IoT Demonstration Platform for Education and Research

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***Abstract*—Internet of things (IoT) and digitalization of industries are changing the skills required from newly graduated engineers. To truly master these skills, they must be included in the curriculum, and a platform on which students can create IoT projects is needed. The research of IoT and related areas also benefits from such a platform. The platform presented in this paper focuses on a simple coffee maker but applies techniques and tools which are also used in larger scale projects, thereby making the system a valid solution for education. The devices and tools applied must be selected to satisfy education and research requirements. The proposed platform is built on IBM Cloud, and it uses Raspberry Pi as an edge device. Hands-on experience with a real IoT platform brings definite advantages that may otherwise be difficult to achieve.**

***Index Terms*—e-Learning in Digital Ecosystems, Digital Ecosystem Basic Technologies, Infrastructures for industrial informatics**

I. Introduction

Internet of things (IoT), where things and sensors are connected to each other via the Internet [1], is gaining ground worldwide. The world is full of equipment and different systems, or "things", which are sources of vast amounts of data. When collected, these data can be used, for example, to provide users with services and new information. One of the earliest applications in IoT was Quentin Stafford-Fraser's *Trojan Room Coffee Pot*, a web camera pointed directly to a coffee jug to give information on whether there is coffee available in the office or not [2]. Nowadays, IoT is gaining popularity on a larger scale, as the ongoing fourth industrial revolution is transforming industries and the way they collect and use the data available with the industrial internet of things (IIoT) [3].

As industries become increasingly digitalized, university education must answer to these changes in order to keep up with the modern trend. Changes in the curricula of electrical engineering, systems engineering, and even mechanical engineering and business administration (MBA) are required to teach more IoT technologies [4]. Therefore, to ensure that graduated engineers and MBA have the required know-how in IoT technologies, there was a need for an IoT platform in a Finnish university for hands-on education. For this purpose, a demonstrative IoT platform on which the capabilities and possibilities of IoT systems were developed to be used in education of electrical engineering and MBA students, and in various research. Following Stafford-Fraser's footsteps, the platform was built around sensoring a coffee maker. The coffee maker was selected as the building ground for the IoT platform because of its simplicity and frequent use.

In this paper, we describe the decisions made during envisioning and implementing the IoT platform called *Café IoT*. This paper answers the following questions:

- What system architecture can be applied to implement an IoT platform to serve both research and education?
- What requirements do the educational goals in business and engineering disciplines set for the system in terms of architecture, interfaces, and further use of data?

This paper presents the techniques of data collection of a regular, non-smart household coffee maker and its surrounding environment. Refinement of data into new value for users is also presented and discussed. Although being a very simple application, the observations made in this paper can also be generalized into larger, even industrial scale IoT systems.

II. Requirements for the Platform

In order to construct a platform that suits both the educational and research-related use cases, a list of requirements must be specified for the system. In this section, we explore the intended use from the viewpoints of both education and research. It is notable that neither of the use case describes an *application*: broadly speaking, the requirements are related to

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a *readiness* to develop various kinds of applications based on different technologies and platforms.

First, we introduce the requirements and driving forces of using IoT in education. Then, the requirements for an IoT platform for research are presented, and finally, the requirements are gathered together to constitute a list of specifications that the platform has to meet in order for it to be useful in both use cases.

A. Requirements set by educational use

IoT systems are cyber-physical systems that connect the digital and physical worlds together. According to [5] and as discussed in [6], cyber-physical systems will be in a widespread use for example in the fields of engineering and computing. The rise of IoT and IIoT is also expected to create new jobs in the market for IoT experts [7]. Therefore, newly graduated engineers ought to master the required skills. Universities and other educational institutes should act fast, as IoT is still in its infancy [8]. The engineers graduating today play a key role in the development and deployment of future smart systems.

