajosana, X., Kim, I.H., Zhou, J., Tuset-Peiró, P., Xhafa, A., Poissonnier, D., Lu, X., 2017. I3Mote: An Open Development Platform for the Intelligent Industrial Internet. *Sensors*, vol. 17, pp. 986.

Mejías, A., Reyes, M., Márquez, M.A., Calderón, A.J., González, I., Andújar, J.M. 2017. Easy handling of sensors and actuators over TCP/IP Networks by Open Source Hardware/Software. *Sensors*, vol. 17, 94, 2017.

Morón, C., Diaz, J.P., Ferrández, D., Saiz, P., 2018. Design, Development and Implementation of a Weather Station Prototype for Renewable Energy Systems. *Energies*, vol. 11, pp. 2234.

Müller, M., Wings, E., Bergmann, L., 2017. Developing Open Source Cyber-Physical Systems for Service-Oriented Architectures Using OPC UA. *IEEE 15th International Conference on Industrial Informatics (INDIN)*, Emden, Germany.

Oprea, S.-V., Bâra, A., Uță, A.I., Pîrjan, A., Căruțașu, G., 2018. Analyses of Distributed Generation and Storage Effect on the Electricity Consumption Curve in the Smart Grid Context. *Sustainability,* vol. 10, pp. 2264.

Pagola, V., Peña, R., Segundo, J., Ospino, A., 2019. Rapid Prototyping of a Hybrid PV–Wind Generation System Implemented in a Real-Time Digital Simulation Platform and Arduino. *Electronics*, vol. 8, pp. 102.

Paul, S., Parajuli, A., Barzegaran, M.R., Rahman. A., 2016. Cyber physical renewable energy microgrid: A novel approach to make the power system reliable, resilient and secure. *IEEE Innovative Smart Grid Technologies*, Melbourne, VIC, Australia.

Pereira, R., Figueiredo, J., Melicio, R., Mendes, V.M.F., Martins, J., Quadrado, J.C., 2015. Consumer energy management system with integration of smart meters. *Energy Reports*, vol. 1, pp. 22-29.

Pisching, M.A., Pessoa, M.A.O., Junqueira, F., Filho, D.J., Miyagi, P.E., 2018. An architecture based on RAMI 4.0 to discover equipment to process operations required by products. *Computers and Industrial Engineering*, vol. 125, pp. 574-591.

Prada, M.A., Reguera, P., Alonso, S., Morán, A., Fuertes, J.J., Domíngez, M., 2016. Communication with resource-constrained devices through MQTT for control education. *IFAC-PapersOnLine*, vol. 49(6), pp. 150-155.

Rahman, M.M., Selvaraj, J., Rahim, N.A., Hasanuzzaman, M., 2018. Global modern monitoring systems for PV based power generation: A review. *Renewable and Sustainable Energy Reviews*, vol. 82(3), pp. 4142-4158.

Raju, L., Morais, A.A., Milton, R.S., 2018. Advanced Energy Management of a Micro-grid Using Arduino and Multi-agent System. *Lecture Notes in Electrical Engineering*, vol. 446, pp. 65-76.

Santos, D., Silva Junior, A.G., Negreiros, A., Vilas Boas, J., Alvarez, J., Araujo, A., Aroca, R.V., Gonçalves, L.M.G., 2016. Design and Implementation of a Control System for a Sailboat Robot. *Robotics*, vol. 5, pp. 5.

Sasaki, T., Sawada, K., Shin, S., Hosokawa, S., 2017. Fallback and Recovery Control System of Industrial Control System for Cybersecurity. *IFAC-PapersOnLine*, vol. 50, pp. 15247-15252.

Segura, F., Bartolucci, V., Andújar, J.M., 2017. Hardware/Software Data Acquisition System for Real Time Cell Temperature Monitoring in Air-Cooled Polymer Electrolyte Fuel Cells. *Sensors*, vol. 17(7), pp. 1600.

Tejado, I., Serrano, J., Pérez, E., Torres, D., Vinagre, B.M., 2016. 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.

Thames, L., Schaefer, D., 2016. Software-defined Cloud Manufacturing for Industry 4.0. *Procedia CIRP*, 52, 12-17.

Trappey, A.J.C., Trappey, C.V., Govindarajan, U.H., Chuang, A.C., Sun, J.J., 2017. A review of essential standards and patent landscapes for the Internet of Things: A key enabler for Industry 4.0. *Advanced Engineering Informatics*, vol. 33, pp. 208-229.

Trilles, S., Calia, A., Belmonte, O., Torres-Sospedra, J., Montoliu, R., Huerta, J., 2017. Deployment of an open sensorized platform in a smart city context. *Future Generation Computer Systems*, vol. 76, pp. 221-233.

Viciana, E., Alcayde, A., Montoya, F.G., Baños, R., Arrabal-Campos, F.M., Zapata-Sierra, A., Manzano-Agugliaro, F., 2018. OpenZmeter: An Efficient Low-Cost Energy Smart Meter and Power Quality Analyzer. *Sustainability*, vol. 10, pp. 4038.

Vivas, F.J., Heras, A., Segura, F., Andújar, J.M., 2019. Cell voltage monitoring All-in-One. A new low cost solution to perform degradation analysis on air-cooled polymer electrolyte fuel cells. *International Journal of Hydrogen Energy*, In press.

Vrabic, R., Erkoyuncu, J.A., Butala, P., Roy, R., 2018. Digital twins: Understanding the added value of integrated models for through-life engineering services. *Procedia Manufacturing*, vol. 16, pp. 139-146.

Wei, C.-C., Lee, Y, Cao, K.S., Lee, W., 2017. Implementation of a data acquisition system for heterogeneous machines. *IEEE/SICE International Symposium on System Integration (SII)*, Taipei, Taiwan.

Wu, D., Liu, S., Zhang, L., Terpenny, J., Gao, R.X., Kurfess, T., Guzzo, J.A., 2017. A fog computing-based framework for process monitoring and prognosis in cyber-manufacturing. *Journal of Manufacturing Systems*, vol. 43, pp. 25-34.

Yang, Q., An, D., Yu, W., Tan, Z., Yang, X. Towards Stochastic Optimization-Based Electric Vehicle Penetration in a Novel Archipelago Microgrid. *Sensors* 2016, vol. 16, pp. 907.