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SENSOR EXPANSION FOR INDUSTRIAL CONTROLLER BASED ON IOT GATEWAY

Based on the current trends of industrial applications and internet of things, a distributed system solution is proposed. The work presents a description of used communication methods, connected devices, the support software and the necessary configuration. Low-cost IoT-based sensor augmentation can be used to keep older machines and companies competitive when new equipment is not available for purchase. The main sensor functions of an older industrial controller can be extended by the data, which is measured on the microcontrollers. This is demonstrated on the example of a system solution with detailed set up and configuration.

Keywords: *sensors; iot; gateway; expansion; controller.*
Fig.: 6. Table: 3. References: 11.

Urgency of the research. In the current economic situation, every legacy machine owner wants to upgrade their machinery or system to a more advanced solution. With the actual available technical and communication solutions the diagnostics and maintenance of the machinery can be solved easily or even remotely from the actual application. Although many vendors offer a wide range of additional features and capabilities, in many cases these devices are out of stock due to extended delivery term. Additionally, many machines work at high efficiency using older type of controllers and there is a risk of the replacement whether the upgrade can fulfill the actual requirements. On the other hand, microcontrollers and their variants standardized for industrial application are gaining on popularity. The possibilities for microcontrollers also include wireless communication, low power consumption and in many cases very low purchase price [1-3].

The current situation created by the COVID-19 pandemic urges to find interdisciplinary solutions and ways to upgrade or at least hold the efficiency of machinery and systems as long as possible. Measuring additional parameters for maintenance and monitoring purposes are the basics steps of protection against unnecessary downtimes or failures [2-5].

Target setting. The concept of a solution to connect information from microcontroller-based measurement to an industrial controller is motivated to help SMEs and legacy OEMs to keep their productivity and efficiency with the already used tools and with a smaller investment to the production.

IoT Gateway. The wave of Internet of Things (industrial and commercial) created a wide range of different microcontrollers and cloud solutions for data transfer and processing. The main goal is simply to share data, at low cost, low power, and if it's possible wirelessly. In many cases these devices are battery powered and easily replaced. With the operation of IoT thing we can monitor parameters as temperature, humidity, presence, vibration etc. The gathered data has to be processed, stored and transferred to other devices like supervisor controller or central control unit where the suitable reactions are also created. [2-5] One of the possible solutions is to use a Raspberry Pi as an IoT Gateway. In this role it will work as a central network node which not only collects all the data, but also transfers them between the other nodes of the network. With its computing capabilities it can also solve other tasks such data logging, remote monitoring interface, etc. Because of the communication interfaces, there are many ways to communicate with such device, and sometimes it's not necessary to work via Internet based connection and it's possible to separate the system physically [7-8].

Requirements for equipment. The proposed example solution includes an industrial programmable relay equipped with digital and analog input and outputs. The system should be integrated to a control cabinet and as main control task it can solve applications like sorting, transporting, handling, manipulation etc. Because of unpredictable requirements the devices in the control cabinet have been changed and also some mechanical parts were replaced. These differences create an uncertainty and danger that the system can fail for high temperature, vibration, factor etc. For this kind of problems, a separated controller and sensor can be applied [6-11].

Communication. The data transfer between each device of the proposed solution combines the gateway functionality of the Node-RED programming environment and the communication capabilities of the other devices. The LOGO! industrial uses its integrated Ethernet interface to communicate using the S7comm protocol. This is a Siemens protocol created primarily to transfer data between the Siemens controllers and SCADA systems. It defines the Session, Presentation and Application Layer of the ISO/OSI model.

MQTT stands for Message Queue Telemetry Transport protocol. This is one of the most popular IoT communication protocols. It uses the client server relation between the network nodes, with publishing and subscription methodologies to transfer messages. The central node of the MQTT network is a broker who ensures the correct connection and quality of the message transportation. Its lightweight, open, simple protocol designed for easy implementation in various platforms. With its main characteristics it's suitable for machine-to-machine and network context.