Considering student persistence, it is recommended to use educational methods that encourage to stay engaged with studies and that address issues relevant in the working life. Creative-minded students have a greater risk of dropping out of the curriculum if the educational methods do not allow them to use their creativity [9], [10]. It is also known that students put more effort when the problems they are presented with are similar to those they expect to face in the workplace after graduation [11]. Project courses are effective in learning both technological and project management skills [12]–[14], which are important in the working life. The project management performance can also be used in grading of the students.

IoT systems consist of many parts and can have a complex architecture. Thus, by using IoT as an educational tool, students can gain wide-scale knowledge. Implementation of an IoT system requires skills for example in programming, systems engineering, sensor technology, electronics, information technology, and data analytics. As these fields are present when working with IoT, learning by doing can take place. IoT has been shown to work as an educational tool in programming, even for complete beginners [15].

Hands-on experience with IoT has been shown to be an effective learning method in IoT [16]. Using these kinds of educational methods for IoT education requires a platform on which students can solve problems, explore solutions, and fail safely. An easily recoverable IoT platform allows this as the system can be easily reset to a stable state. To prepare students for working life IoT challenges, an IoT platform where projects are carried out should allow practicing and improving a wide area of skills.

Thus, the platform should incorporate many different types of connections, such as Bluetooth, Wi-Fi, USB, and general-purpose input-output (GPIO). Moreover, different data processing methods, cloud, and edge computing, should be used. The platform must be easily modifiable and the tools for development must be available for students. For example, the coffee maker must be located in a room accessible to students, and the cloud system must have free student access. The components of the system have to be easy-to-use enough. For example, in [19], the usage of modular IoT kits is presented as a viable solution.

Fig. 1. Break room where the platform is located. Daily activities are not affected by the sensor placements: IR sensor (1) monitors movement. Brewing of coffee is monitored with a multifunction power analyzer located in the breaker panel (2). The analyzer measures the energy consumption at the electrical outlets (4) that power the coffee maker (5). Environmental data are measured with a Bluetooth beacon located next to the Raspberry Pi (3), into which all data are collected. Raspberry Pi also acts as an IoT controller and a gateway to the Internet.

B. Requirements set by research use

The motivation to have an on-premises IoT platform for research purposes arises from the common needs of typical IoT-related research projects. An IoT platform located in a university allows fast testing of different IoT technologies, as changes in the platform are easy to deploy—there is no need for traveling to a remote data collection site, for example. Researchers also have full control over the platform and the data collection. The platform should have a somewhat modular structure so that for example new sensors can be tested and studied.

The research use of the platform sets requirements that are partially different from those set by the educational use. Research projects can be expected to have a more in-depth scope than student projects. On the other hand, the problems are possibly more open ended. It is unlikely that all needs of all or even most research projects can be thought of during the planning stage of the IoT platform. For this reason it is important that the platform has many interfaces that can be opened for external services if and when needed.

C. Summary of common requirements

In education and research, the requirements for the IoT platform are slightly divergent but also overlapping. Both use cases require the ease of use of the system, but from different perspectives. Research approaches the issue more from the aspects of tools and data usage and retrieval, whereas for students, the system also has to be easy to use as they do not necessarily have as much time resources available as researchers do. A modular architecture is important for both users.

Based on the presented user case-specific requirements, the platform should meet the following requirements to work well both in education and research:

- *Modular structure:* hassle-free deployment of new components
- *Easy-to-use components:* compatibility e.g. with IoT kits and high-level programming languages
- *Resourceful hardware:* wide-scale connectivity, adequate processing power
- *Accessible tools:* the tools used for development have to be easily accessible and shareable for students and research personnel. The tools have to be free for students.
- *Recoverability:* the platform has to be able to restore to a stable state if failures occur.
- *Connectivity:* the platform has to support a wide range of connection methods and interfaces.

With the presented requirements in mind, a demonstrative IoT platform can be built. The implementation and architecture of the system are discussed in the following.

III. Implementation

The platform presented in this paper, *Café IoT*, is focused on the collection and use of data from a coffee maker and its surroundings located in a break room of a Finnish university (Fig. 1). The break room features a double-jug coffee maker, capable of brewing two jugs simultaneously.

