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Configuration of an IoT microhydraulic power generation system for education

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ABSTRACT

Internet of things (IoT) involves the communication of all kinds of things embedded with sensors, electronics, software and people connected to the internet. Knowledge of IoT in the classroom provides an experience for engineering students to explore different career options. Under this scope, an IoT platform on the Arduino UNO and Raspberry Pi 3 development boards was built for academic purposes. The IoT platform was configured to monitor a microhydraulic power generation system used for the study of small-scale hydraulic power production, using a hydraulic head provided by a system of hydraulic pumps in series and/or parallel connection. The platform was designed considering a monitoring station for the acquisition of analog, digital, SPI and PWM data; a control station that receives data from the monitoring station and sends data to the cloud. The communication between modules was established using a publication/subscription system. The platform allows to registrate, visualize and process data directly in the cloud. Meaning that the IoT systems connected to this platform can be monitored from a cell phone, tablet or PC with internet access, promoting immediate access to the emerging information generated in the operating system.

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1. INTRODUCTION

The main components of Industry 4.0 related to engineering are the internet of things (IoT), data analytics, engineering simulation using virtual reality and augmented reality, manufacturing optimization and sustainable processes to reduce energy consumption [1]-[3]. Through IoT systems, an engineer may be able to gather large amounts of data from sensors and processes, which can be used for the optimization of manufacturing processes, and for real-time monitoring and control applications [4], [5].

Under this scope, it is important to prepare students in the recent trends on the use of technology in the industry. The design of projects of IoT may improve their technology abilities and also might increase their job seeking opportunities by enhancing their courses curriculum. As mentioned in [6], the inclusion of IoT projects may help the students to be industry ready for smart applications and to introduce a multidisciplinary working environment for the development of projects.

Engineering students should engage in hands-on projects with the purpose to solve real world design problems by applying technical knowledge. Taheri *et al.* [7], mention that most universities use makerspaces to provide an environment to promote the interaction of education, experimentation and communication with the purpose of offering opportunities for hands-on and technical experience. A survey presented in [8] concludes that IoT systems in education and research, motivates either the students and the staff by using modern techniques in classrooms. Also, the use of smart laboratories creates engagement and facilitate scientific communication among teachers and students.

IoT systems are composed of sets of sensors and intelligent systems that in most cases require integration stages that may include pre-processing adjustments to calibrate, filter, amplify or compensate signals from various sensors [9], [10]. IoT systems are supported by the cloud so the limitations of data access, storage, scalability and computing are solved through services that offer different cloud computing architectures [11]-[13].

The implementation of IoT technology for industrial applications is known as the industrial internet of things (IIoT). According to [9], the IIoT architecture includes three basic elements or tiers: edge, platform, and enterprise. The edge collects valuable data and transfers it to the platform, which offers administrative, operations and data analytics functions. The enterprise level produces interfaces for end users between other support systems.

The IIoT architecture varies according to its application, several platforms have been designed and successfully implemented for academic engineering project applications. Guo *et al.* [14] present an IoT platform for engineering education and research that includes gateways, personal-area and local-area wireless connections, end nodes with sensors, actuators, data base, cloud and users. The design considerations include flexibility, easiness and it was developed using lowcost commercially available devices. Fabrício *et al.* [15], the proposed IoT platform uses sensor-actuator modules as monitoring stations that are connected via USB to a data concentrator that is used as a control center. The monitoring station is implemented in Arduino UNO R3, while the control center is programmed in Python and contained in an Acer Aspire 2920z personal computer. The data is sent to a cloud-hosted monitoring system through Tago. The IoT platform presented in [16] uses the Thingspeak cloud service. The platform is based on the use of an MCP 3208 analog-digital converter and a Raspberry Pi board, that works as a monitoring station and control center. In the arrangement generated in [17], the authors present the conversion of a power generation system to a monitoring IoT system through a web interface which is based on a web server programmed on a Raspberry Pi board. In the IoT platform proposed in [18], the signals are acquired, adapted and processed through electronic modules with specific design for the application. The processed data is sent directly to the cloud using IoT2040 gateways.

In this work, an IoT platform was used to interconnect a microhydraulic power generation system with the cloud. The data generated by the arrangement of sensors and actuators is collected, processed and visualized during the operation of the microhydraulic power generation system. The cloud service allows to observe the system's water flux, the water pressure, the power generation and the relationship among these variables.