The research objective. The main objective of this article is a proposal and subsequent testing of a hybrid automated system that collects data from microcontroller-based platform and transfers data via another network device to industrial controller to extend its sensorial peripheries. The proposed system can be used as a working example, or as a template solution for similar combination of devices.

The statement of basic materials. The main control device of an example industrial machinery is the Siemens LOGO! With its basic version it has integrated inputs and outputs. The LOGO! is suitable for small industrial automation applications where logical relations between the input signals are used to create a response. It's used also in building automation, remote monitoring, and logistics applications etc. The main central unit without additional hardware supports Ethernet based communication via S7 communication protocol. The LOGO!Soft Comfort software was used to program the LOGO!. The technical parameters of the LOGO!12/24 RCE are in the following table.

Table 1. Technical parameters LOGO! 12/24 RCE

Power supply	24 VDC
Digital Inputs	8 x (4 configurable)
Analog Inputs	Up to 4 x (configured from the digital inputs)
Digital Outputs	4 x Relay type
Integrated display	Up to 6 rows, 3 color backlight
Communication Interface	1 x Ethernet Port (10/100 Mbps)

The external signal for the LOGO! controller is created by measurement of temperature via microcontroller. ESP32 is used in the proposed system. The ESP32 has integrated I/O pins, but the major difference is that the operation voltage is not a classic 24VDC, but 3.3 and 5V. Additionally the ESP32 has integrated Wi-Fi and Bluetooth interfaces. The control program for both ESPs was created in Arduino IDE. The main technical parameters are listed in the next table.

Table 2. Technical parameters ESP32

Power supply	3.3-5 VDC
Digital I/O	30 pins
Integrated Peripherals	capacitive touch, ADCs, DACs, UART, SPI, I2C
Processing memory	512 kB RAM
Clock freq. of proc.	240MHz
Communication Interface	Wi-Fi and Bluetooth

The ESP32 has multiple communication interfaces and to measure the environment temperature a DHT11 and DS18B20 temperature sensors were connected to each module. This temperature can be represented as temperature in the control cabinet, or contact temperature, where critical mechanical part has high friction. Based on this measured value we can predict or prevent malfunction and reduce downtimes, depending on the control logic and connected appliances we can turn on a safety device, turn of the relevant output or call maintenance. The basic functionality for both ESPs was to collect the temperature data and additionally connect to Wi-Fi network. A topic was updated after the successful connection via MQTT protocol. The Node-RED was subscribed to this topic. In this case, the values represented temperature for 2 different positions of a production line/experimental trainer.

Node-RED is a free programming environment. Its main functionality is to connect various hardware devices and software services. Thanks for its browser-based editor it can work on different platforms i.e., pc, raspberry pi, server, virtual machine. The principle of work is to separately process “message payloads” with usually small code and functions, then transfer this “payload” to a different function and make another action with it. There is a lot of predefined functions and solutions already available, and with JavaScript based programming new functions and solutions are implementable to the environment.

Communication configuration. The following configuration steps has been taken to successfully set up each node of the proposed solution. First the LOGO! Programmable Relay was configured. The necessary steps include IPv4 addressing and S7comm permission. Part of the example control program with the communication configuration of the relay is shown on the following Fig. 1.