Although the platform itself does not describe a specific application, it was decided that the construction of the platform starts with the development of a simple demonstration application. This application can then be improved or extended by student projects, or used as a template for future applications. This demonstration application was designed to take the sensor data and refine them into information on whether there is coffee available or not. The application also provides information on how busy the break room is, should one prefer to have coffee in quiet or join others. People are also often interested in the environment, such as the room temperature and air humidity, and therefore, this information is also included.

The demonstration application measures and visualizes the amount of coffee brewed, simple information on room usage, and air quality measurements (temperature, humidity, and pressure). These application-specific goals determine the needs for sensors present in the system.

A. Technology background

An IoT system architecture usually consists of sensors (IoT devices) for data collection, an IoT gateway and/or IoT controller for on-site (edge) processing and data handling, an Internet connection, and a cloud server [17]. The parts of the architecture can be assigned to layers of a three-layer IoT architecture consisting of perception, network, and application

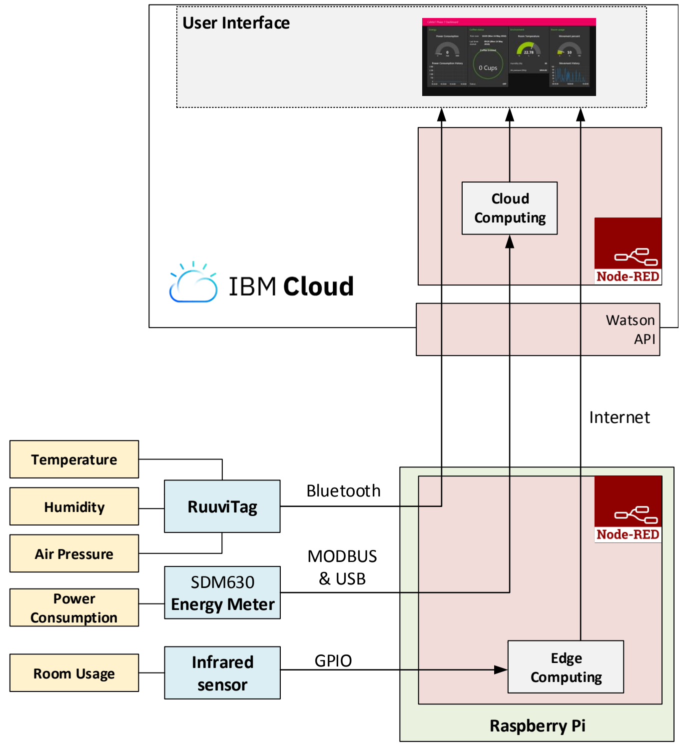

Fig. 2. Block chart of the system presenting the quantities measured and the sensors measuring them, the IoT controller & gateway Raspberry Pi and its wide range of different connections, and the flow of data. The "Cloud Computing" block in IBM Cloud contains the programming logic presented in Fig. 6. and the "Edge Computing" block contains the programming described in Chapter II, Section E.

layers [18]. The perception layer connects the digital and physical worlds together; it consists of the sensors and other hardware. There are a vast array of different sensors and IoT controllers available, and the best solution depends on the use case. As for the platform described in this paper, the selection of sensors and hardware is based on the needs of education and research.

The network layer represents the data connections in the system between the IoT devices, controllers, and the cloud. The application layer contains the smart features of an IoT system—the data analytics, service flows, and the actual value of the system. In some definitions, IoT is divided into five layers, one of which is the business layer [18]. The application and business layer solutions can be built on a cloud platform; in a case like the platform discussed in this paper, it is recommended. There are many different cloud providers offering IoT solutions as a platform-as-a-service (PaaS) model, including Amazon Web Services, Microsoft Azure, IBM Cloud, and Google Cloud. The cloud allows for example IoT device management, cloud processing, data storage, and data visualization.

The platform consists of an edge computer ("IoT controller", typically a single-board computer), sensors, local and cloud processing, and a user interface (Fig. 2). The different parts of the platform architecture are presented in further detail later in this chapter.

