doi: https://doi.org/10.4995/WDSA-CCWI2022.2022.14788

IOT.H2O - SUPERVISION AND CONTROL FOR WATER SYSTEMS BASED ON LOW-COST HARDWARE AND OPEN-SOURCE SOFTWARE

Harald Roclawski[1], Laura Sterle[2], Martin Böhle[3] and Thomas Krätzig[4]

[1,2,3] TU Kaiserslautern, Institute of Fluid Mechanics and Turbomachinery, Gottlieb-Daimler-Str. 44, 67663 Kaiserslautern, Germany
[4]Dr.Krätzig Ingenieurgesellschaft mbH - Süsterfeldstr. 25 - D-52072 Aachen, Germany

[1]roclawsk@mv.uni-kl.de, [2]laura.sterle@mv.uni-kl.de, [3]roclawsk@mv.uni-kl.de, [4]infoline@dr-kraetzig.com

Abstract

An adequate monitoring and control of water production and distribution systems is essential for operating the system efficiently, avoiding water losses and preventing damage to the system. Usually this is achieved by SCADA systems. But SCADA systems are technically complex and expensive. They are often not affordable for small water utilities. Their systems are operated with a very low level of automatization and monitoring causing inefficient operation, water loss or even interruption of service. The Internet of Things concept is very promising to realize a cost-effective tool for monitoring and control of water systems. The potential of this approach is investigated in the research project IoT.H2O funded in the WaterJPI call IC4WATER.

In the paper, the concept of the IoT system for monitoring and control of water supply systems is explained. Special gateways and IoT devices have been developed which communicate with the IoT platform by the LoRaWAN network protocol or WiFi. It is shown how a pump test rig can be controlled with these devices. Also, results of field installations in a water distribution system in Germany are presented. Moreover, it is shown how data from existing SCADA systems and results from network simulations with EPANET can be included in the IoT system and how the data can be processed and evaluated by the IoT platform. By combining the data of different systems, the developed IoT system provides the user a cost-effective tool for monitoring and control of a water system.

Keywords
Internet of Things, LoRaWAN, smart water, digital twin, Thingsboard, EPANET.

1 INTRODUCTION

Usually SCADA (Supervisory Control and Data Acquisition) systems are used for monitoring and operation of major water transport and distribution systems. However, because of their complexity and expensiveness, they are often not achievable for small water utilities and therefore their distribution network has to be operated with a very low level of automatization or even manually. The results are high water losses by frequent reservoir overflows or interruption of water supply because of empty storage tanks and pipe bursts caused by overpressure [1], [2], [3].

Also, the number of sensors for monitoring the water system which are connected to the SCADA system is usually limited. Based on our experience from previous research projects with water supply companies, we found that very often some data is monitored but not evaluated or the dataset is incomplete. Therefore, it is not possible to ensure a reliable operation of the system and to judge for example, the efficiency of pumps, which are the biggest energy consumers in water supply systems. Studies of pump manufacturers show that many pumps are very often not operated close to their point of best efficiency. In [4] 2500 well pumps were investigated, showing that about 37% of these pumps were operated under off-design conditions. In a press information [5] Grundfos states that for more than two thirds of the pumps installed in industry energy savings of up to 60% are possible. Based on our experience from energy audits with water supply companies we found that these numbers are realistic and not marketing numbers.

For judging pump operation, a complete set of data is essential. Then, based on engineering knowledge, pumps can be selected guaranteeing high energy efficiency. On top, by applying advanced optimization tools, additional savings are possible. But there is more than pumps in water supply systems. As an example, tank levels, water demand and quality or pressure in the network have to be monitored and controlled.

One of the United Nations sustainable development goals is to "Ensure availability and sustainable management of water and sanitation for all". Thus, in order to realize monitoring and control systems for small water utilities or systems in developing countries, the technology has to be very cost-effective. With the technological progress in ICT (Information and Communications Technology), new possibilities for technologically advanced but low-cost solutions for monitoring and control of water systems are available. Especially the Internet of Things (IoT) concepts is very promising.

Considering open-source software and cost-effective hardware there are already reports available in the literature. For monitoring and control of a water system, in [6] a system based on a Raspberry PI, a GSM module and Arduino UNO microcontroller is presented. With IoT devices, it is possible to measure pressure and flow rate, control a motorized electric valve and start a pump using a solid state relay switch. For interacting with the IoT system, a web application was created. By means of a fuzzy logic algorithm the operators are informed in case of events where specific actions should be performed as starting or stopping the pump.

An IoT system for pressure monitoring in water supply networks is proposed in [7]. IoT devices based on Arduino microcontrollers send pressure data using the Sigfox communication protocol to the IoT platform ThingSpeak where the data is analyzed and visualized. Alarms can be generated for the case that anomalous pressure data is detected. The system is in operation in a real water distribution system in Spain. In contrast to the LoRaWAN communication which is used in this work, for using Sigfox, the customers pay per year and per connected device. Also, customers relie on network coverage which is in hand of the operator. For ThingSpeak, according to the authors it is only possible to connect four devices free of charge. For more devices estimated costs of 70€ to 580€ apply depending on the subscribed functionalities.

The monitoring of water consumption of households and commercial buildings by an IoT system based on low-cost hardware is described in [8]. On each faucet, Hall-Effect flow sensors which are connected to a NodeMCU are installed. The data is sent using WiFi to a Heroku cloud database and can be accessed by a web browser.

In [9], the authors present the IoT framework REFlexWater based on the FIWARE platform. The focus of the paper is more on the processing of data than on the technology of IoT devices. REFlexWater uses declarative processes to model water systems which allows operators to handle routine situations and unforeseen occurrences. The data from low-cost IoT devices installed in a water system is sent to servers. The servers use Complex Event Processing methods to process the data in real-time for identifying water loss. In this case alarms are generated so that the operators can take suitable actions for solving the issue.

In the project IoT.H2O, which is funded by the European initiative „Water Challenges for a Changing World“ (Joint Programming Initiative, JPI Water), the potential of the Internet of Things concept for supervision and control of water systems is investigated. In the project, an IoT-system based on low-cost hardware and open-source software has been developed. The central element of the system is an open-source IoT platform. With the platform it is possible to receive, visualize and store data from IoT devices and to control components like pumps and valves. In addition, software models like network models, optimization tools or digital twins of pumping stations as well as additional data like a weather forecast can be virtually connected to the platform. In the paper, the design of the IoT system and the IoT devices are presented in detail and several use cases are discussed.

2 IOT SYSTEM

Figure 1 shows the concept of the proposed IoT architecture based on a three-layer model. Physical objects like pumps, valves or storage tanks equipped with appropriate sensors or actuators belong to the field layer. Microprocessors are connected to the sensors and actuators and transmit data from measurements or commands for actuators. In the transport level, several different communication technologies are possible. In IoT.H2O, the microcontrollers communicate via WiFi in case of short distances. For longer distances and when there is no WiFi available the LoRaWAN network protocol is used to transmit data from remote locations. In this case, the data is sent via LoRaWAN to a gateway which is connected to the internet. In the third level, the application level, all data is organized by an IoT platform. In IoT.H2O, the open-source platform Thingsboard is used. The users can interact with Thingsboard using mobile devices or computers through a web browser and visualize measurement data or control devices in dashboards.

