Utilization of Open-Source in Upgrading Technological Devices for Industry 4.0 readiness

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Abstract*. The concept of Industry 4.0 currently represents the first choice according to which industrial equipment is designed and implemented. There are visible trends in integrating open-source solutions into the industry. At the same time, the advancement in science and technology development has decreased prices for sensing, processing, and sharing technologies. Retrofitting existing equipment brings additional opportunities for incorporation into factory automation. In this contribution, the focus was put on upgrading an older climate chamber to meet current requirements utilizing the Node-RED solution. The solution fully replaces the legacy control system while providing options for low-cost additional hardware and software extensions.*

Keywords. open-source, Industry 4.0, Node-RED, sensor, PLC.

1 Introduction

The concept of Industry 4.0 currently represents the first choice according to which industrial equipment is designed and implemented. Smart devices and automation are the trend of the times and will continue to expand unstoppably.

This paper aims to propose the concept of using open-source solutions to upgrade existing technological equipment. Many such devices have become obsolete during their many years of usage, and it is impossible to upgrade their automation level to a higher level easily. Such an upgrade involves a complete replacement of the control system and possibly further technological enhancements in the areas of sensors, actuators, and drives. Many advanced technologies are available and already in use. For example, the authors of this paper dealt with using 1-wire networks for industrial applications. Later they designed a universal module for connecting various sensors (Dudak et al., 2018).

However, several factors nevertheless make such equipment upgrades advantageous:

- can still carry out its function,
- simple repairs,
- spare parts availability,
- economic sense of replacement with new equipment.

The upgrade of the control system of an older climate chamber used by a local company in the Slovak Republic was chosen as a practical example for this proposal. It is a device with analog control, which does not allow for programmed heating and cooling. The device also does not allow remote management, control, or reporting of operating states.

Climate chambers, also known as environmental test chambers or climatic chambers, are specialized enclosures used to simulate and control various environmental conditions such as temperature, humidity, light, and sometimes other factors like pressure or vibration. The primary purpose of climate chambers is to replicate real-world conditions in a controlled setting, allowing researchers and engineers to assess how materials, components, or products perform under specific environmental conditions. By subjecting items to different temperature and humidity levels, for example, manufacturers can ensure their products can withstand extreme climates or identify weaknesses that might lead to failure.

The proposed design aims to simplify operators' use and validate open-source technologies applicable to the company's products. The focus was put on using easily accessible and cost-effective solutions so that the results would be widely applicable in the small and medium-sized enterprises (SME) sector, for which significant investments are not always possible.

2 Related work

There are now visible trends in integrating open-source solutions into the industry, which was proved in authors' previous research on identifying essential attributes and needs for small and medium-sized enterprises (Barton et al., 2022). One of the reasons for this is the drop in price and the widespread availability of suitable hardware components. As the authors note, industrial and consumer internet of things (IoT) solutions are becoming economically and technologically viable, and in some instances, they are implementable in highly automated lines. At the same time, the general advancement in science and technology development has decreased prices for sensing, processing, and sharing technologies. Thereby, IoT technologies are now widely adopted in many commercial and industrial products (Martikkala et al., 2021). The involvement of open-source solutions in industrial applications is further discussed by the authors (Rathee & Chobe, 2022), who argue that industries that have been around for more than a century, like automotive and agriculture, and the industries formed much more recently, like aerospace, have all embraced open-source technologies and there is hardly any industry that has not dabbled in open-source software. Another example of open-source utilization is implementing a supervisory control and data acquisition (SCADA) system for a hybrid power system based on the Node-RED solution (Omidi et al., 2023). The authors declare their study to be a pioneer in developing open-source SCADA systems that are low-cost and low-power in their design. In most cases, SCADA systems are made up of hardware and software components that collaborate to gather and analyze data from sensors, control devices, and other sources before giving operators a graphical user interface (GUI) for managing and overseeing these operations. Due to their many benefits, open-source solutions have grown in favor recently, even among SCADA systems. Software with publicly available source code, allowing anybody to examine, alter, and distribute the code, is called "open source". In contrast the proprietary software, whose owner is a particular entity, does not provide source code to the general public. Typically, a community of individuals or organizations that work together and contribute to the codebase develops open-source software.

These characteristics can be utilized and, on their basis, can be concluded:

1. **Cost-Effective:** Compared to proprietary solutions, open-source SCADA systems are frequently more affordable, which is one of its main advantages. Traditional SCADA systems may require pricey licensing, hardware, and continuing maintenance fees, making them costly to adopt and operate. Contrarily, open-source SCADA systems are frequently cost-free to operate, require no license costs, and can function on affordable hardware, making them more affordable for enterprises on a tight budget.
2. **Customization and Flexibility:** Open-source SCADA systems allow program modification to satisfy particular needs. Companies can alter the source code to add or remove features, combine the software with other systems, or customize it to suit their requirements. In proprietary SCADA systems, where companies may have little control over the software's functionality and may need to rely on the vendor for modification, this level of customization is not often accessible.
3. **Transparency and Security:** Since the source code is made accessible for public inspection by the community, open-source SCADA systems provide transparency. It makes it possible for impartial security audits, which can assist in finding and fixing flaws and guarantee the security and dependability of the software. Because the source code is available, security upgrades and patches are not dependent on a single vendor, which might give more control over security precautions.
4. **Interoperability and Integration:** Open protocols and standards are frequently used to design open-source SCADA systems, which can help with interoperability and device integration. Enterprises can link the SCADA system with their current infrastructure, such as programmable logical controllers (PLC), remote terminal units (RTU), human-machine interfaces (HMI), and other industrial devices, without being constrained by proprietary protocols or interfaces.
5. **Community Support:** Open-source SCADA systems frequently have a vibrant user and development base that offers support via forums, mailing lists, and other platforms. It can give businesses access to a plethora of information and know-how, as well as plugins, modules, and documentation made by the community.