B. IoT controller

The main component of an IoT system is the IoT controller or controllers, to which sensors are connected. There is a wide selection of IoT-capable devices to choose from, from low-powered microcontroller boards to heavier computer equipment. The application of edge computing and multiple connection types sets certain requirements for the IoT controller, as it has to have enough compute power to execute the program code. In the system presented in this paper, Raspberry Pi 3 Model B, a single-board computer running Linux, was selected as an IoT controller for the break room because of the ease of use and the wide range of functions. The device is capable of connecting to the Internet—acting as an IoT gateway—and pre-processing of the data [20]. It is also easy to connect external measurement devices and sensors to the Raspberry Pi [20], and it is affordable as its price is less than forty euros. Raspberry Pi is well suited for educational use as it is running a full version of Linux making it is easy to configure, and it supports high-level programming languages like Python.

As the use of the platform evolves further from the initial demonstration application, it is likely that new sensors must be added to the system either by students or researchers. In that case there are two options: the sensor can be added to the existing IoT controller, or new IoT controllers can be connected to the cloud platform. Allowing student access to the edge device was considered to be a bad idea owing to the possibility of causing problems to the initial application or other applications based on the demonstration system. Therefore, adding new sensors requires adding a new IoT controller on the site. This approach has the added benefit of allowing the student or researcher teams to choose their own tools—they are not tied to work on a Raspberry Pi.

C. Sensors for the coffee maker

The monitoring of the coffee brewing process was decided to be implemented by measuring the energy consumption of the coffee maker. Energy consumption is a viable metric as it can also be used for energy cost analysis, and energy monitoring reflects green values featured in education. A direct correlation between the energy consumption of the coffee maker and the brew process was found by measuring the energy consumption. During the testing, both jugs were active, one with a full tank of water and one 60 percent full. Once the less full jug is ready, the power consumption halves, and once both are ready, the consumption decreases to approx. 50 W (Fig. 3). The power consumption of the coffee maker is approx. 1400 W per jug during brewing. The measurements were conducted with a Paget Trading Ltd. 9149 energy meter, which plugs directly to the electrical socket from which the coffee maker is powered. As the load characteristic of the coffee maker can be considered resistive, the accuracy of the affordable power meter can be deemed sufficient.

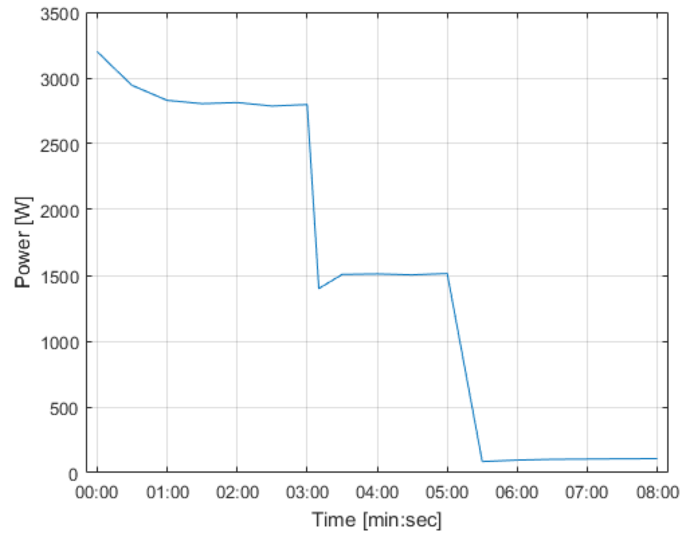

Fig. 3. Power consumption of the coffee maker. The coffee machine has two jugs, and the end of the brew of each jug can be detected. The power consumption of the coffee maker is approximately 1400 W per jug during brewing.