In contrast to centralized SCADA systems, which receive information from remote sensors and control components, the IoT concept relies on a decentralized approach. Additional IoT devices can be easily added to the IoT platform by adding their specification in the software. Hardware changes on a centralized computer, which is often the reason for a limited amount of sensor data for SCADA systems, are not necessary. The IoT platform offers the possibility to combine data from different systems. Since the communication between the IoT platform and the devices is based on software protocols, a software for network calculation or optimization of pump schedules can be connected to the IoT platform. Also, data from already existing SCADA systems can be included. So, it is not absolutely necessary to completely replace a SCADA system by an IoT system. Instead, the functionality of the SCADA system can be extended by the IoT system. In the following sections the functionality of single components of the IoT system will be presented in more detail.

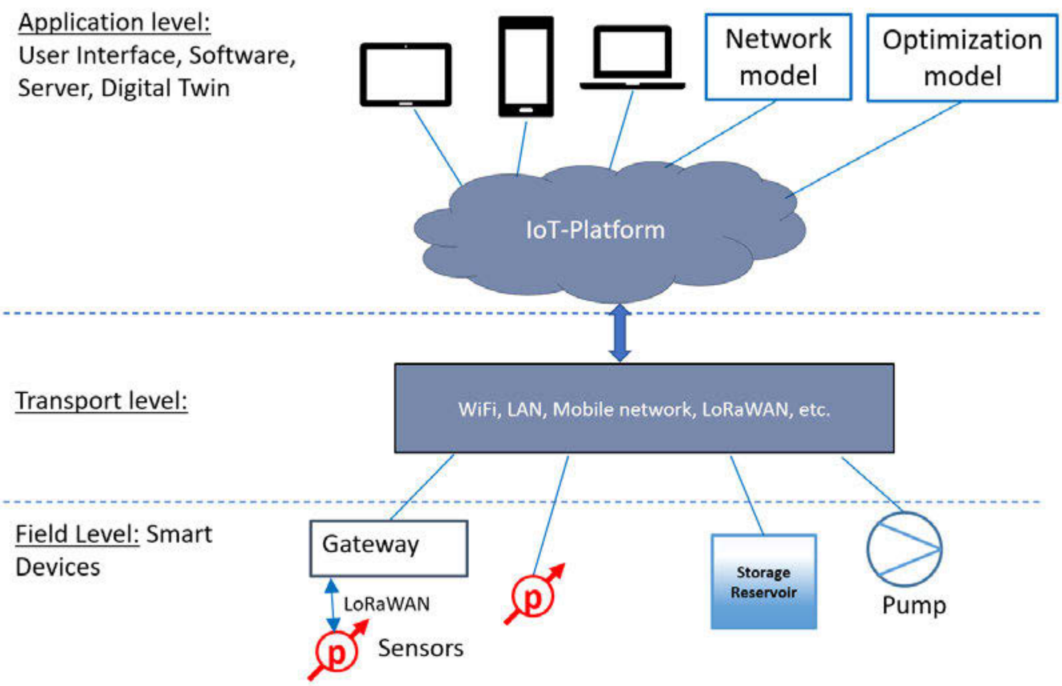

Figure 1: IoT architecture (IoT.H2O)

2.1 IoT platform

In IoT.H2O, the open source IoT platform Thingsboard is used for data storage, data visualization and control of devices with dashboards. In Thingsboard, the components of the water distribution system, e.g. pumps, valves, tanks, pipes or sensors are mapped as devices. Thingsboard offers several possibilities for connecting the devices. In IoT.H2O, the open-source Message Queuing Telemetry Transport protocol (MQTT) is used. In this case, the Thingsboard server acts as MQTT broker which transports messages between sender and receiver. MQTT is a so called publish-subscribe network model. This means, that the sender publishes a message with a specific topic and the receiver has to subscribe to this topic to ensure that only the desired data is received.

For MQTT, there are many software libraries available. For the IoT field devices, the Arduino PubSubClient is used. The communication with actuators, like a control valve or a frequency converter, is realized with Remote Procedure Calls (RPC) based on MQTT. With RPC it is possible for the IoT platform to run programs on a different computer and return the results of the code execution to the IoT platform. This can be, for example, a microcontroller controlling the control valve position or any other code. For RPC, specific control widgets like an on-off switch or a knob control arranged in a dashboard communicate with the actuator. To ensure that each RPC command is received by its corresponding actuator, the control widget is mapped to a device. In case of RPC, the message is sent in JavaScript Object Notation (JSON) format and consists of a method name and parameters.

The method name indicates whether the “RPC get value” or “RPC set value” method is used. With the set value method, changes in the Thingsboard control widget are passed to the device. This is the case when the user changes for example the position of the control valve or the frequency of the motor. With the get value method, parameters can be passed from the device to Thingsboard for transmitting the current status of a device to the IoT platform. It is also useful for checking if a device is online. For each control widget, the function names for the get value and set value method can be specified in Thingsboard so that the correct device can be identified by the method in the callback function.

All telemetry data which is received by Thingsboard is stored in a database and can be visualized in a dashboard. Dashboards can be created by the user by drag & drop of predefined widgets. So, no programming of a web interface is necessary. However, it is possible to modify these widgets or to create new widgets. The dashboard will be described in a later section in more detail.

Another important feature of Thingsboard is the rule engine. With the rule engine, it is possible to automatically process or filter incoming data or generate alarms according to defined thresholds. In case of the water distribution system, it is possible to automatically generate an alarm for the case that a tank level is too high or too low. In our case we are also using the rule chain for calculating the hydraulic head and efficiency of a pump based on the incoming data of pressure, flow rate, torque and speed.

2.2 IoT-devices

In the IoT.H2O project, devices based on microcontrollers have been developed which can be connected to sensors for measuring e.g. pressure, flow or temperature. For cases where the IoT devices belong to a local wireless network and are powered by mains, the sensor data is transmitted by WiFi. For cases where there are no local WiFi network and wired power supply available, devices are battery powered and belong to a wireless Low-Power Wide-Area Network (LPWAN). In IoT.H2O the LPWAN is set up with Semtech’s LoRa radio technology in combination with the LoRaWAN network protocol where gateways relay data packages between the IoT devices in the field and the central network server and the IoT platform.

A requirement for the development of the IoT devices was to use as much as possible already available, cost-effective and functional modules which are usually in stock of suppliers. In case of LoRaWAN, the gateways were built based on a Raspberry PI and several different LoRaWAN Concentrators. Figure 2 shows a prototype of a LoRaWAN gateway with an iC880A - LoRaWAN® Concentrator 868MHz of IMST GmbH. The design is based on the GitHub project of Gonzalo Casas [10].

