electronics

Article

The Use of the MQTT Protocol in Measurement, Monitoring and Control Systems as Part of the Implementation of Energy Management Systems

Anna Manowska [1,*], Artur Wycisk [2], Andrzej Nowrot [1] and Joachim Pielot [1]

1 Department of Electrical Engineering and Automation in Industry, Faculty of Mining, Safety Engineering and Industrial Automation, Silesian University of Technology, 44-100 Gliwice, Poland
2 Department of Safety Engineering, Faculty of Mining, Safety Engineering and Industrial Automation, Silesian University of Technology, 44-100 Gliwice, Poland
* Correspondence: anna.manowska@polsl.pl

Abstract: The Internet of Things (IoT) market is currently one of the most dynamically developing branches of technology. The increase in the number of devices and their capabilities make them present in every area of life—from construction to medicine. Due to flourishing industrial automation and wireless connectivity, all devices in buildings can be networked, which significantly improves comfort, energy efficiency, and thus significantly affects the promotion of the idea of sustainable development. This article proposes to build a system to monitor an energy management system by collecting information about temperature, humidity and pressure. The concept of the system is based on the Message Queue Telemetry Transport (MQTT) communication protocol, a wireless network, an ESP8266 microcontroller and a BME280 sensor. Sensors and actuators are connected to the ESP8266, and a Mosquitto-based MQTT broker is placed on the RPi and set up for remote monitoring and control. An innovative approach to the use of database systems dedicated to time series on the example of InfluxDB and data visualization in the Grafana environment was also presented. The proposed system was built in laboratory conditions in 2022 and used to monitor and control energy consumption in real time, depending on Polish weather conditions.

Keywords: Message Queuing Telemetry Transport (MQTT); ESP8266; Mosquitto; measurement system; monitoring and controlling in energy management

Citation: Manowska, A.; Wycisk, A.; Nowrot, A.; Pielot, J. The Use of the MQTT Protocol in Measurement, Monitoring and Control Systems as Part of the Implementation of Energy Management Systems. *Electronics* **2023**, *12*, 17. https://doi.org/10.3390/electronics12010017

Academic Editor: Bor-Ren Lin

Received: 29 November 2022
Revised: 18 December 2022
Accepted: 19 December 2022
Published: 21 December 2022

1. Introduction

Reducing energy consumption and reducing waste are issues of increasing importance to the EU [1]. In 2007, EU leaders set a target of reducing the EU's annual energy consumption by 20% by 2020. In 2018, the Clean Energy for All Europeans package set a new target of reducing energy consumption by at least 32.5% by 2030 [2–6]. Ensuring energy efficiency is increasingly recognized not only as a means of ensuring a sustainable energy supply, reducing greenhouse gas emissions, increasing security of supply and reducing energy import expenses but also as promoting the EU's competitiveness. Energy efficiency is therefore a strategic priority of the Energy Union [7]. In July 2021, the Commission proposed a revision of the Energy Efficiency Directive (COM(2021)0558) as part of the Reaching the European Green Deal package and in line with the new climate ambition of reducing EU greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels and achieving climate neutrality by 2050 [8]. It proposes to increase the primary and final energy consumption reduction targets to 39% and 36%, respectively, by 2030, as measured by updated 2020 baseline projections. In absolute terms, EU energy consumption by 2030 as proposed will amount to no more than 1023 and 787 million tons of oil equivalent for primary and final energy by 2030. In September 2022, the European Union again tightened the regulations on reducing electricity consumption by another 10%. This price was imposed on units of the public finance sector in connection with the current crisis in the market of energy carriers, resulting from the geopolitical situation. The intention of the Act is to strengthen the exemplary role of the public finance sector in the field of energy savings, and thus encourage a wide range of recipients to take effective measures to reduce electricity consumption. Joint actions of public sector entities should significantly reduce energy consumption and thus strengthen energy security. Significant actions to improve energy efficiency include, among others: [9]:

(1) Limiting external lighting, turning off the daily or holiday illumination of buildings;
(2) Striving to ensure the temperature of the rooms: when heating the building at the level of 19 degrees Celsius, when cooling the building at the level of 25 degrees Celsius;
(3) Modernization or replacement of lighting;
(4) The use of measurement, monitoring and control systems as part of the implementation of energy management systems;
(5) Introduction of organizational improvements as well as educational and information activities rationalizing energy consumption by office employees;
(6) Use of waste heat from the server room to heat the occupied buildings.

This, in turn, highlights the growing need for data collection for monitoring and control as part of the implementation of energy management systems. It should be added that the exchange of information must take place in various types of devices, due to age, technology and type of communication [10]. Another aspect is the ease of implementing the new system in old devices. The solutions used so far must be compatible with those that are older. A large amount of data also requires some aggregation so that the information is useful to the end user. The purpose of this article is to use the MQTT protocol as a tool for distributed measurement communication and to develop a measurement system using data processing in microprocessor systems using Node-RED as an innovative approach to programming, using database systems dedicated to time series on the example of InfluxDB and visualization data (measurements, diagnostics, reports) in the Grafana system.

The major contributions of this paper are the following:

– Explains designing and development of a power management system that is based on open-source solutions so the system is economical but also secure and reliable as MQTT has built-in SSL security features;
– Monitoring and control can be done from remote locations; this system is connected via Wi-Fi;
– This solution is adapted to all devices, regardless of time or technology;
– Designing and installing the server on a local machine and communication channel makes it useful in remote locations without Internet access.