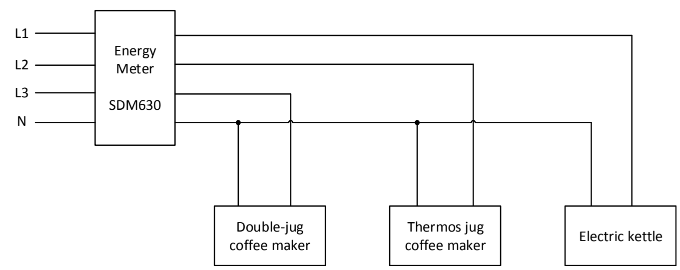

Fig. 4. Circuit diagram of the electrical installations in the break room. Three phases pass through the energy meter, and the power consumption of the double-jug coffee maker can be measured, if the maker is the only device using phase L3. The system allows also other kitchen appliances to be measured, but they are ignored in the first implementation of this platform.

The above-presented energy meter used to measure the energy consumption is not, however, suitable for IoT use because it is not capable of communicating with other devices. For the IoT platform, an Eastron SDM630 multifunction power analyzer was selected as a replacement. It is easily connectable to Raspberry Pi through Modbus and USB, and it can be installed on the DIN rail of the breaker panel. The meter was installed in the breaker panel so that the electrical wiring to the coffee maker goes through it. Thus, the power consumption of the coffee maker can be collected if no other devices are connected to the same socket group as the coffee maker. The break room also features an electric kettle and a thermos jug coffee maker. These appliances were connected to different groups in the breaker panel. Their energy consumption is measured and the data are transmitted to the cloud platform. These data are not used in the demonstration application, but they are available for other applications to be developed on the Café IoT platform (Fig. 4).

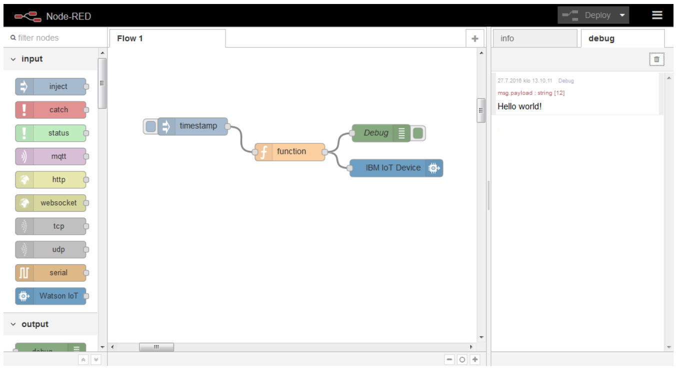

Fig. 5. Screenshot of Node-RED. It is a graphical programming tool, which consists of a drag-and-drop interface. With Node-RED, data flows can be controlled and data can be processed.

D. Environment sensing hardware

The quantities to be metered from the break room air were temperature, pressure, and humidity. There are different sensors available for Raspberry Pi capable of measuring these quantities. For the presented platform, a sensor device called RuuviTag was selected. RuuviTag is a battery-powered device, which was connected the IoT controller by Bluetooth. The device was selected because it contains the sensors necessary for measuring the desired quantities, and being wireless, it is easily employed in the break room.

The usage of the break room was monitored using a Panasonic EKMC1603111 passive infrared sensor. The sensor detects whether there is movement in its field of vision. The sensor model was selected because of its wide angle and distance of detection (102°× 92°, 12 m) and its digital output. A digital output makes programming of the sensor reading easier, because Raspberry Pi does not have any analog inputs. The sensor connects to Raspberry Pi's GPIO pins.

E. Software

A crucial task of an IoT controller is the control of data flows, for example, from the sensors to the cloud. The control of data flows in Raspberry Pi was implemented with Node-RED, a graphical programming tool designed for data flow control for example in the IoT use. It contains multiple premade blocks or nodes, which allow different data handling functions. Node-RED is proven suitable for education [21], and as all students may not have programming backgrounds or skills, programming with Node-RED is accessible as it is done using a drag-and-drop interface (Fig. 5) [22].

The data flow of the presented system has four steps: data collection, preprocessing & cloud integration, cloud processing, and visualization. The steps are presented in further detail below.