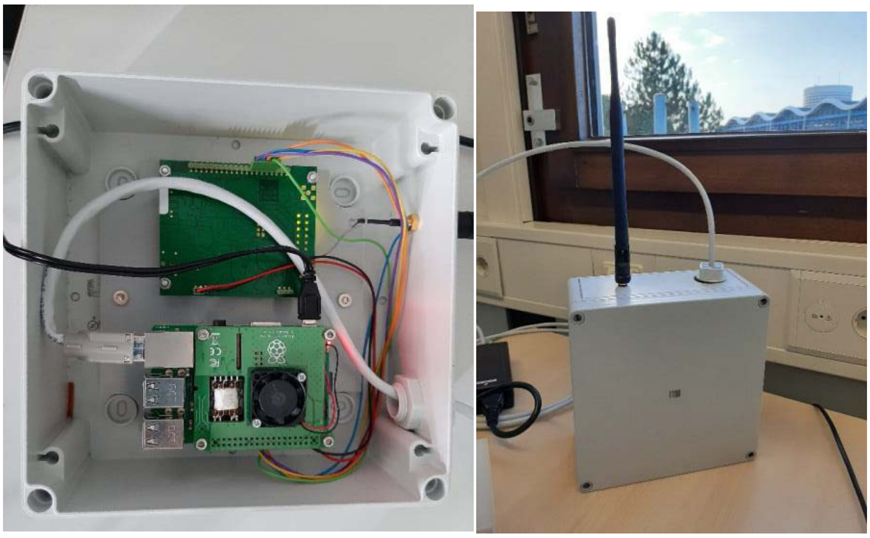

Figure 2: Prototype of LoRaWAN Gateway

While it was possible to use standard components for the design of the gateway, for the design of the field units, special printed circuit boards (PCB) had to be developed. The field units are directly connected to the devices or sensors and are responsible to transmit measurement data or receive commands for controlling actuators.

Figure 3 shows, as an example, a field unit of the first generation which can be used for pressure measurements. On the left side, the microcontroller is located. For the first prototype a Heltec ESP32WiFi LoRa32 (V2) module was installed. This module offers the possibility to use either LoRaWAN or WiFi for the communication with the IoT platform. The microcontroller is programmed in C using the Arduino IDE. On right side, exchangeable PCB modules can be installed according to the application of the field unit. Several options are available. There are modules with an analog to digital converter (ADC) for directly connecting sensors with a voltage output of 0-5 V or 0-10 V. In the later case, a voltage divider is integrated into the PCB of the ADC. For sensors with current output, an additional PCB with a current-voltage converter can be installed.

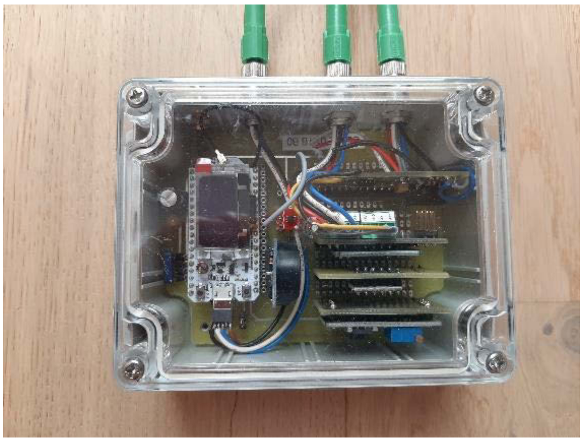

Figure 3: IoT.H2O Field Unit

Currently, we are working on the development of a second prototype where we want to replace the Heltec ESP32 Development Kit by a bare Espressif ESP32/WROOM microcontroller module and a separate LoRa modem in order to improve the energy consumption of the device and extend the timespan of operation when the device is battery powered.

Central piece of the IoT field units is the microcontroller (MCU). The design provides for different low-power MCUs, however main focus is on Espressif's ESP32 MCU family. Due to the ESP32 relatively high power consumption for battery operated devices, the MCU is put in "deep sleep mode" or disconnected from power supply during idle phases in order to extend battery lifetime. For connection to the LoRaWAN network a LoRa radio module is implemented. The IoT.H2O project team decided to implement time synchronization for all actions (measurements, actuator operation) of the IoT devices within the network. For WiFi connected networks, the synchronization can be achieved by a "system clock signal" broadcasted to all network participants, time granularity can be set to low values in the range of seconds. LoRa systems transmit in a "free" industrial, scientific and medical (ISM) radio band and must follow technical and legal requirements demanding special provisions to guarantee synchronous operation. Most important is the inclusion of a high precision real-time clock (RTC) in the hardware design. Even with best available RTCs additional clock adjustment over the network must be implemented. A 60 seconds time granularity for the IoT.H2O LoRaWAN devices was established.

Most commercially available sensors for the water industry focus on the classic automation sector. In practical, these sensors are designed for 4-20mA current loop, 0-5V or 0-10V interfaces. Battery powered systems preferentially operate in lower voltage ranges, e.g. 3.6 V. For this reason, the IoT.H2O Field units are provided with multi voltage capacities including voltage booster system (from voltages down to 2 V up to 10 V) and additional "level shifter" for in-system data communication.

In order to reduce power consumption in addition to MCU deep sleep or power off, "load switches" are used to cut power supply to all peripheral electronic components when not in use. A functional block diagram of the second-generation field unit which will be manufactured shortly is depicted in Figure 4.

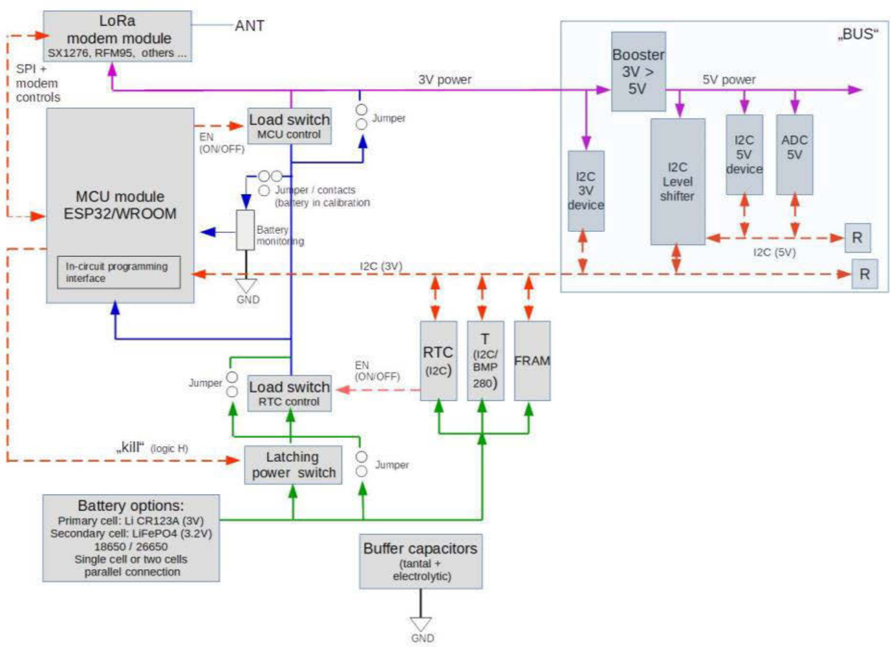

Figure 4: Functional block diagram IoT.H2O Field Unit V2.0

With the field units, every minute the data is sent by LoRaWAN to the Gateway which is connected through the internet with a LoRaWAN network server. In IoT.H2O, the "The Things Stack" LoRaWAN server (V3) is used. It is operated by The Things Network (TTN) providing an open network. Everyone is able to register gateways and devices under the premise that all gateways can be used by the community. In the IoT.H2O project, a private server based on the community edition of The Things Stack has also been installed on a local machine and operates a completely independent network.