Based on the IIoT architectures previously described, the IoT platform configured for the microhydraulic power generation system was developed for academic purposes, considering three main objectives. The first objective is to collect data from both digital and analog sensors commonly used in the engineering field to monitor temperature, humidity, pressure, liquid levels, voltage, among others. The second objective is to control actuators using digital signals. As in [19]-[21], the third objective is to use an IoT cloud service that can serve as a repository for sensor data and that can be accessed using the internet.

The IoT platform is based on Arduino and Python, considering the Arduino UNO R3 (UNO) and the Raspberry Pi 3 (RPi 3) development boards. The cloud service is the free version of Thingspeak that includes tools to visualize and process data using computers, tablets, and smartphones.

2. METHOD

2.1. IoT platform

As suggested in [22], the IoT platform is built with the following architecture: a physical layer or hardware layer that includes the sensors; a computing layer to convert sensor signals into numerical data, to perform computations, to adjust data, and to develop interfaces to communicate with the user; an interface layer or communication layer to establish communication between the physical layer and the computing layer.

The monitoring station (hardware layer) is based on an UNO board that collects data in order to send it to the control center (computing layer), this stage works also as a trigger for the actuators. The control center is portable and adaptable with a graphical user interface (GUI) that provides information from sensors and actuators. The control center creates a communication port with the user and the cloud service, it is built in a RPi 3 board due to its portability and its ability to host Python. The user can view the sensor data in real time through GUI, developed with Tkinter, by connecting a PC screen or a liquid-crystal display (LCD) to the board. The user is able to visualize data streams that can be published by various devices in the cloud service Thingspeak, but it is also able to perform online analysis and process data using MATLAB code.

The functional architecture of the platform is shown in Figure 1. The sensors communicate with UNO using digital and analog signals or pulse width modulation (PWM), other sensors use more specific communication protocols such as I2C or serial peripheral interface (SPI), which allows a single *master* device and one or more *slave* devices to communicate. Communication with Thingspeak is established through Python code that runs in parallel (threading) within the control center. The interaction between the system and the user occurs through the GUI, where the user can observe the current state of the system and also can activate or deactivate the actuators. UNO and RPi 3 communicate over a local area network (LAN), UNO connects to LAN using Ethernet while RPi 3 uses WiFi.

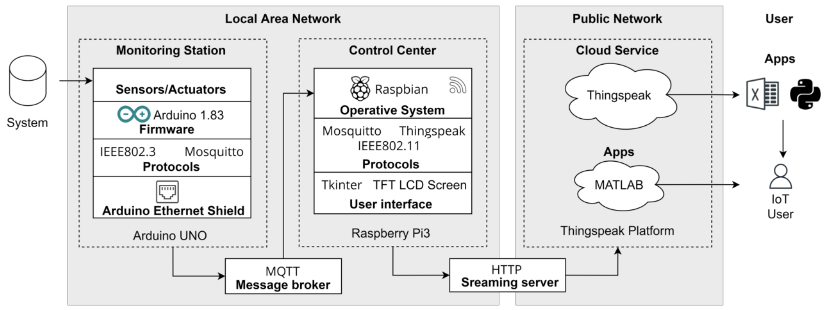

Figure 1. Architectural model of the IoT platform that includes the interaction of the system function

2.2. Hardware y protocols

Raspberry Pi is a low cost and high portability small computer that can run on Linux or Windows based operating systems, its default operating system is Raspbian Pi OS. The control center gets data from the monitoring station over a LAN and establishes communication with the cloud service offered by the Thingspeak platform. Since all tasks must occur in real time, functions in Python are implemented in parallel (threading or multithreading). The control center transmits data to Thingspeak using the Python Thingspeak library to enable this communication. Each signal is assigned to a channel that can be named to maintain a labeled record of the data.

The communication between Python and Arduino is established using a system of publication/subscription through a broker. The UNO board works as an HTTP client with the Python MQTT web server IoT messaging protocol. The IoT platform uses Mosquitto midldeware to enable MQTT on RPi 3. MQTT uses TCP/IP for network connectivity. The MQTT Mosquitto broker is used to create a communication channel between Arduino and Python: Mosquitto uses the MQTT corridor as a platform for message communication, while organizing the MQTT editor and subscriber clients at the Arduino and Python endpoints. Each device is connected to a LAN using a standard communication protocol, Ethernet with the IEEE 802.3 standard and WiFi with the IEEE 802.11 standard. In order to connect the UNO the LAN, an Ethernet Shield or a WiFi module is connected to the board.