The rest of the article is organized as follows. Section 2 describes the work done so far in the field of MQTT in IoT networks. Section 3 contains detailed information on the components used. Section 4 contains the problem statement and illustrates the proposed system architecture. Conclusions and future direction of work are presented in Section 5.

2. Review of Related Publications

The MQTT protocol is currently particularly applicable due to fast and reliable data exchange as well as communication encryption and security mechanisms [11–24]. In the article [11], the authors proposed a communication platform for a Multi-Microgrid (MMG) energy management system using a combination of communication protocols in a hierarchical architecture. In the proposed platform, an Internet of Things (IoT) gateway has been designed the purpose of which is to connect many micro-networks and the MQTT protocol has been adopted for communication between the central controller and the cloud. In the work [12], Message Queue Telemetry Transport (MQTT) was used as a way to develop intelligent control of home appliances using resource-constrained devices to measure environmental parameters, such as temperature, gas, humidity, and presence detection, but even an integrated power grid analyzer. The manuscript [13] has proposed an Internet of

Things (IoT)-enabled multiagent system (MAS) for residential DC microgrids (RDCMG). The MAS has consisted of smart home agents (SHAs) which used message queuing telemetry transport (MQTT) publish/subscribe protocol via MQTT brokers to cooperate each other to alleviate the peak load of the RDCMG and to minimize the electricity costs for smart homes. The communication encryption, integrity and authentication with minimal impact on protocol performance and MQTT simulated on the power system was analyzed in [14]. Chien and Wang have designed a new OTA model based on MQTT where the IoT application manager can fully control the OTA process via an end-to-end (E2E) channel. This model is based on the new features and functions of MQTT 5.0. In the work [15], MQTT was used in facilitating the over-the-air (OTA) updating mechanism in many IoT platforms. An analysis of the technological progress brought by the Internet of Things (IoT) in terms of communication in the Ministry of Economy was written in [16]. The paper proposes a wireless communication architecture based on the Message Queuing Telemetry Transport Protocol (MQTT) and shows how the current control structures of the potential energy management system seamlessly integrate with the proposed communication based on the MQTT protocol. The authors in the work [17], presented a data collection architecture for situational awareness (SA) oriented microgrids. A prototype has been developed that can provide a great deal of data collection from smart meters, which is collected using the MQTT protocol. The following papers [18–25] address the incorporation of MQTT systems into custom key agreement schemes as a two-phase authentication mechanism. There are papers that focus solely on authentication mechanisms for MQTT, such as [26–30]. There are also studies that propose a distributed architecture for MQTT without focusing on security solutions [31–35].

Contrary to previous works, the aim of this article is to develop a solution capable of transmitting data obtained by external sensors to a centralized server using multiple wireless technologies, using the pub-sub paradigm via the MQTT protocol, thus enabling the collection of information from distributed devices and the use of open source technologies to build a measurement, monitoring and control system as part of the implementation of energy management systems.

3. Materials and Methods

The MQTT protocol is based on the publication/subscription pattern working on top of the TCP (Transmission Control Protocol) / IP (Internet Protocol) layer. It is a lightweight data transmission protocol designed for transmission for devices that do not require high bandwidth [36]. By limiting the transmission speed, the protocol provides greater reliability. This protocol is ideal for machine-to-machine connections, the Internet of Things (IoT), mobile devices, and where bandwidth and energy savings are required. The MQTT protocol was created by Andy Stanford-Clark from IBM and Arlen Nipper from Arcom (now Eurotech) in 1999. The central element of communication is the MQTT broker (acts as a server), which is responsible for sending all messages between senders and waiting recipients. Each client that wants to send a message through the server in the MQTT protocol nomenclature is a Publisher (publisher/sender). The broker filters incoming messages and sends them to clients interested in receiving the messages. Clients who register with a broker and are interested in specific types of messages are known as Subscribers. Therefore, both publishers and subscribers establish a connection with the broker [37]. The MQTT server is responsible for the authentication and authorization of MQTT clients. After successful authorization and authentication, customers will be able to become publishers as well as recipients. Grafana is a tool installed on the server, whose only task is to read data from a selected source and visualize them using various types of charts or tables. This tool in itself will not provide the ability to prompt the server, retrieving information directly about the infrastructure—this is where InfluxDB, a database designed to collect time-based metrics, comes in handy. At the moment, the creators provide three different versions of the software, which can be selected depending on the needs [38].

Grafana Cloud is a version of the cloud service, due to which we do not have to install Grafana on our own server, but we will use the SaaS version hosted in the client's infrastructure [39]. The second available product is, of course, Grafana in the Enterprise version, for large organizations that need full and quick support in implementing the tool in their organization.

The last version is, of course, Community, or simply the Open Source version, which we can easily install on any of our servers. During the installation, remember that monitoring tools, such as Grafana, should not be hosted on the same instances as our application, because then we lose the possibility of effective monitoring and notification of exceptional situations [39].

Grafana can be installed in the environment of our choice (MacOS, Windows, Linux), and detailed installation instructions can be easily found in the official documentation.