The LoRaWAN server does not store the data permanently. For this reason, the data has to be collected from the server. In our case, we established a MQTT connection to the LoRaWAN server using the graphical programming tool Node-RED. Then, in Node-RED the LoRaWAN data is converted to a format which can be sent as JSON message by MQTT to the IoT platform.

An important advantage of LoRaWAN is that it is possible to send data over large distances. So far, with the IoT.H2O field units, we were able to send data over a distance of 23km. The range strongly depends on the topography of the landscape. If there is a direct line of sight the LoRaWAN range should be even larger. Hills and buildings block the LoRaWAN signal. Data can be transmitted over hills, but in valleys there is no coverage. In this case additional gateways have to be installed. In urban areas we achieved a coverage of 1.4 km and the LoRaWAN signal can pass several buildings. The range is also dependent on the combination of antennas which are used for gateway and IoT device [11].

3 USE CASES

3.1 Monitoring and control of pumps

The development and testing of the IoT devices was first performed on a laboratory scale. An already existing pump test rig was equipped with the IoT devices. With these devices, it is possible to change the control valve position and set the speed of the pump through the IoT platform. Also, the data of the sensors for measuring pump performance are collected by IoT devices and can be monitored in the IoT platform.

Figure 5 (left) shows a 3D CAD model of the test rig. All input values are indicated with blue arrows, all measurement values with red arrows. The measurement data are acquired with the IoT devices. Then the data is sent either by LoRaWAN or by a WiFi connection to the IoT platform. In the laboratory application we rely on WiFi, since then we can achieve a higher temporal resolution of the measurements.

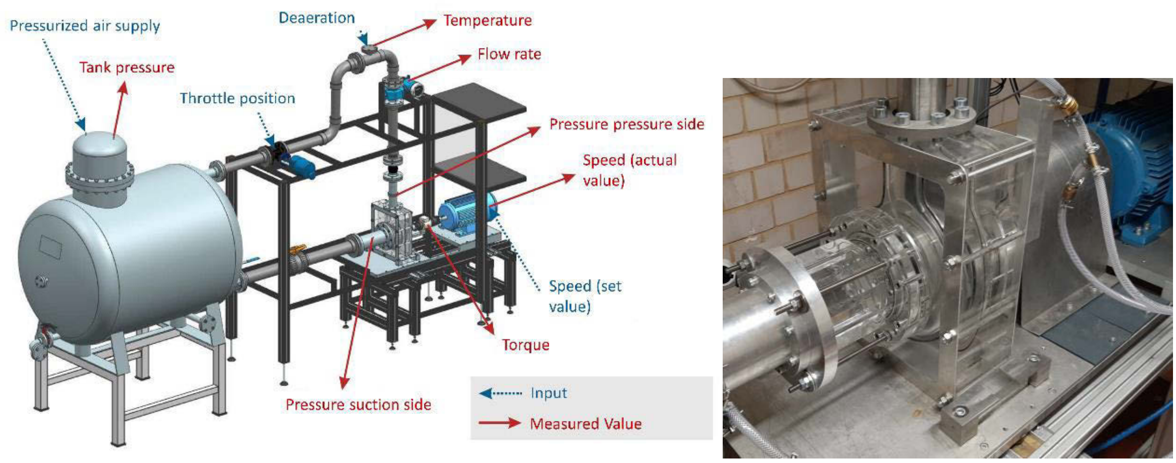

Figure 5: CAD model of pump test rig [12] and centrifugal pump

The centrifugal pump was developed at the Institute for Fluid Mechanics and Turbomachinery of the Technical University of Kaiserslautern and manufactured by rapid prototyping. The casing is made of acrylic for flow visualization experiments (Figure 5 (right)).

For controlling the test rig, a 16-bit digital to analog converter is connected using the I2C interface to an ESP32 microcontroller. With this setup it is possible to send a signal between 4 to 20mA to the control valve or the frequency converter, respectively for defining the valve position and the pump speed.

The test rig can be operated by a dashboard which is defined in Thingsboard (Figure 6). The test rig can be started with the on/off switch in the upper left part of the dashboard. The settings for control valve position and the frequency converter are applied by control knobs. The communication is based on RPC calls. The measured values are shown on cards and in a table. The chart widgets show the current operating point of the pump on the head and on the efficiency curve. Usually, in Thingsboard all data is plotted versus time in the predefined dashboard widgets. We modified the chart widget by JavaScript programming so that it is possible to plot any other quantity on the x-axis.