3. RESULTS AND DISCUSSION

The IoT platform was used in a microhydraulic power generation system that consists of an arrangement of two hydraulic pumps that can be connected in series or parallel, offering a wide range of variable pressure and variable flow conditions to the system. This pump system feeds a pipe system connected to an electric generator (micro hydro generator F50-12V). In engineering, this type of arrangements are used to perform analysis of hydraulic circuits in order to observe changes in the water pressure and the water flow in pumping systems. In a series configuration the water pressure increases, in a parallel configuration the water flow increases.

The microhydraulic power generation system is described by a diagram in Figure 2. The system has three points for pressure measurement: i) two analog sensors P1 and P2, one digital sensor P3 (1.2MPa water pressure sensor), ii) two digital points for flow measurement: Q1, Q2 (YF-S201 flowmeter), and iii) five manual valves for the manipulation of the water flow.

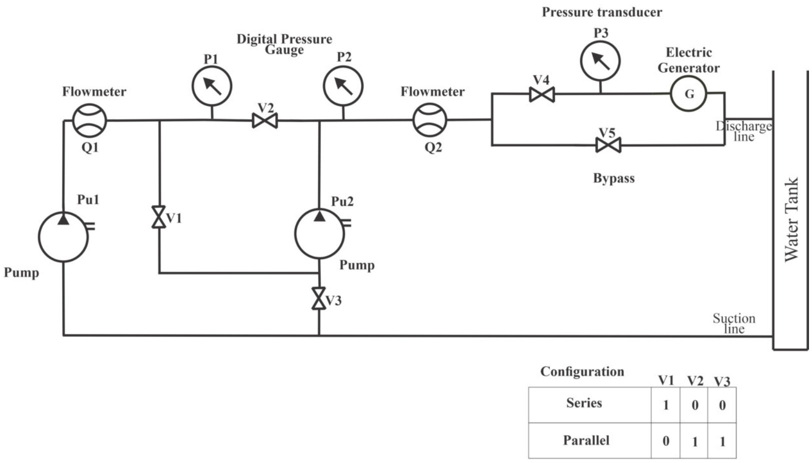

Figure 2. Diagram of the microhydraulic power generation system

Figure 3 shows the microhydraulic power generator system with the implementation of the IoT platform as configured in the lab. Figure 3(a) shows the monitoring station. A conditioning signal stage was added in order to adjust the output voltage of the microhydraulic generator from 0-12 V to 0-5 V. Figure 3(b) shows the control center implemented in a RPi 3 board with a LCD touchscreen, although it is not mandatory, a keyboard and a mouse were added to simplify the manipulation of the control center. Figure 3(c) shows the microhydraulic power generation system.

(a) (b) (c)

Figure 3. Physical components of the microhydraulic power generation system with IoT: (a) monitoring station, (b) control center with display, and (c) microhydraulic power generation eench

To upload the data to the cloud service, four fields keep records of the water flow measured in flow 1 (Q1), the water flow measured in flow 2 (Q2), the pressure measured in pressure (P3) and the voltage delivered by voltage generator (G). The registration of data in the cloud occurs every 30 seconds.

In the experiment conducted for this work, Pu1 was activated allowing the water to flow in Q1, after that Pu2 was activated in a parallel configuration, increasing the water flux in Q2. Both pumps worked under similar operational conditions so that the flow in Q2 was doubled. The water pressure and the power generation was observed under this conditions and finally, V4 was closed and V5 was opened in order to observe a decrease of the water pressure in P3. The data of the experiment was stored in the cloud, so it was exported as a comma-separated values (CSV) file and processed in MATLAB to create curves in order to observe the relations among the data.

Eight visualizations were created to analyze the most important parameters for the production of microhydraulic energy in the system (Figure 4), with the aim to observe the transformation of hydraulic power to electric power. Figures 4(a) and 4(b) shows the water flow registered in Q1 and Q2, respectively. Figure 4(c) shows the water pressure registered in P3, while Figure 4(d) shows the voltage in the microhydraulic generator. The relation between the water flow in Q1 and Q2 helped to observe the water flow generated by the hydraulic pumps.