InfluxDB was built from scratch as a time series database [30]. InfluxDB is part of a comprehensive platform that supports the collection, storage, monitoring, visualization and alerting of time series data. The entire InfluxData platform is built with an open source core. There are four fields that are part of the TICK stack: (Telegraph, InfluxDB, Chronograph, and Kapacitor). Each of these tools has a very specific role: collecting metrics, storing data, visualizing time series or having defined post-processing functions on data (Figure 1).

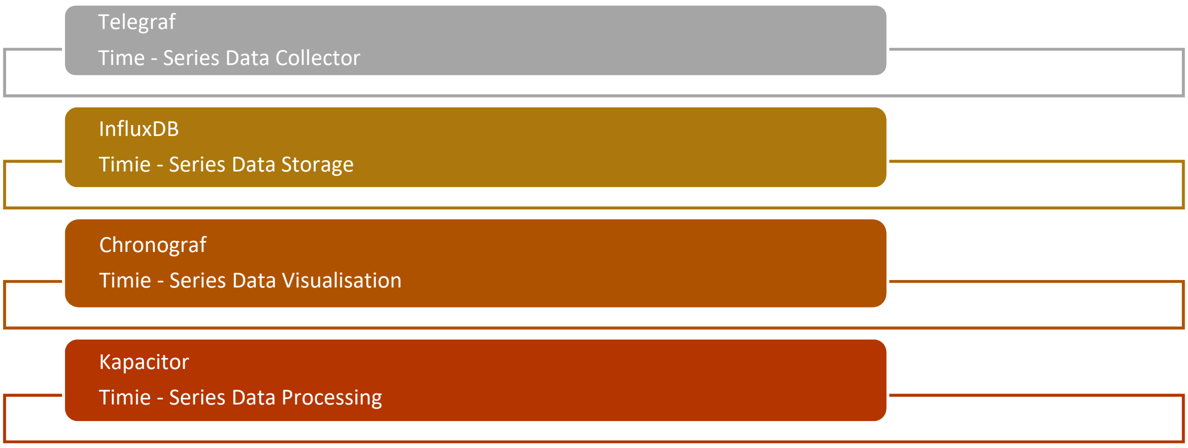

Figure 1. InfluxDB database, source [40].

Node-RED is a programming environment in which we can create a program algorithm using blocks. Node-RED is based on node.js (JavaScript—scripting language). The project, which was initiated by IBM and handed over to the community, is currently developing very dynamically. The project works on all platforms, i.e., Windows, MacOS and Linux, and allows you to easily enter the world of the Internet of Things, as shown in Figure 2. Node-RED runs locally on http://localhost:1880. It also offers options to quickly build a live data dashboard using the Node-RED user interface module. The user interface is accessible from http://localhost:1880/ui using a browser [41]. Node-Red flow can be made by using simple drag and drop options and flow can also be saved, imported and exported as a JSON file.

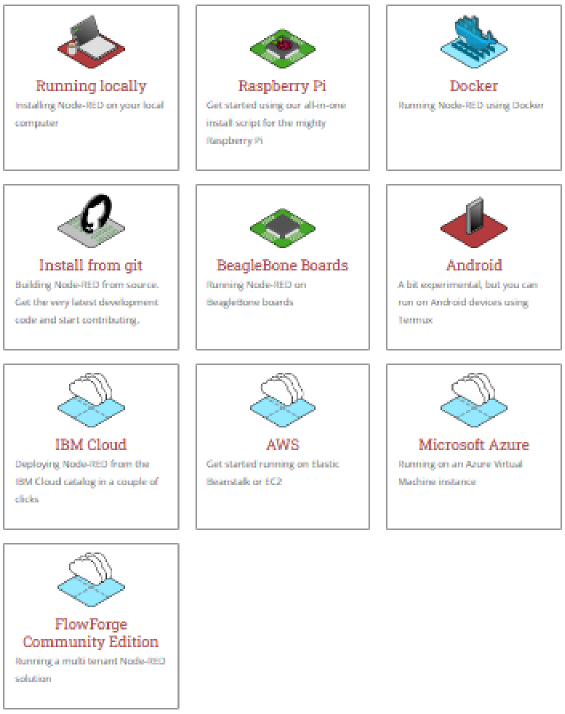

Figure 2. Node-RED environment, source [42].

4. Results

The climatic situation in the world forces the inhabitants of apartments and houses to have greater control over the electricity or heat consumed, due to high energy prices and its availability. In order to meet this need in a modern, easily accessible and easy-to-use way, the article presents a system for wireless communication and data collection from measurement and control devices. Thanks to this solution, it is possible to connect many devices in a common network, as shown in Figure 3.