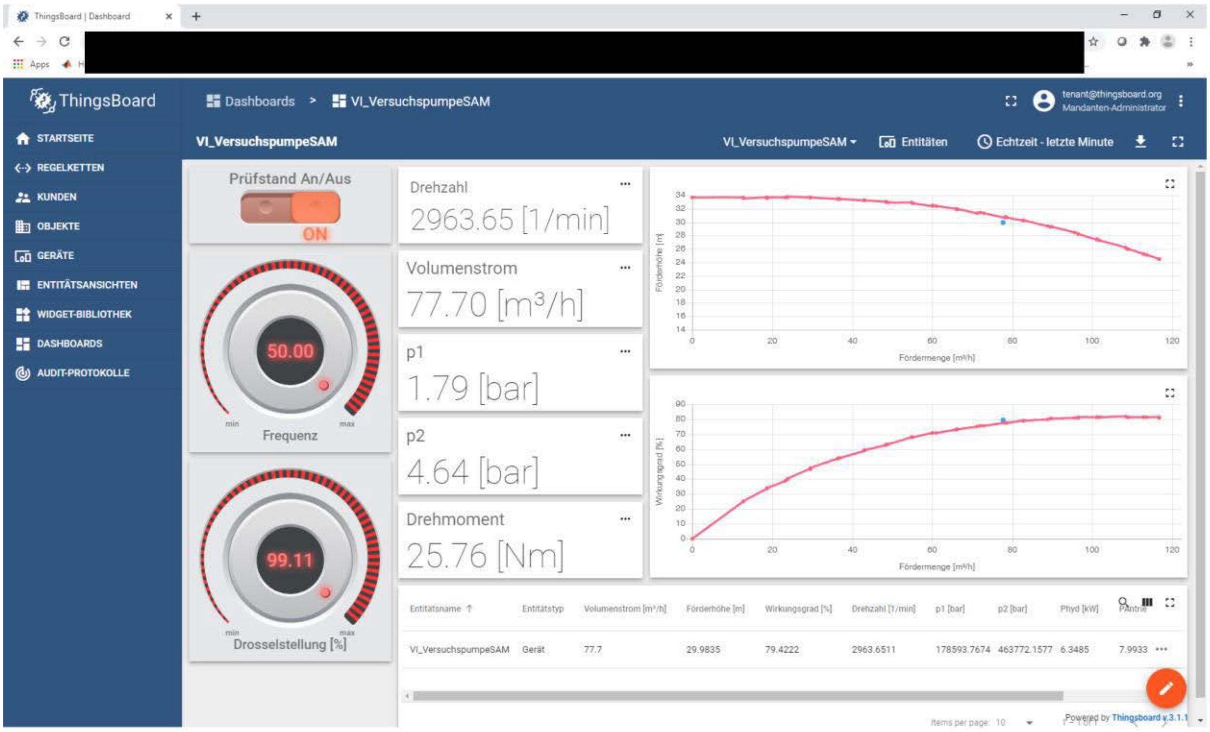

Figure 6: Dashboard for pump operation

The IoT controlled test rig is also used in laboratory classes for mechanical engineering students. Because of the COVID19 pandemic, the access of the students to the test rig was restricted. But with the IoT system, they were able to run their test online in a web browser. Because of safety issues they are not operating the real test rig. For the laboratory classes a virtual model of the test rig is operated based on a script running on the programming and numeric computing platform MATLAB. With these virtual tests, the students can measure head and efficiency curves at different speeds and investigate the behavior of pumps in different systems and with different control strategies. Another advantage of the virtual model is that different pumps can be investigated by just exchanging the pump characteristic curves in the software model. The biggest benefit however is, that now each student is able to run the test by himself. Before, the tests were run in groups because of time constraints. In the future the students will run the virtual test and work on the real test rig to ensure that they also get an understanding of the test rig setup and instrumentation. The design of the virtual test rig setup is described in detail in [13].

3.2 Field deployment in a water distribution system

After the first successful tests in the laboratory, prototypes of the IoT devices were installed in the water system of the “Zweckverband für Wasserversorgung Germersheimer Südgruppe” (ZWGS) in Germany. The ZWGS is supplying 13 small townships in the southwest of Germany with a total of 60000 inhabitants and, in addition, an industrial complex. In the network with a length of 330 km, two water utilities, a booster station and three water towers are operated.

One of the test devices is measuring the pressure of a well pump, a second device is used for measuring the pressure at the suction and pressure side of a water distribution pump (Figure 7). The devices are in continuous operation sending data at a time interval of one minute since 2020. Over time, more devices were installed for measuring pressure at two other well pumps and recently, a device was installed at the water tower Rülzheim for acquiring the water level. For the later one, the system is used as backup for an existing system where the data is transmitted by a mobile network which has been lately subject to several interruptions.

The data of the devices are currently sent to the LoRaWAN network server operated by The Things Network. From there the data is collected using Node-RED as described in section 2.2. As an example, for the visualization in Thingsboard, in Figure 8 the dashboard for a well pump is shown. On the upper left the time series of the pressure is plotted. In the table below, the pressure readings are listed for the past 15 minutes and in the OpenStreetMap widget provided by Thingsboard on the right, the locations of water utilities and water towers are shown.

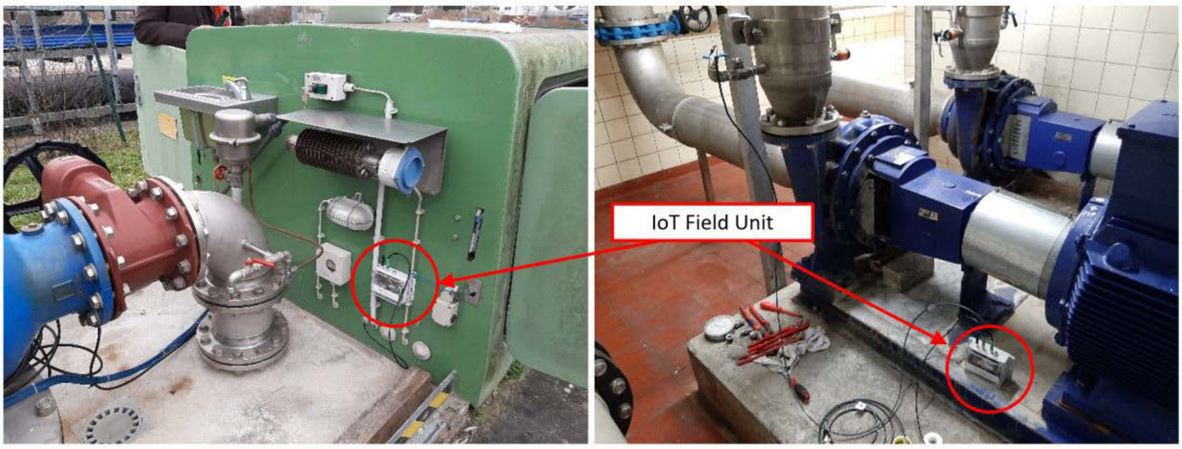

Figure 7: Test installations of IoT field units at a well pump (left) and a water distribution pump (right)

Usually, in existing water distribution systems there are already many sensors installed. These sensors are not IoT-ready. In order to receive a full set of data from the ZWGS system, data from the SCADA system is also sent to the IoT system by connecting the SCADA to the IoT platform. In this case a C-code running on a Raspberry PI was developed with support of the system operator. The program uses the library snap7 which is open source and supports a direct communication with the Siemens S7 Programmable Logic Controller (PLC) which is installed in the system. With the C-code, the data is read from the S7 PLC every minute and sent to Thingsboard as a JSON message by MQTT. There, the data is stored in a database and visualized in a dashboard. Figure 9 shows the SCADA data for the measurements of flow rate at two water utilities (upper left), the water level in the three water towers (middle), the flow rate and pressure of a booster station (upper right) and the pressure at the discharge pipe of a water utility (lower left).