1) Data collection: The data flows start from the sensors, and the sensor data can be read with Node-RED, as it is also capable of running external scrips on the device it is running. Therefore, for example, Python scripts can be used for reading values from external devices. The data collection was implemented mostly using this feature; a script that reads and calculates the value of the movement sensor is started by Node-RED once a minute, and the result is returned to Node-RED. The RuuviTag sensor disc sends measurement data over Bluetooth once per second, and Node-RED was configured to catch the data transmission as it detects it.

The data collection from the energy meter, on the other hand, was implemented using an HTTP interface named GoSDM. With GoSDM, a local server can be set up on the Raspberry Pi, and measurements can be read using a REST API (Representational State Transfer Application Programming Interface.) The API is called once a second by Node-RED.

All the data are eventually integrated into IBM Cloud for further processing. The integration process uses the IBM Watson Internet of Things platform, where each IoT gateway is registered and an unique API is created for data flow. This allows secure data transactions between the IoT gateway and the cloud.

2) Preprocessing & cloud integration: The motion sensor data were preprocessed in the Raspberry Pi. This is because the sensor only gives a binary output of 1 or 0, depending on whether there is movement in front of the sensor or not. These data itself are not very useful, and therefore, to make the data more sensible, measurements are taken once in a few seconds, and once per minute the number of positive measurements is compared against the total number of measurements. This gives a percentage of movements over the past minute, which is a much more useful value to be presented in the user interface than the true/false flag constantly fluctuating between the two.

This technique of preprocessing data on the IoT controller is called edge computing, and it is becoming more common as the computational power of IoT controllers increases as the technology advances. Edge computing is used to bring the processing closer to the physical world, decreasing latency [23]. Edge computing can also decrease the stress put on the network, if less data are sent over the Internet to the cloud [24]. In larger scale applications, the need for edge computing becomes more crucial, as the amount of collected data rises beyond the transmission speed of the network [24].

3) Cloud Processing: The cloud processing was implemented in an IBM cloud, which was selected as the cloud provider for the platform owing to its features and the partnership between the university and IBM. As the platform is to be used also in education, IBM is a good choice as cloud provider because the partnership program offers free IBM Cloud access for students of the university. The tools available in IBM Cloud also allow the storage of collected data, thus making further processing of the data, for example data analytics and machine learning, possible.

The implementation in IBM Cloud consists of two parts: IBM Watson IoT Platform and a cloud foundry application running Node-RED. The Watson IoT Platform connects individual devices to the cloud and provides an API to move data. The Cloud Foundry application features a Node-RED

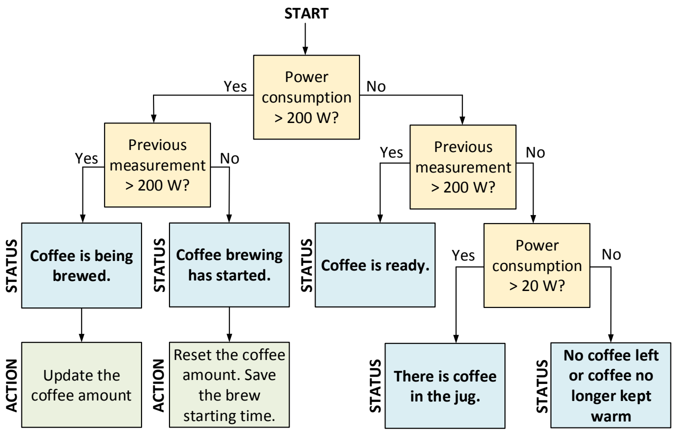

Fig. 6. Programming logic to estimate the amount of coffee. The script is ran every time a data packet containing power consumption data arrives, and the estimates are based on the current and previous power consumption measurements.

environment similar to the one running in Raspberry Pi. The IoT controller sends data to the cloud application through the IBM Watson IoT service. This service is necessary as it allows easy management and access control of IoT devices. Especially, it allows new IoT controllers to be connected to the platform later. The NodeRED application takes care of processing and visualization of the data.