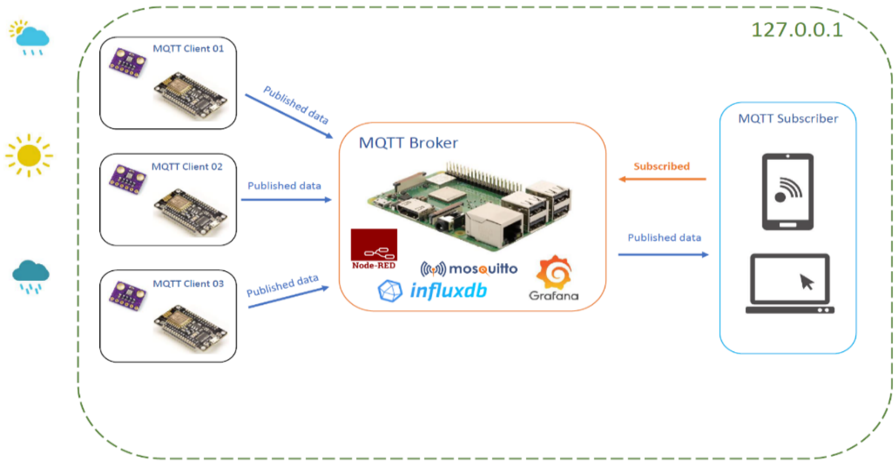

Figure 3. System concept, own study A. Wycisk.

This solution improves the level of comfort of users, can have a significant positive impact on improving energy efficiency, and also increases the level of safety of flats and houses and reduces expenses on energy sources.

The Raspberry Pi 3 model 3+ microcomputer was used to create the system. The microcontroller itself was just because of the very good cooperation with the above programs, low energy consumption and support for wireless Internet due to the built-in WiFi module. Figure 4 shows the used microcomputer in a casing.

Figure 4. Raspberry pi 3 model B+ in a case, own study A. Wycisk.

The system also uses systems with the ESP 8266 microcontroller with built-in WiFi module, which will work perfectly in the presented system. This model of the device was chosen because of a very good development environment, which is the Arduino IDE, which allows you to easily and quickly download the necessary libraries required to write the code. The microcontroller itself consumes very little electricity, has a small size and is easily available on the market. The model of microcontrollers used is presented in Figure 5.

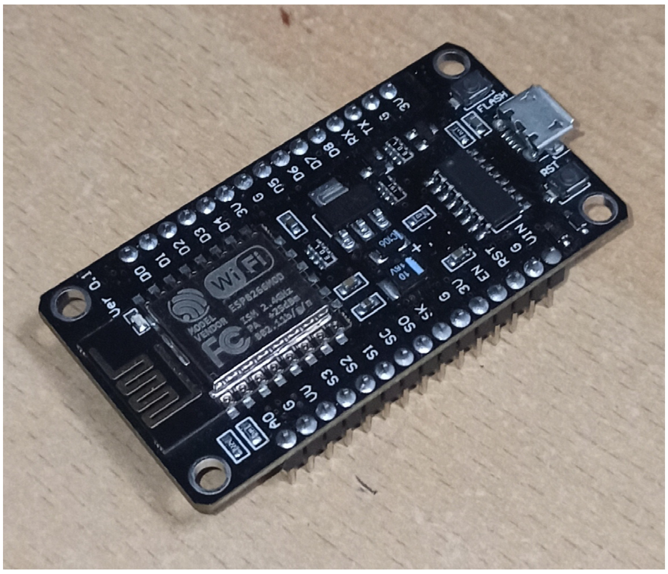

Figure 5. ESP8266, own study A. Wycisk.

The tested system will collect information about the state of the environment, i.e., temperature and humidity. As an example and presentation of the system's capabilities, the BME280 sensor will be used. This sensor was chosen because of the very good cooperation from the above ESP8266 microcontroller and high level of measurement accuracy. The BME 280 sensor is shown in Figure 6.

An additional assumption of the project is the high ability to configure the system for your own needs, which is why the only devices required in the system are the Raspberry pi and the ESP8266 microcontroller, and instead of the BME280 sensor, it is possible to connect other types of measuring devices. This solution extends the usability and the area of application of the proposed solution. The entire system was mounted on the prototype board shown in Figure 7.

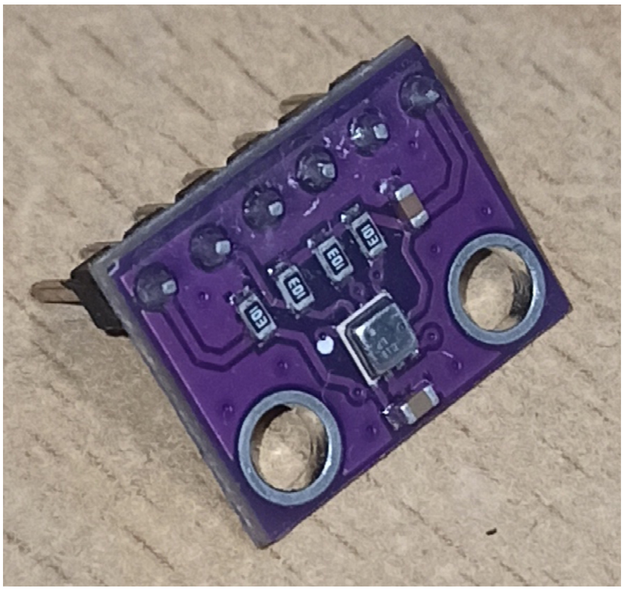

Figure 6. BME 280 sensor, own study A. Wycisk.