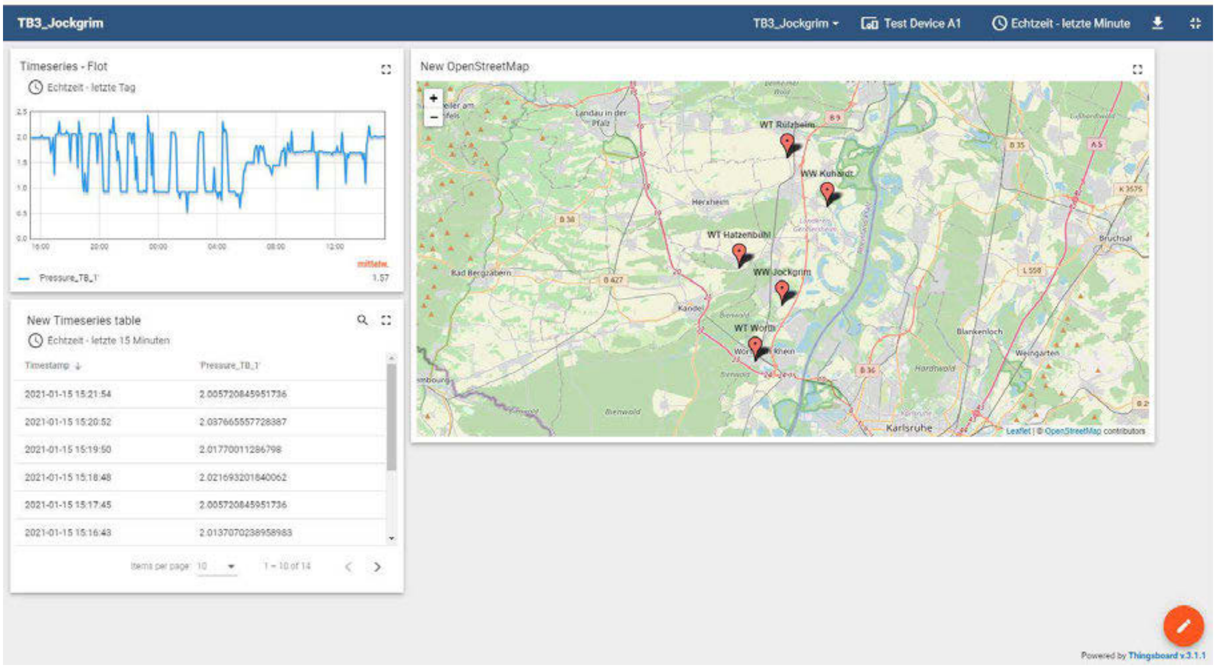

Figure 8: Visualization of LoRaWAN data of a well pump

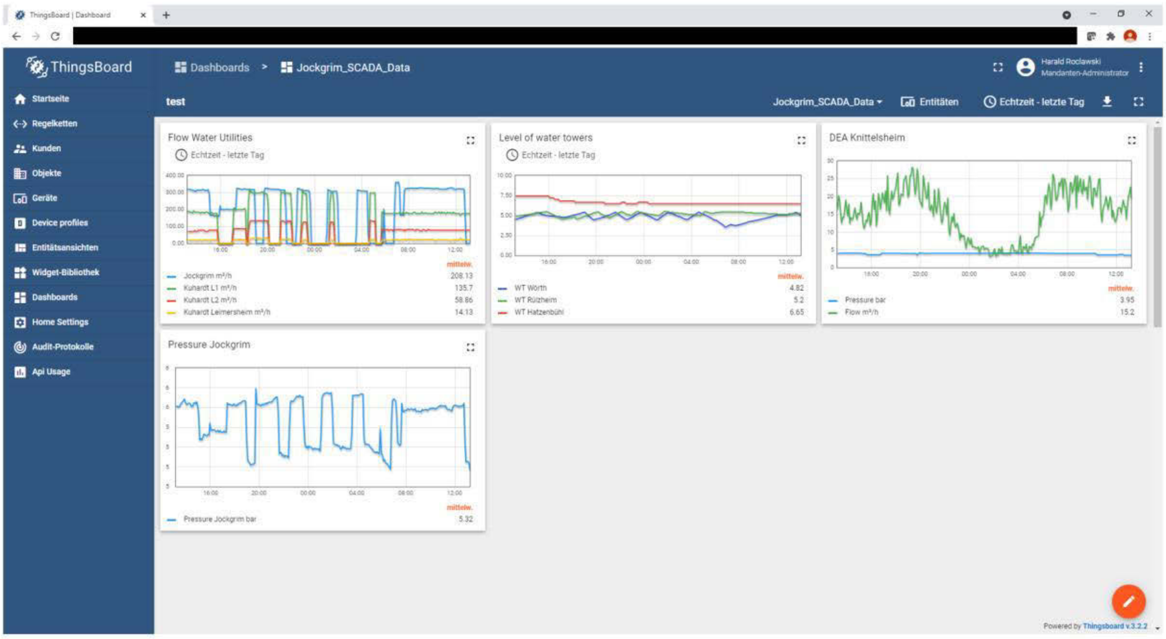

Figure 9: Visualization of SCADA of ZWGS in a dashboard

By this method already existing data can be included in the IoT platform. The existing dataset can then be easily extended using new IoT devices. This is especially useful in case of the ZWGS system since the current SCADA system does not allow to include more sensors without major changes in the hardware. It is also possible to combine this complete dataset with data from simulation software e.g. with results from network simulations. This is described in the next section.

3.3 Integration of simulation software to the IoT platform

The RPC functionality of Thingsboard allows the execution of an arbitrary code on any other machine which is connected by MQTT to Thingsboard. So, as a consequence, it is possible to start network simulations of water distribution systems with Thingsboard. Live data from the IoT system can be used as boundary condition and the simulation results can then be sent back to the IoT platform for comparison with the measured data and detection of abnormal system behavior.

For this objective, a method was developed on a physical model of a water distribution system of our project partner from The Centro de Pesquisas Hidráulicas e Recursos Hídricos of the Federal University of Minas Gerais, Brazil (CPH). The test rig is depicted in Figure 10 in the picture on the lower left. On each node of the network pressure sensors and flow meters are installed. In addition, it is possible to simulate leakages by opening valves. All measurement data is acquired using IoT technology developed in the IoT. H2O project and sent by MQTT to a local Thingsboard server for data storage and visualization. Because of the decentralized Internet of Things approach it is also possible to operate the Thingsboard server and run the network simulations in completely different locations as long as they are accessible through the Internet. The test rig of the water system is described in more detail in [14]. In IoT.H2O, the water network modelling software EPANET is used. Figure 10 shows a dashboard for combining data from EPANET simulations and measurements. The test rig layout is represented by a JPEG image in the background of the dashboard. Then the location of each pressure sensor was added as a red marker on the dashboard. Each sensor is defined as device in Thingsboard.

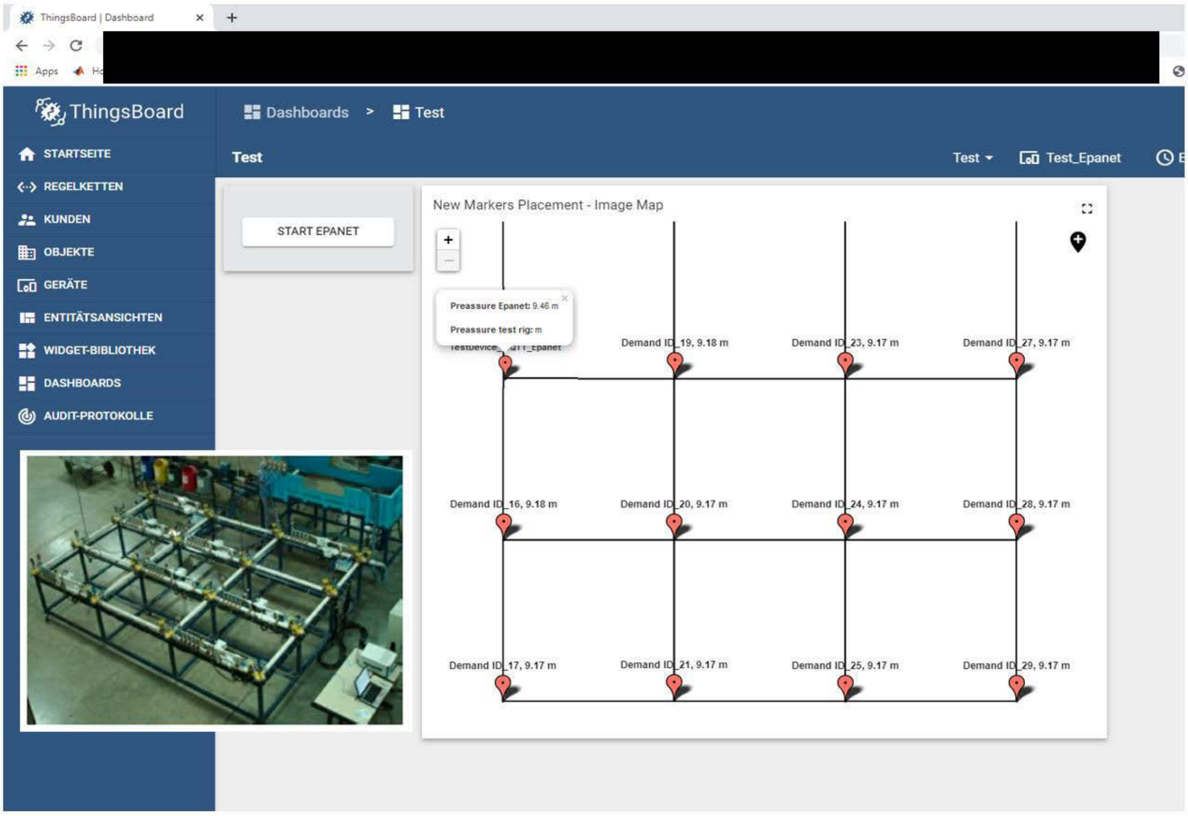

Figure 10: Test stand for water networks (Federal University of Minas Gerais, Brazil)