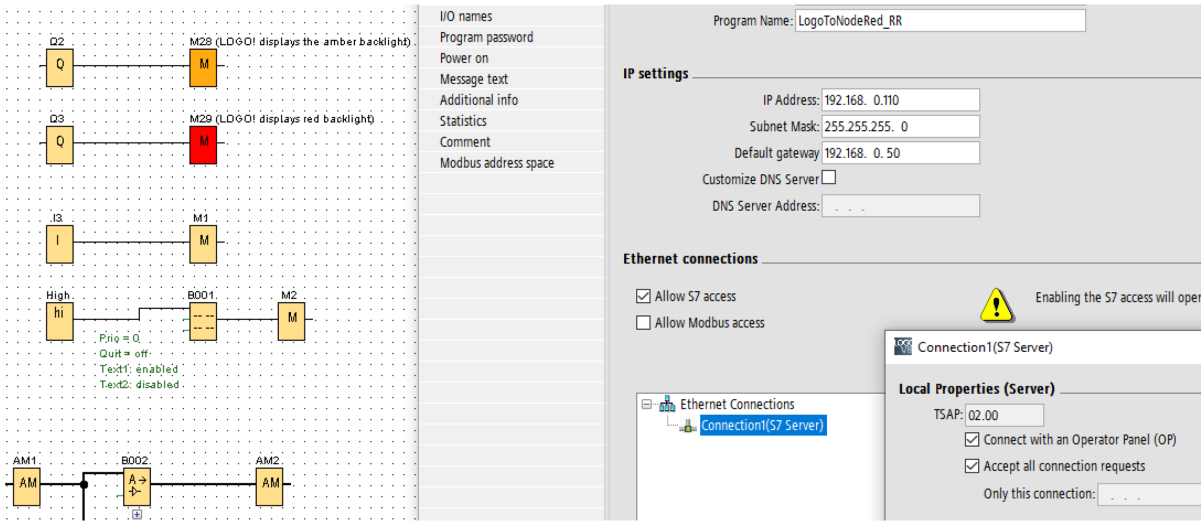

Fig. 1. LOGO!Soft Comfort and configuration

The next step was to set up the Node-RED connection to the LOGO!. The main parameters for this setup are shown below. (Fig. 2). This includes TCP communication between the LOGO! and the Node-RED. The base is the IP address of the devices, with additional communicated variables inside the hardware.

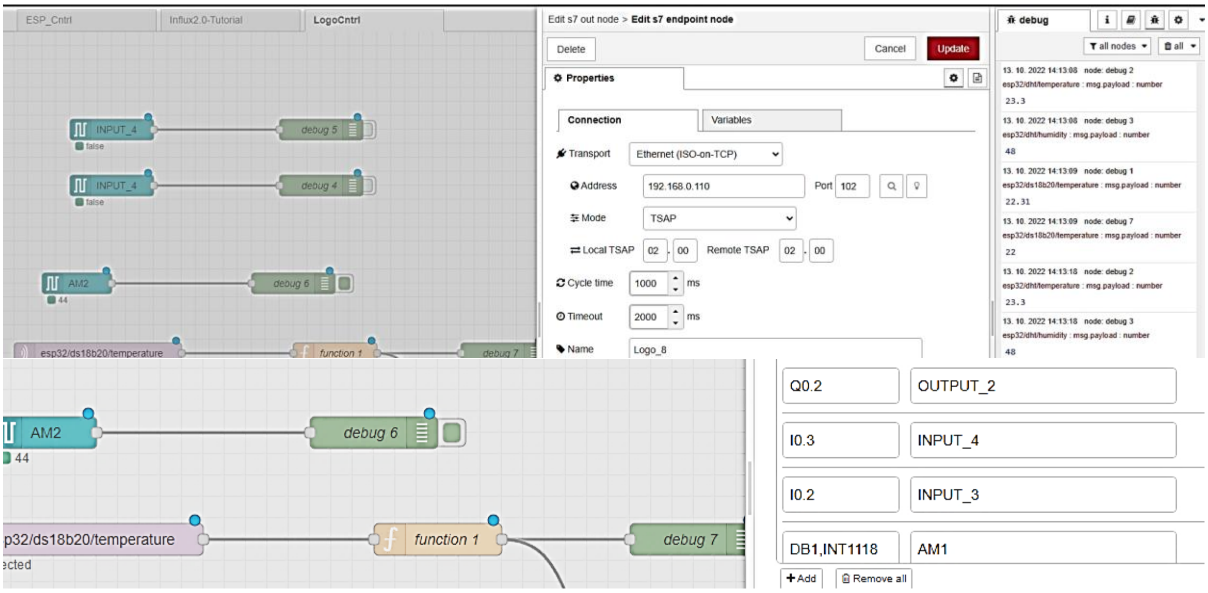

Fig. 2. Node-RED communication setup-LOGO!