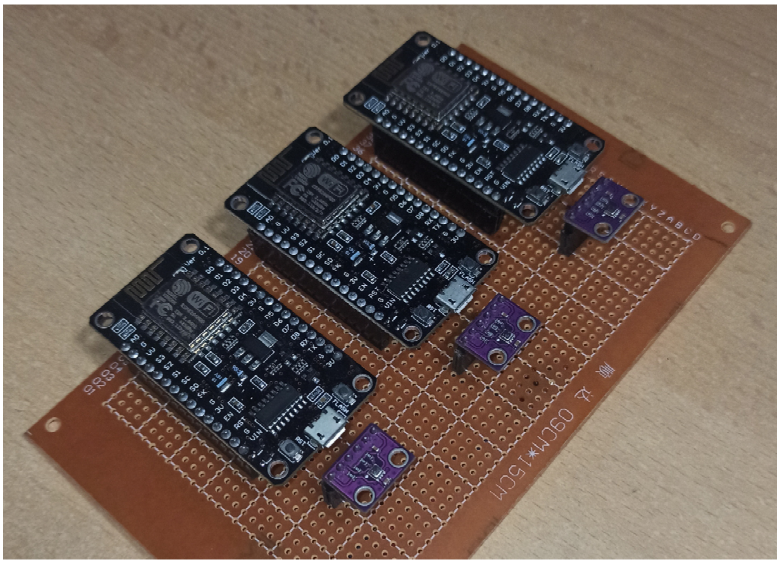

Figure 7. ESP8266 and BME280, own study A. Wycisk.

The microcontroller module, using the program code, connects to the wireless network and sends the data collected from the environment by the BME280 sensor via the MQTT protocol to the broker, which is the configured Raspberry Pi 3 model B+ [43]. Through a program written in the Node-Red environment (Figure 8), the measurements from the sensors are sent to the InfluxDB timer database. Grafana, shown in Figure 9, is used to display data in an intuitive and legible way.

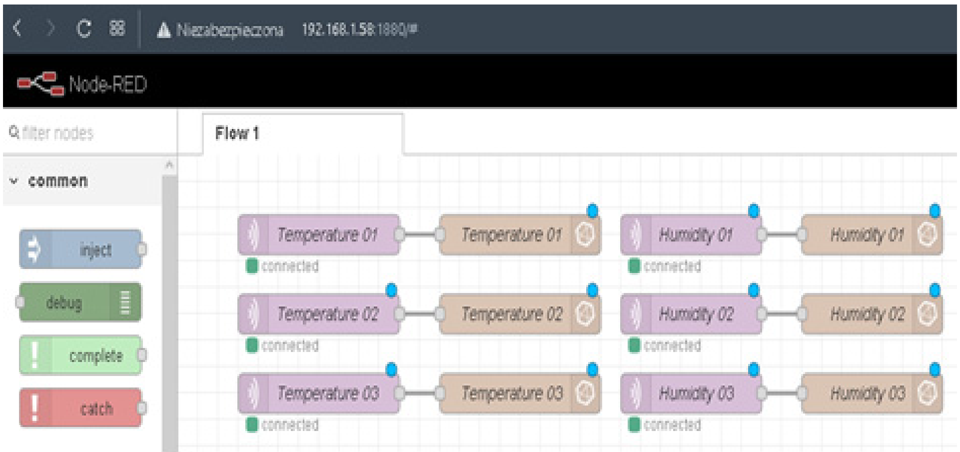

Figure 8. Node—Red, own study A. Wycisk.

Figure 9. Grafana, own study A. Wycisk.

The image from Grafana can be displayed on any device with a display and connected to the same wireless network as Rpi (Figure 10).

The article describes innovative solutions enabling efficient and safe management of services in metering systems for monitoring and controlling energy management. In the era of energy crisis, which is associated with the collapse of the fuel and energy market but also with the rising prices of carriers, such as electricity, gas and coal, the need for energy management is growing. This need can be addressed with advanced IoT technologies that are suitable even for older devices. This article proposes a system that is able to monitor and collect data in real time through the proper use of various communication technologies (e.g., MQTT), devices (e.g., ESP8266, Android, Raspberry PI) and software technologies (e.g., Node-Red). The ability to use commonly used devices, such as Android smartphones, as well as making the entire system code available on an open source basis, allows for quick implementation of the proposed solution in smart city scenarios. This proven viable solution also relies on flexible open source software that enables support for future services. The systems proposed so far are the main IoT solutions based on ad hoc data collection, which lack flexibility and scalability. However, the solution proposed in this article shows that using typical, ready-made elements, it is possible to design a highly scalable and flexible

IoT system, which, although used for monitoring and controlling energy management, can also be used for other purposes, even with data collected by the same set of sensors. We also hope that showing the complete workflow for this type of interfaces can foster the development of large-scale IoT systems of interest not only to scientists but also to enterprises. The next steps in expanding the system will include the introduction of multiple users who can act as both publisher and subscriber to enable a user-to-user communication paradigm and privacy and security concerns of the system need to be addressed. At the moment, the solution covers basic online security mechanisms, but it is widely known that MQTT requires additional security mechanisms [44,45], which will become part of the project in the future. The presented system meets the imposed requirements, which were based on the use of modern wireless control technologies in industry [46–48]. The solution is characterized by a very small number of required elements, which makes it easy to implement in already existing industrial systems. This solution has great possibilities that will reduce the amount of energy consumed, which will have a positive impact on the natural environment and will help entrepreneurs meet the requirements of the European Union.