Currently, the EPANET simulation is started manually by clicking on the RPC button "START EPANET" on the upper left part of the dashboard. By clicking the button, an MQTT message is sent to a python script. The Python script is continuously checking if the button was pressed. Then the EPANET simulation is started from the Python script by executing the Windows executable of

EPANET using the Windows command line. At the end, the EPANET output is evaluated with Python and the pressure at each node is returned to Thingsboard. In this case both values of measurement and simulation are shown in a card in the Dashboard. Other forms of visualization in tables or charts are possible.

Currently the EPANET Programmer's Toolkit and a JavaScript version of EPANET called epanet-js [15] is tested for replacing the Windows executable so that the boundary conditions can be edited dynamically according to the live data from the water system of ZWGS. Epanet-js has the advantage that a graphical representation of the network can be included in the Thingsboard dashboard (Figure 11). It is our vision to be able to represent the current status of the system by the EPANET simulations for improving the monitoring of the system. This requires in the future the installation of additional sensors in the network to improve the accuracy of the model. For testing this method, we plan to install temporarily pressure sensors in a small town of the network and use data of flow meters which are already permanently installed at all pipes supplying the town.

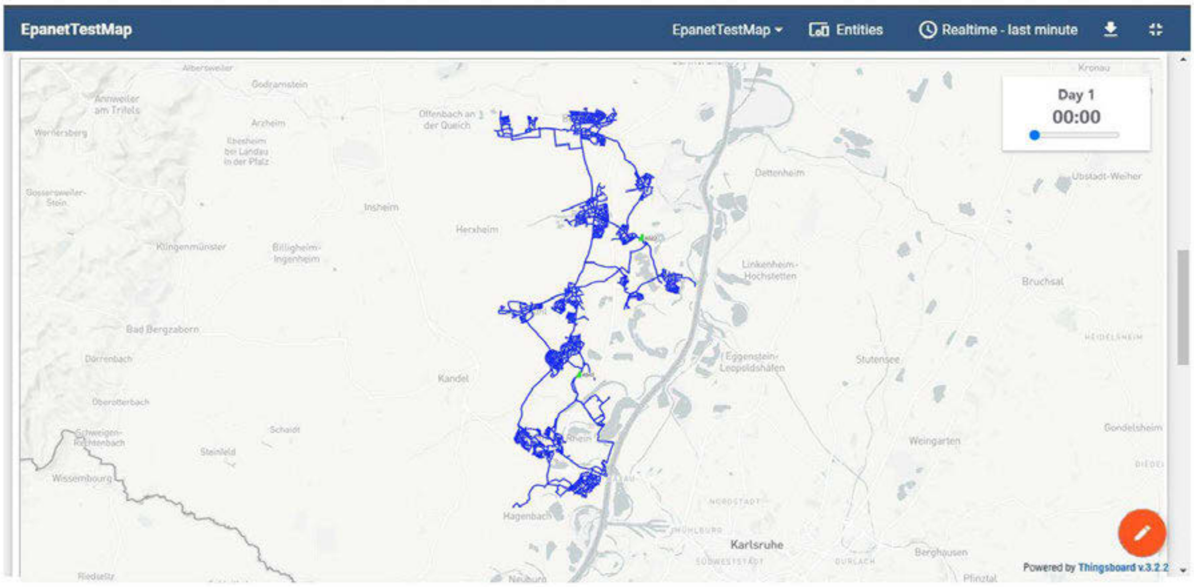

Figure 11: Representation of the network of ZWGS in Thingsboard using EPANETJS

For combining the data from SCADA system, IoT field units and network simulation a main dashboard was created (Figure 12). The main dashboard shows the current levels of the three water towers, the current flow rate of the water utilities and the booster station, the current water consumption, the status of the well and distribution pumps and a map of the network.

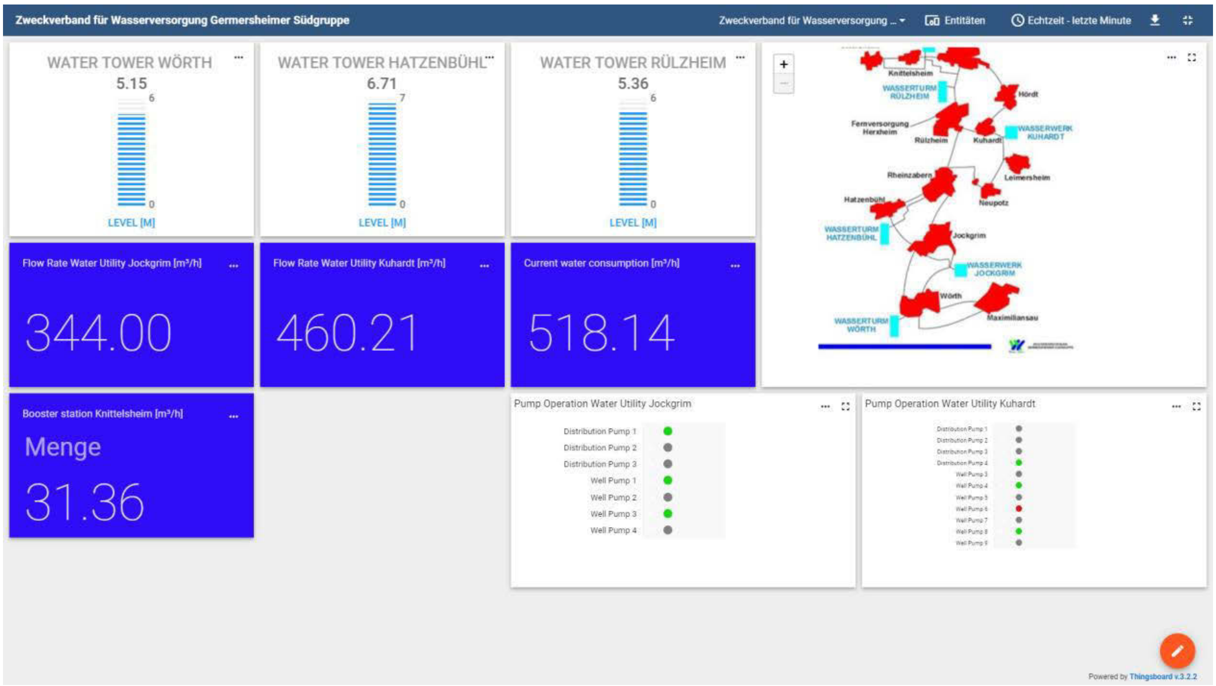

Figure 12: Main dashboard for ZWGS water distribution system

The current water consumption is actually not measured. Instead it can be calculated from the flow rates of the water utilities, the change in water level of the water towers and the flow rate of the booster station. These calculations are performed in Thingsboard using the rule engine. By clicking on the three dots, which are shown in the upper right corner of each dashboard widget, it is possible to get more detailed information by navigating to additional dashboards.