This water flow feeds the microhydraulic generator depending on the connection between the pumps Pu1 and Pu2 (in series or parallel), as shown in Figure 4(e). Figure 4(f) shows the relation between the pressure measured at P3 and the voltage generated by the electric generator G. Figure 4(g) contains the relation between the flow rate in Q2 and the voltage at G. Figure 4(h) shows the relations between the pressure at P3 and the flow at Q2. According to the results, it was found that the relationship between Flow 1 and Flow 2 is almost linear. The maximum generated voltage by the microhydraulic power generator is reached at a water pressure of 100 Mpa and when the water flow measured in Q2 (Flow 2) reaches approximately 20 litres per minute. It can also be observed that the water pressure in P3 decreases almost linearly when the water flow in Q2 increases.

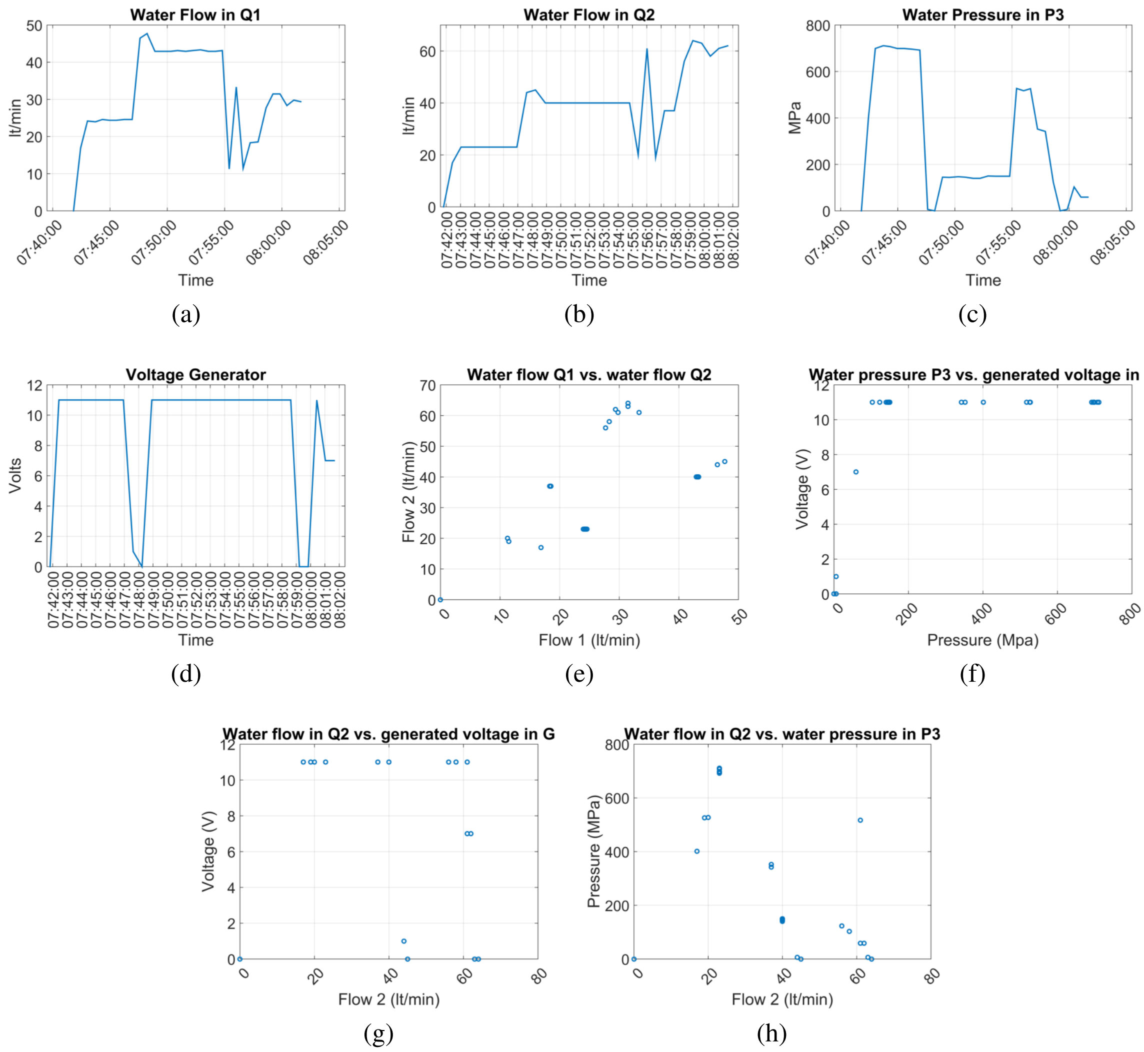

Figure 4. MATLAB visualizations of the data provided by the microhydraulic power generation system with IoT: a) water Flow 1 in Q1, b) water Flow 2 in Q2, c) water Pressure in P3, d) generated voltage in G, e) flow 1 and flow 2 relation, in Q1 and Q2, f) relation of the pressure in P3 and the generated voltage in G, g) relation of the flow in Q2 and the voltage in G, and h) relation of the pressure in P3 and the flow in Q2

The application of the IoT platform in the microhydraulic power generation system was implemented using a single monitoring station. The fact that different modules can be connected to the control center makes the system scalable, allowing the integration of various systems that can provide information of interest to measure either the hydraulic and the electric operational ranges. In similar projects described in [15] and [18], the authors use monitoring modules to acquire the sensor signals that are sent to a control center. The control station receives the data and sends it to the cloud [16], [17].

The microhydraulic power generation system with IoT could be successfully implemented using commercial, open source and relatively low cost development boards. Fabrício *et al.* [15] explained the monitoring station was also implemented in UNO. The platforms described in [15]-[17] use control stations that can be implemented on Raspberry Pi boards.

For this work, only visualizations were included in the cloud service, but it is important to remember that through MATLAB, Thingspeak integrates numerical computing in the cloud. The services that allow computing in the cloud favor its application in various engineering projects. Researchers [15], [16] use cloud services to process data in the cloud, while [17] and [18] use web servers based on Python and Raspberry Pi. As mentioned in [23–25] it is important to consider areas such as privacy and security of the IoT system. Hence, using affordable computers such as RPi provides a good platform to implement suitable data protection techniques.

4. CONCLUSION