To determine the amount of brewed coffee, the power consumption data were processed in the cloud. An estimate of the amount of brewed coffee can be calculated, if the brew rate of the coffee maker is known (Fig. 6). The brew rate was measured by brewing ten cups of coffee and measuring the time it took. After 330 s, all of the water had run out. Therefore, the brew rate can be estimated at approximately 0.03 cups per second.

If the power consumption of the coffee maker is more than 200 W, it can be assumed that coffee is being brewed. If two subsequent measurements exceed 200 W, the status indicator is set as ”Brewing”, and the amount of coffee brewed between the measurements can be calculated by multiplying the time interval of the measurements by the brew rate. The time interval of the measurements is ideally one second, if all data packets arrive. By not assuming the interval and calculating it using the packet time stamps, error can be eliminated.

When the consumption decreases below 200 W, and the previous measurement is over 200 W, coffee can be assumed to be ready. The status of the maker is set as ”Ready” and the current time is saved as the brew finishing time. When the consumption decreases below 20 W, the heating element has turned completely off. This indicates that the coffee maker is switched off, and thus, the coffee has all been served or it is at least 40 min old, as the European Union requires all coffee makers sold to have an automatic turn-off after 40 min. In this situation, the status of the maker is set as ”OFF”. When the consumption rises again above 200 W, it means that new coffee is being brewed. The counters are reset, and the state is set as ”Brew starting”. The script is run each time a data packet containing a power consumption value arrives.

4) Visualization: The sensored data were visualized using the Dashboard add-in of Node-RED (Fig. 7). The data gathered from the environment using RuuviTag were presented as numeric values and a temperature gauge. The usage percentage and power consumption values were presented with a gauge and a time plot. The estimated amount of brewed coffee along with the status of the maker and coffee brew start times were also presented.[1]

IV. Discussion

As described above, the main result of our work was the formulation of a list of requirements and implementation of the platform. The implementation also includes a demonstration application allowing the users to monitor the amount of coffee brewed and the use of the break room.

The described system was set up in a break room of a Finnish university. At the time of writing, the system is capable of presenting the measured values and an approximation of the amount of brewed coffee on a web user interface. The platform is flexible: new sensors can be connected to the platform as required, and new services can use the data through application programming interfaces. In other words, the platform is easy to modify and extend, and many kinds of data handling are possible. As such, the system can be used in both education and research.

For research purposes, there is significant value in the fact that the platform is located on the university premises. Testing and evaluation of new solutions such as sensors, algorithms, and cloud platforms before industrial-scale deployment is easy. No questions with data ownership are raised when development is done locally. The research staff has full control over the data and the system architecture. There are no obstacles for example to data retrieval, which can be difficult in an industrial production environment. All this leads to faster system development and testing, and thereby, results.

With the platform, students can learn valuable skills associated with IoT technologies. Students can, for example, use the system to test sensors, try new programming tools, learn cloud services, and practice data analytics. A platform like *Café IoT* establishes a firm building ground for multidisciplinary project learning. The aspects of education and research also support each other, as further research can be conducted and new case studies can emerge as the platform evolves with student input.

The system has already been tested by both engineering and MBA students. In late 2018, a group of students attending an electrical engineering undergraduate course *Electronics Project* started working on developing a better solution for brewed coffee estimation based on measurements with load cells. The students have also considered improvements to the user interface in collaboration with students from another institute providing higher education. The student learning outcomes were assessed with using peer review and grading based on how well the project was carried out.