In case of the water towers, an additional dashboard is shown, showing charts with time series of water levels and in- and outflow as well as cards with the current values of these quantities. For the flow rate cards, also time series of these values are plotted and additional values as e.g. pressure of the water utilities are shown as in Figure 9. By clicking on the pump status, it is planned to show dashboards with the current operating data and plot the operating point on the head and efficiency curve similar to Figure 6. This work is currently in progress. By clicking on the map widget, the dashboard related to the network simulation (Figure 11) is shown.

4 CONCLUSION

An IoT system based on open-source software and cost-effective hardware has been presented. It was shown that with the IoT platform Thingsboard data from different systems can be easily combined. For the communication with the IoT platform, IoT devices were developed which can be connected to sensors with voltage or current output and send the measurements by LoRaWAN or WiFi to the IoT platform using the MQTT protocol. In case of LoRaWAN, Gateways based on a Raspberry PI are used.

It was demonstrated that it is possible to control and monitor a pump test rig with the IoT devices. The system can also be used for educating students in pump operation.

In field tests, the IoT devices were installed at pumps and a water tower in a water distribution system in Germany. By including the data of the SCADA system into the IoT platform, already existing sensors can be used to combine the data from IoT devices with the SCADA data. With the IoT devices it is possible to extend the number of sensors in a cost-effective way. Also, it was shown that simulation tools like EPANET can be included in the IoT platform. The method was developed on model of a water distribution network on a laboratory scale. For the ZWGS network, it is planned to install additional sensors within the network for improving the model quality in the future. We want to be able to analyze the current status of the network by EPANET simulations and to detect abnormal system behavior at an early stage by comparing simulation data and measurements.

All data, from SCADA system, IoT devices and network simulation, can be organized in different dashboards. Starting from a main dashboard, users can navigate to sub-dashboards for getting more detailed information on individual devices.

The IoT system offers the possibility to combine data from different systems and provide the user a complete and detailed set of data for analyzing system operation. By using the rule engine functionality, the incoming data can be automatically evaluated and processed for calculating other quantities. It is not necessary to export data to a third-party software which ensures that important quantities can be monitored and evaluated continuously.

5 ACKNOWLEDGMENTS

We would like to thank our project partners Aloysio P. M. Saliba (The Centro de Pesquisas Hidráulicas e Recursos Hídricos of the Federal University of Minas Gerais, Brazil), Benjamin Dewals (Research group Hydraulics in Environmental and Civil Engineering, University of Liege, Belgium), Thomas Pirard (Research group Hydraulics in Environmental and Civil Engineering, University of Liege, Belgium), Laurent Vercouter (LITIS LAB, MIND Group, INSA Rouen France) and Henrique Donancio Nunes Rodrigues (LITIS LAB, MIND Group, INSA Rouen France) for their comments and suggestions regarding this work. The authors acknowledge Minas Gerais State Agency for Research and Development – FAPEMIG, Brasil, Federal Ministry of Education and Research of Germany, Agence Nationale de la Recherce de France and Fonds de la Recherce Scientifique Belge, for funding this research by the project IoT.H2O on the IC4Water JPI call. We would like to express our gratitude to Ralf Friedmann (ZWGS) and Markus Justen (ZWGS) for the possibility to realize the field tests in the water distribution system of ZWGS.

6 REFERENCES

[1] F. Ramos da Fonseca, Modelo de Sistema de automação aplicado a setorização de redes de abastecimento hídrico. Tese de doutorado., Escola Politécnica da Universidade de São Paulo, 2011.

[2] A. S. Spolaor, „Automação nos sistemas de abastecimento de água. Caso do controle da reservação de distribuição. Tese de mestrado.," 2001.

[3] M. P. dos Santos und J. K. C. de Oliveira, „Automação de baixo custo para reservatórios de água.," in Revista Princípia N°. 25, João Pessoa, 2014.

[4] S. Brodersen, „Lebenszykluskosten für Förderanlagen – Auswahlkriterien für wirtschaftliche Entscheidungen," in wat2006, Berlin, 2006.

[5] Grundfos GmbH, „Presseinformation Energieeinsparung," 2017.

[6] J. G. Natividad und T. D. Palaoag, „IoT based model for monitoring and controlling," IOP Conf. Ser.: Mater. Sci. Eng. 482 012045, 2019.

[7] J. Pérez-Padillo, J. García Morillo, J. Ramirez-Faz, M. Torres Roldán und P. Montesinos, „Design and Implementation of a Pressure Monitoring System Based on IoT for Water Supply Networks.," Sensors, 20, 4247. https://doi.org/10.3390/s20154247, 2020.

[8] A. C. Tasong und R. P. Abao, „Design and Development of an IoT Application with Visual Analytics for Water Consumption Monitoring".Procedia Computer Science, Volume 157, 2019, Pages 205-213,ISSN 1877-0509,https://doi.org/10.1016/j.procs.2019.08.159..

[9] R. Gonçalves, J. J. M. Soares und R. M. F. Lima, „An IoT-Based Framework for SmartWater Supply," Future Internet , Bd. 114, Nr. https://doi.org/10.3390/fi12070114, p. 12, 2020.

[10] G. Casas, „From zero to LoRaWAN in a weekend," 06 11 2018. [Online]. Available: https://github.com/ttn-zh/ic880a-gateway/wiki. [Zugriff am 10 05 2022].

[11] H. Roclawski, T. Krätzig, L. Sterle und M. Böhle, „Influence on antenna design on range of LoraWAN devices – a practical test," in EGU General Assembly, online, 19–30 Apr 2021, EGU21-458, 2021.

[12] A. Knapp, Numerische und experimentelle Untersuchung der Auswirkungen von Auslegungsmethoden für Spiralgehäuse auf die Performance einer Kreiselpumpe, Düren: Shaker Verlag, 2019.

[13] H. Roclawski, L. Sterle und M. Böhle, „VIRTUAL CENTRIFUGAL PUMP TEST RIG FOR LABORATORY CLASSES BASED ON IOT TECHNOLOGY," in Proceedings of ASME Turbo Expo 2022 Turbomachinery Technical Conference and Exposition GT2022, Rotterdam, Netherlands, 2022.

[14] D. Moraes, L. Sterle, A. Saliba, G. M. LIMA, H. Roclawski, T. Kratzig, B. Dewals und L. Vercouter, „LOW-COST MONITORING FOR WATER DISTRIBUTION SYSTEMS," in XXIV SIMPÓSIO BRASILEIRO DE RECURSOS HIDRÍCOS, Belo Horizonte, Brazil, 2021.

[15] „Water distribution modelling in the browser using JavaScript," [Online]. Available: https://epanetjs.com/. [Zugriff am 12 05 2022].