Finally, the MQTT communication is configured. The IP address also needs a connection for the appropriate "topic" and quality of service. Details of this program part are shown below (Fig. 3).

Fig. 3. Node-RED communication setup-ESP

Wireshark application can be used to check the ongoing communication between each network node. We can collect additional data, catch the transferred packets via this network tool. The Node-RED debugger view also provides help as a basic communication window.

Detailed view of the ongoing communication between the LOGO!, Raspberry Pi and ESP32s is shown on the following figures.

Figure 4, on the next page, shows the created working network activity, where the sending, receiving IP addresses with the protocols and the details of what data are „caught ". The Table 3 below lists the message system with IP address, name and protocol for the proposed system.

Table 3. Parameters of the network

Sender	**Receiver**	**Protocol**	**Message Detail**
192.168.0.51 (MQTT broker)	192.168.0.84 (ESP32_DS18B20)	MQTT	Received Message on Topic
192.168.0.80 (ESP32_DHT11)	192.168.0.51 (MQTT broker)	MQTT	Topic Published to Broker
192.168.0.110 (LOGO!)	192.168.0.51 (Node-RED)	S7comm	Variable Reading Job
192.168.0.51 (Node-RED)	192.168.0.110 (LOGO!)	S7comm	Acknowledge of correct data

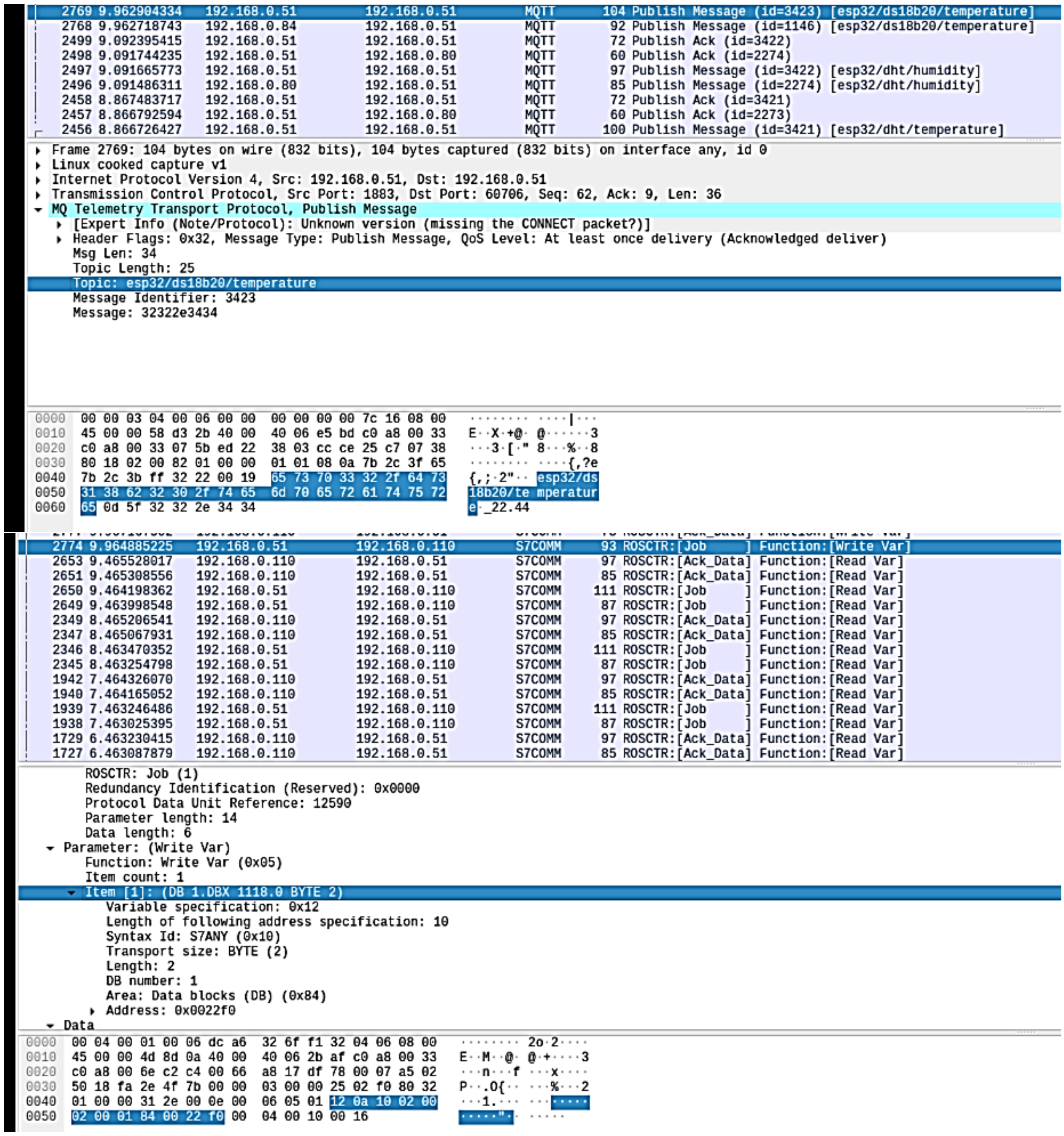

Fig. 4. Wireshark communication check

Used method. The aim of this solution is to extend the sensorial functions of programmable relays. With the help of additional sensors, an older controller, an outdated machine can be connected to another controller, even a microcontroller or a device with non-standard sensor options. The overall concept of the system consists of industrial controller, two microcontrollers and an IoT Gateway. The main control unit, or programmable controller, solves its main purpose, to control the ongoing industrial process or machinery. These kinds of systems typically are equipped with digital and analog I/O cards. In some cases, there are additional specialized expansion modules for tasks like temperature or weight measurement. Usually at least one or two communication interfaces are also available to transfer relevant signals to a different controller or SCADA system. The controller is connected to IoT Gateway, which in our case is Raspberry Pi with installed Node-RED. Their function is to separately collect and transfer data between other devices of the network. The next group of devices include microcontrollers and sensors connected to them. The measured value is transferred via wireless connection to the IoT Gateway and processed. Optionally the data can be sent to industrial controller, database or other service on the server or cloud.

The proposed system structure is shown on Fig. 5.