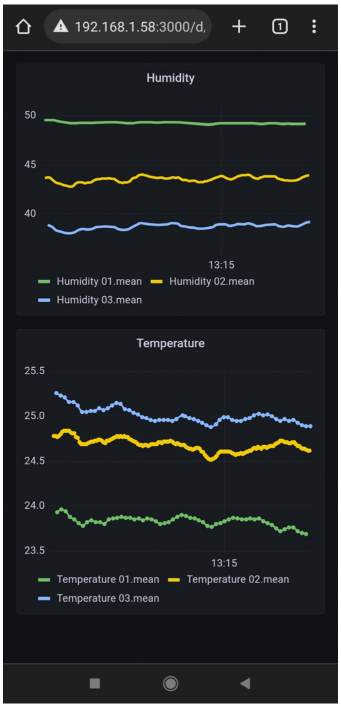

Figure 10. Mobile Grafana, own study A. Wycisk.

5. Conclusions

This article presents a measurement system for monitoring and control in the implementation of open source energy management systems based on the Internet of Things (IoT). The hardware implementation of the proposed solution using energy-saving, open source and easily available components was also presented. When designing the system, care was taken to ensure data security and integrity as well as system reliability. These solutions have been implemented through the use of Raspberry Pi. Therefore, the server was hosted locally and self-managed in the network, due to which security and data integrity measures, such as authentication, authorization, and access control, are self-managed by the system administrator. We also showed the use of the lightweight MQTT protocol for data transmission. At the moment, the solution covers basic online security mechanisms, but the additional security mechanisms will become a part of the project in the future. Although the proposed system has only been tested in a laboratory setting, it can be used in other applications requiring real-time data acquisition, remote monitoring and supervisory control, such as power trans-mission and distribution systems, and home energy and climate management systems. The SMART concept, which has been presented in this article, is a proposal for a measurement, monitoring and control system as part of the implementation of energy management systems. This idea can become the basis for changing traditional buildings into interactive objects, using sensors and controllers of systems, such as air conditioning, central heating, ventilation, lighting, electronics and household appliances or alarm systems. The controlling elements and sensors communicate with the control panel, which can cooperate with all devices, regardless of the manufacturing technology. This makes the proposed system very versatile. Another advantage of the solution is the fact that the building is no longer a dead solid and starts to communicate with the environment, sending information and accepting commands. The new concept allows you to control devices and monitor their status from any place with Internet access. It was also indicated that this is a method of using information technologies, including the Internet of Things, the use of which may increase energy efficiency, as well as improve the degree of use of electricity. It should be added, however, that their use requires the development of algorithms that enable effective control of electricity consumption by these devices.

Author Contributions: Conceptualization, A.M., A.W., A.N. and J.P.; methodology, A.M., A.W.; software, A.M., A.W.; validation, A.M., A.W., A.N. and J.P.; formal analysis, A.M., A.W., A.N. and J.P.; investigation, A.M., A.W., A.N. and J.P.; resources, A.M., A.W., A.N. and J.P.; data curation, A.M., A.W., A.N. and J.P.; writing—original draft preparation, A.M., A.W., A.N. and J.P.; writing—review and editing, A.M., A.W., A.N. and J.P.; visualization, A.M., A.W., A.N. and J.P.; supervision, A.M., A.W., A.N. and J.P.; project administration, A.M.; funding acquisition, A.M. All authors have read and agreed to the published version of the manuscript.

Funding: Publication supported under the rector's pro-quality grant and statutory research, Silesian University of Technology, BK number 06/010/BK_22/0054.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Zhou, L.; Li, J.; Li, F.; Meng, Q.; Li, J.; Xu, X. Energy consumption model and energy efficiency of machine tools: A compre-hensive literature review. *J. Clean. Prod.* **2016**, *112*, 3721–3734. [CrossRef]
2. Bluszcz, A. The Emissivity and Energy Intensity in Eu Countries—Consequences for the Polish Economy. In Proceedings of the Energy and Clean Technologies. Recycling, Air Pollution and Climate Change, Sofia, Bulgaria, 1–7 July 2018; Volume 18, pp. 631–638.
3. Bluszcz, A. European economies in terms of energy dependence. *Qual. Quant.* **2017**, *51*, 1531–1548. [CrossRef] [PubMed]
4. Manowska, A. Analysis and Forecasting of the Primary Energy Consumption in Poland Using Deep Learning. *Miner. Eng.* **2020**, *21*, 217–222. [CrossRef]
5. Manowska, A. Using the LSTM network to forecast the demand for electricity in Poland. *Appl. Sci.* **2020**, *10*, 8455. [CrossRef]
6. Rybak, A.; Rybak, A. Methods of Ensuring Energy Security with the Use of Hard Coal—The Case of Poland. *Energies* **2021**, *14*, 5609. [CrossRef]
7. Manowska, A.; Nowrot, A. The importance of heat emission caused by global energy production in terms of climate impact. *Energies* **2019**, *12*, 3069. [CrossRef]
8. A European Green Deal. European Commission. Available online: Europa.eu (accessed on 11 November 2022).
9. Available online: www.gov.pl/web/klimat (accessed on 15 November 2022).
10. Nowrot, A.; Mikołajczyk, M.; Manowska, A.; Pielot, J.; Wojaczek, A. Low Cost Solar Thermoelectric Water Floating Device to Supply Measurement Platform. *Informat. Autom. Pomiary Gosp. Ochr. Środ.* **2019**, *9*, 78–82. [CrossRef]
11. Moghimi, M.; Jamborsalamati, P.; Hossain, J.; Stegen, S.; Lu, J. A Hybrid Communication Platform for Multi-Microgrid Ener-gy Management System Optimization. In Proceedings of the IEEE International Symposium on Industrial Electronics, Cairns, QLD, Australia, 13–15 June 2018; pp. 1215–1220.
12. Bellido-Outeirino, F.J.; Flores-Arias, J.M.; Palacios-Garcia, E.J.; Pallares-Lopez, V.; Matabuena-Gomez-Limon, D. M2M home data interoperable management system based on MQTT. In Proceedings of the IEEE International Conference on Consumer Electronics—Berlin (ICCE-Berlin), Berlin, Germany, 3–6 September 2017; pp. 200–202.