The IoT platform presented in this work has an architecture that can be adapted to different inputs and outputs through simple modifications of the code of the monitoring station in Arduino, as in the control center based on Python. The platform allows data to be sent to the cloud, updating the records in programmable time periods according to the user's needs. The fact that the implementation of the system can be achieved with commercial, open source and relatively low-cost boards, encourages the students to redesign the architecture of the platform in order to create different configurations, or to integrate complex systems structured as several stations. So the students can build various academic engineering projects and integrate them as IoT systems. The MATLAB and Python support of the Thingspeak cloud service, engages the user to an efficient tool to generate different visualizations; and to perform data analysis that are fully integrated and run in the cloud.

The implementation of IoT platforms with an architecture based on monitoring stations connected to a control center allows versatility for the integration of engineering projects as IoT systems for academic purposes. In terms of interoperability, several companies focused on the commercialization of open source development boards have been developing specific technology for IoT applications. For example, node-type modules, whose purpose is to allow sensors to connect directly to the network. The UNO boards become systems connected to the network with the use of an Ethernet Shield or WiFi Shield module, obtaining stations that are capable of receiving and sending signals from digital and analog sensors commonly used in engineering projects.

Control centers establish a data reception and an exit point, implementing these control centers in both personal computers and single board computers allows the designer to consider encryption and data protection strategies. The later allows the students to cover areas such as privacy and security of the IoT system. Arduino boards are low-cost commercial devices that have been widely popularized in education for teaching microcontroller programming. There are a variety of sensors that have been converted into modules compatible with Arduino, promoting the integration of systems or prototypes with a wide range of measurement options. For industrial applications or technology integration projects, it is advisable to consider more specific devices designed for IIoT, such as gateway IoT nodes and IoT nodes.

Future works to improve this IoT platform includes to add more sensors to redesign the hydraulic system in order to monitor the performance of the microhydraulic power generator by modifying the operational conditions of the hydraulic system. Also, a module to test encryption and data protection strategies may be added to the IoT platform architecture.

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