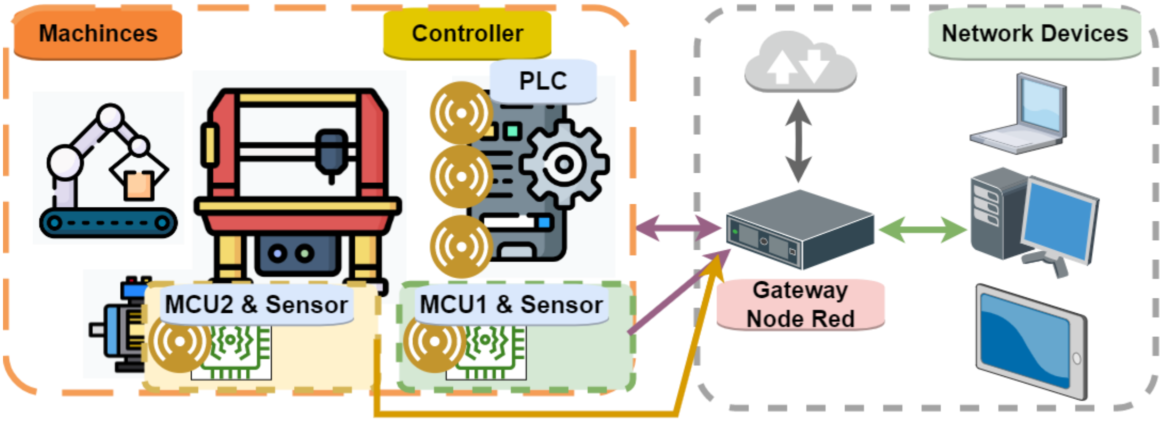

Fig. 5. System structure

Conclusion. This paper describes a proposal of sensorial expansion for industrial controllers based on IoT gateway and microcontrollers. While the modern industrial applications and control units support a wide range of additional maintenance and diagnostic functionalities, many existing companies are not able to upgrade or have concerns about replacing their current systems. In the actual situation after the pandemic, many industrial device vendors are not able to fulfill the demand on required devices in short time, therefore an interdisciplinary solution is proposed to add extra capabilities to legacy machines. The integrated microcontrollers allow to connect sensors that can create useful data about the temperature, vibrations, presence and other parameters from the ongoing process. With the proposed Gateway it's possible to transfer data between different devices, and software services locally or remotely. The article aims to introduce the essential steps for successful IoT implementation of the system design and describes a functioning principle of the proposed devices and the communication methods. The most important solution aspect was to create a working communication channel between the industrial programmable relay and the microcontroller.

The proposed system is divided into 4 main devices and software parts. The main industrial unit is a Siemens LOGO!, which can directly control an industrial process. S7comm protocol is available for communication with other devices. This is used to connect to the IoT Gateway. The 2 microcontrollers measure the temperature in the example temperature of the control cabinet and the mechanical part. The ESPs use MQTT communication to transfer data to the gateway. Raspberry Pi, the Node-RED software support the interchange between various communication channels on the IoT Gateway, and if needed, transforms or process the data. The flow of the Node-RED, an alarm, database, visualization and other services can extend the function of the current solution depending on the program. The proposed system can be used as a basis for real application or as knowledge basis for further experiments and development.

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РОЗШИРЕННЯ СЕНСОРІВ ДЛЯ ПРОМИСЛОВОГО КОНТРОЛЕРА НА ОСНОВІ ШЛЮЗУ IOT

Використання сучасних розробок і доступних технічних і комунікаційних технологій дозволяє збільшити сенсорну здатність різних пристроїв управління, таких як програмовані реле або промислові програмовані логічні контролери. Базу датчиків можна значно розширити, розподіливши збір даних через недорогі пристрої, такі як мікроконтролери.

У минулому в процесі проєктування промислових виробничих ліній або автоматизованих систем зазвичай не було цілей самодіагностики системи або діагностики машин. У поточній ситуації на ринку промислових пристроїв, де багато пристроїв недоступні або відсутні в наявності, рішення для оновлення сенсорної частини застарілого обладнання є важливим.

Фактичні наукові дослідження та аналіз рішень щодо сенсорного розширення промислових програмованих контролерів показали, що сьогодні більшість додатків не розраховуються з відсутністю нового апаратного забезпечення або плат розширення для контролерів.

Мета статті – запропонувати рішення для модернізації застарілого промислового обладнання, де потрібні датчики нового типу для моніторингу поточного процесу або збору діагностичних даних для завдання технічного обслуговування.

На основі принципів і підходів функціонального аналізу технічних систем в роботі представлено метод розширення сенсорних можливостей промислових контролерів для цілей обслуговування та діагностики. Основні програмні та апаратні компоненти описані як приклад рішення.

У цій роботі пропонується недороге сенсорне розширення для програмованих реле. Описано технічні параметри використовуваних засобів зв'язку та принцип їх роботи. Визначено функції технологічних пристосувань та продемонстровано їх прикладне застосування. Представлені матеріали та конфігурацію можна використовувати для підтримки реальної інтеграції в існуючу автоматизовану систему, наприклад, обробки матеріалів, сортування, автоматизації будівель тощо, де потрібно контролювати додаткові параметри. Незважаючи на те, що запропоноване рішення є прикладом проєкту, орієнтованого на IoT, у поточному вигляді не потрібно використовувати пряме підключення до Інтернету та воно може працювати в локальній мережі компанії.

Ключові слова: *датчики; iot; шлюз; розширення; контролер.*

Рис.: 6. Табл.: 3. Бібл.: 11.

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