13. Adhikaree, A.; Makani, H.; Yun, J.; Qiao, W.; Kim, T. Internet of Things-enabled multiagent system for residential DC mi-crogrids. In Proceedings of the IEEE International Conference on Electro Information Technology, Lincoln, NE, USA, 14–17 May 2017; pp. 100–104.
14. Kondoro, A.; Dhaou, I.B.; Tenhunen, H. Enhancing the security of IoT-enabled DC microgrid using secure-MQTT. In Proceedings of the 6th IEEE International Energy Conference (ENERGYCon 2020), Gammarth, Tunisia, 28 September–1 October 2020; pp. 29–33.
15. Chien, H.-Y.; Wang, N.-Z. A Novel MQTT 5.0-Based Over-the-Air Updating Architecture Facilitating Stronger Security. *Electronics* **2022**, *11*, 3899. [CrossRef]
16. Arbab-Zavar, B.; Palacios-Garcia, E.J.; Vasquez, J.C.; Guerrero, J.M. Message Queuing Telemetry Transport Com-munication Infrastructure for Grid-Connected AC Microgrids Management. *Energies* **2022**, *14*, 5610. [CrossRef]
17. Amir Alavi, S.; Rahimian, A.; Mehran, K.; Alaleddin Mehr Ardestani, J. An IoT-Based Data Collection Platform for Situa-tional Awareness-Centric Microgrids. In Proceedings of the Canadian Conference on Electrical and Computer Engineering, Quebec, QC, Canada, 13–16 May 2018.
18. Aagri, D.K.; Bisht, A. Export and Import of Renewable energy by Hybrid MicroGrid via IoT. In Proceedings of the 2018 3rd International Conference on Internet of Things: Smart Innovation and Usages (IoT-SIU 2018), Bhimtal, India, 23–24 February 2018.
19. Friansa, K.; Haq, I.N.; Santi, B.M.; Kurniadi, D.; Leksono, E.; Yuliarto, B. Development of Battery Monitoring System in Smart Microgrid Based on Internet of Things (IoT). *Procedia Eng.* **2017**, *170*, 482–487. [CrossRef]
20. Numair, M.; Mansour, D.E.A.; Mokryani, G. A Proposed IoT Architecture for Effective Energy Management in Smart Mi-crogrids. In Proceedings of the 2nd Novel Intelligent and Leading Emerging Sciences Conference (NILES 2020), Giza, Egypt, 24–26 October 2020; pp. 594–599.
21. González, I.; Calderón, A.J.; Portalo, J.M. Innovative multi-layered architecture for heterogeneous automation and monitoring systems: Application case of a photovoltaic smart microgrid. *Sustainability* **2021**, *13*, 2234. [CrossRef]
22. Samanta, H.; Bhattacharjee, A.; Pramanik, M.; Das, A.; Das Bhattacharya, K.; Saha, H. Internet of things based smart energy management in a vanadium redox flow battery storage integrated bio-solar microgrid. *J. Energy Storage* **2020**, *32*, 101967. [CrossRef]
23. Alhasnawi, B.; Jasim, B.; Sedhom, B.; Hossain, E.; Guerrero, J. A New Decentralized Control Strategy of Microgrids in the Internet of Energy Paradigm. *Energies* **2021**, *14*, 2183. [CrossRef]
24. Alhasnawi, B.; Jasim, B.; Rahman, Z.-A.; Guerrero, J.; Esteban, M. A Novel Internet of Energy Based Optimal Multi-Agent Control Scheme for Microgrid including Renewable Energy Resources. *Int. J. Environ. Res. Public Health* **2021**, *18*, 8146. [CrossRef] [PubMed]
25. Ali, W.; Ulasyar, A.; Mehmood, M.U.; Khattak, A.; Imran, K.; Zad, H.S.; Nisar, S. Hierarchical Control of Microgrid Using IoT and Machine Learning Based Islanding Detection. *IEEE Access* **2021**, *9*, 103019–103031. [CrossRef]
26. Al-Turjman, F.; Zahmatkesh, H.; Shahroze, R. An overview of security and privacy in smart cities' IoT communications. *Trans. Emerg. Telecommun. Technol.* **2022**, *33*, e3677. [CrossRef]
27. Javed, A.R.; Shahzad, F.; Rehman, S.U.; Bin Zikria, Y.; Razzak, I.; Jalil, Z.; Xu, G. Future smart cities: Requirements, emerging technologies, applications, challenges, and future aspects. *Cities* **2022**, *129*, 103794. [CrossRef]
28. Roldán-Gómez, J.; Carrillo-Mondéjar, J.; Gómez, J.M.C.; Martínez, J.L.M. Security Assessment of the MQTT-SN Protocol for the Internet of Things. *J. Physics Conf. Ser.* **2022**, *2224*, 012079. [CrossRef]
29. Bang, A.O.; Rao, U.P. Design and evaluation of a novel White-box encryption scheme for resource-constrained IoT devices. *J. Supercomput.* **2022**, *78*, 11111–11137. [CrossRef]
30. Ortiz, G.; Boubeta-Puig, J.; Criado, J.; Corral-Plaza, D.; Garcia-de Prado, A.; Medina-Bulo, I.; Iribarne, L. A microservice architecture for real-time IoT data processing: A reusable Web of things approach for smart ports. *Comput. Stand. Interfaces* **2022**, *81*, 103604. [CrossRef]
31. Mishra, B.; Mishra, B.; Kertesz, A. Stress-Testing MQTT Brokers: A Comparative Analysis of Performance Measure-ments. *Energies* **2021**, *14*, 5817. [CrossRef]
32. Babiuch, M.; Foltýnek, P. Creating a Mobile Application with the ESP32 Azure IoT Development Board Using a Cloud Platform. In Proceedings of the 2021 22nd International Carpathian Control Conference (ICCC), Velké Karlovice, Czech Republic, 31 May–1 June 2021; IEEE: Piscataway, NJ, USA, 2021.
33. D'Ortona, C.; Tarchi, D.; Raffaelli, C. Open-Source MQTT-Based End-to-End IoT System for Smart City Scenarios. *Futur. Internet* **2022**, *14*, 57. [CrossRef]
34. Santhosh, P.; Singh, A.K.S.; Ajay, M.; Gaayathry, K.; Haran, H.S.; Gowtham, S. IoT based Monitoring and Optimizing of Energy Utilization of Domestic and Industrial Loads. In Proceedings of the 2021 5th International Conference on Intelligent Computing and Control Systems (ICICCS), Madurai, India, 6–8 May 2021; pp. 393–397. [CrossRef]
35. Salunkhe, A.S.; Kanse, Y.K.; Patil, S.S. Internet of Things based Smart Energy Meter with ESP 32 Real Time Data Monitoring. In Proceedings of the 2022 International Conference on Electronics and Renewable Systems (ICEARS), Tuticorin, India, 16–18 March 2022; pp. 446–451.
36. Available online: Mqtt.org (accessed on 15 November 2022).
37. Hussein, N.; Nhlabatsi, A. *Living in the Dark*: MQTT-Based Exploitation of IoT Security Vulnerabilities in ZigBee Networks for Smart Lighting Control. *IoT* **2022**, *3*, 450–472. [CrossRef]