[1]The user interface for the system: https://cafeiot-phase7.mybluemix.net/ui/

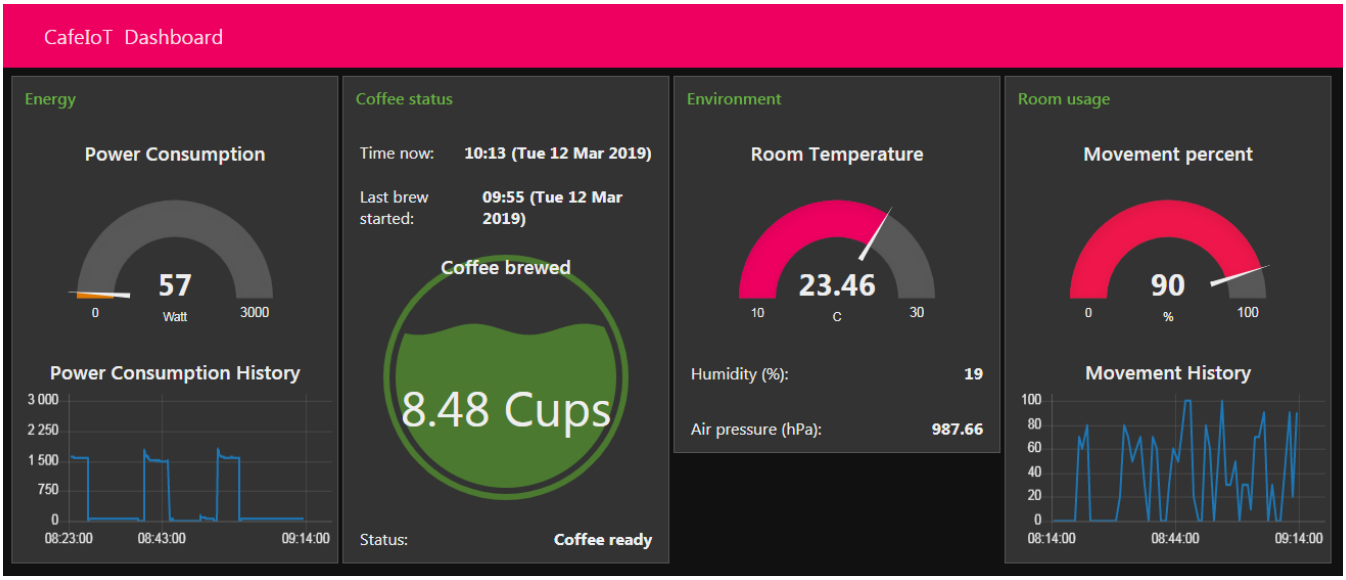

Fig. 7. User interface of the system. The measured quantities and their graphical representations are divided into four columns. At the moment of the screen capture, approximately 8.48 cups of coffee were brewed 18 min ago. The power consumption of the system is 57 W, indicating that there may still be coffee left in the jug. The room is also quite busy.

The components of the system were selected to meet both education and research needs. Raspberry Pi as an IoT controller works well, as it is easy to use, powerful enough for edge processing, and affordable to purchase. The low price makes the system easily scalable; no major investments are needed. Raspberry Pi also works well with different kinds of sensors. The use of different connections and communication protocols is encouraged from an educational point of view, as students thus gain wider scale knowledge.

V. Conclusion

This paper presents the design of a demonstrative IoT platform based on a coffee maker and the surrounding break room. Such a platform can be used in education and research, as using an IoT platform as a learning platform teaches different kinds of skills. The platform discussed in this paper is an example of an IoT application where different sources of data of various forms and data types are connected together. The technologies and tools used in building the platform, such as APIs and edge computing, are viable and used on a large industrial scale. Hands-on experience with a real IoT platform brings definite advantages, which may otherwise be difficult to achieve, and the technologies learned when students work on the platform are important skills to master after graduation.

In the design of a platform, its usage in both education and research imposes some requirements, as the architecture has to be modular, compatible with multiple connections and interfaces & easy-to-use components, and recoverable in failure situations. The sensors, devices, and tools have to be selected to be user-friendly enough so that students have access to them and they can use them safely and without constant supervising. The tools used for platform development have to be accessible for both students and researchers. With an on-site Raspberry Pi -based IoT platform focusing on a coffee maker and its surroundings, the requirements can be met, as rapid testing and development of the platform is possible for both education and research.

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