38. Chakravarthi, V. *Internet of Things and M2M Communication Technologies*; Springer: Berlin/Heidelberg, Germany, 2021.
39. Grafana: The Open Observability Platform. Available online: https://grafana.com/ (accessed on 20 November 2022).
40. InfluxDB: Time Series Platform for Developers. Available online: https://www.influxdata.com/ (accessed on 20 November 2022).
41. Kodali, R.K.; Anjum, A. IoT Based HOME AUTOMATION Using Node-RED. In Proceedings of the 2018 Second International Conference on Green Computing and Internet of Things (ICGCIoT), Bangalore, India, 16–18 August 2018; pp. 386–390. [CrossRef]
42. Available online: https://nodered.org/ (accessed on 21 November 2022).
43. Available online: https://www.raspberrypi.com/ (accessed on 21 November 2022).
44. Butun, I.; Osterberg, P.; Song, H. Security of the Internet of Things: Vulnerabilities, Attacks, and Countermeasures. *IEEE Commun. Surv. Tutor.* **2020**, *22*, 616–644. [CrossRef]
45. Singh, M.; Rajan, M.; Shivraj, V.; Balamuralidhar, P. Secure MQTT for Internet of Things (IoT). In Proceedings of the 2015 Fifth International Conference on Communication Systems and Network Technologies, Gwalior, India, 4–6 April 2015; pp. 746–751.
46. Majid, M.; Habib, S.; Javed, A.R.; Rizwan, M.; Srivastava, G.; Gadekallu, T.R.; Lin, J.C.-W. Applications of Wireless Sensor Networks and Internet of Things Frameworks in the Industry Revolution 4.0: A Systematic Literature Review. *Sensors* **2022**, *22*, 2087. [CrossRef]
47. Atif, S.; Ahmed, S.; Wasim, M.; Zeb, B.; Pervez, Z.; Quinn, L. Towards a Conceptual Development of Industry 4.0, Servitisa-tion, and Circular Economy: A Systematic Literature Review-2021. *J. Sustain.* **2021**, *13*, 6501. [CrossRef]
48. Maddikunta, P.K.R.; Pham, Q.-V.; Prabadevi, B.; Deepa, N.; Dev, K.; Gadekallu, T.R.; Ruby, R.; Liyanage, M. Industry 5.0: A survey on enabling technologies and potential applications. *J. Ind. Inf. Integr.* **2021**, *26*, 100257. [CrossRef]