Open-source SCADA systems have several benefits: affordability, adaptability, customization, transparency, security, interoperability, and community support. Before selecting an open-source SCADA system, organizations should carefully assess their unique needs and available resources. It is because these systems may have drawbacks like a potential lack of commercial support, varying levels of user-friendliness, and potential differences in features from proprietary systems.

Retrofitting existing machines into Industry 4.0-ready equipment also brings additional opportunities for incorporation into factory automation. Those are, in particular, M2M communication options, with many applications one can adopt in any domain (Chakravarthi, V.S., 2021). Another example is that deploying such new technologies continuously increases demands for real-time wireless large data collection and acquisition (Big data), emphasizing simplicity and speed (Vagas et al., 2019).

3 Original equipment status and upgrade options analysis

The climatic chamber was custom-built for low temperature curing of potting compounds up to 100°C about 20 years ago. The work procedure is as follows:

1. The potting compound is prepared according to the datasheet. It is used for potting of electronic products, specifically specialized sensors.
2. Products are then placed in the climate chamber, operating parameters are set, and the process of curing the compound is started.
3. After a defined time, the products are unloaded, and the curing quality and the functional test are checked.
4. If the product is finalized according to the manufacturer's requirements, it is further packed and ready for shipment from the factory.

The climate chamber body chassis is made of stainless-steel plates for easy maintenance and cleaning. Heating was provided using heating elements connected in parallel, which were located on three sides of the chamber (excluding the door). A fan homogenizes the temperature inside the chamber. The schematic layout of the original chamber design is shown in Figure 1.

Such a device is a typical representative of the time of its creation, focused on simplicity of control solutions without the need for integration into other systems or other communication features. Due to the nature of the use and the high financial cost of such extensions at the time, the equipment was used until last year in its original state. The high entry costs of proprietary solutions have been reduced over time due to the rapid development of open-source solutions.

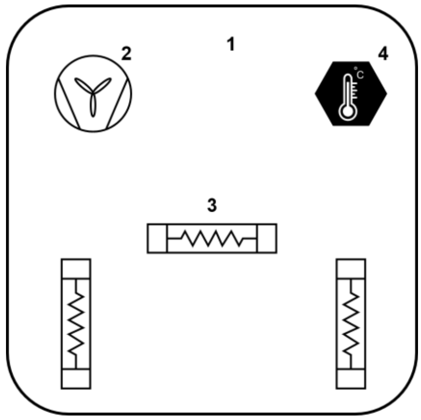

Figure 1. Chamber block schematics
1. Chamber chassis, 2. Fan, 3. Heating elements, 4. Thermometer

Open-source solutions have also been marginalized in the past due to their low uptake and lack of support. This concern is no longer valid today, and many suitable solutions are available as free software. An example is the Linux OS, several distributions of which are broadly used as both server and desktop solutions. In addition, the deployment of Linux-based systems is often seen in commercial manufacturers' solutions (SIMATIC Industrial OS - The Linux-based operating system for SIMATIC IPC - ID: 109766374 - Industry Support Siemens, 2019). A significant advantage is that hardware manufacturers also support open-source solutions, often providing their devices with pre-installed or easy-to-install open-source software. An example is the Raspberry Pi single-board computer (Teach, learn, and make with the Raspberry Pi Foundation, 2023), which is often the first choice for deployment in prototypes and final solutions. It is due to its acquisition price, the number of peripherals, and the broad client support from the manufacturer and the community. A suitable local example is the Unipi family of PLC controllers (Unipi, 2023), widely applicable in several areas ranging from home and building automation to industrial solutions. It is also preferable to use an open-source solution for programming the devices.

Since there was PLC Unipy Axon S155 on hand, it was decided to use this hardware with available heating elements, sensors, and other parts to implement the solution. The following chapter describes its set-up, hardware wiring, and programming.

4 Upgrade implementation

The proposal for upgrading the climate chamber was already implemented during several phases in 2022. The design also considered the students' final theses (Fabusova, J., 2022), (Hlavatovic, J., 2022). In this solution was used PLC Unipi Axon S155 as a controller for handling inputs, outputs, and communication with the user shown in a proposed block schematics in Figure 2.

The digital output of the PLC was used to control the switching of the heater. In the same way, for the fan switching, the digital output of the PLC utilizing pulse width modulation (PWM) was used. The PWM was used as a typical digital output technique to regulate the energy supplied to various types of electrical equipment. In this case, to control the fan speed.

A digital PLC input was used to operate the emergency stop button. A 1-wire digital communication interface was used to operate a 1-wire bus on which 4 DS18B20 digital thermometers were connected. Sensors installed at multiple locations inside the chamber measure the temperature distribution. Based on these measurements, the heater and the fan circuits will engage. An Ethernet interface was used for communication with the user, of which two are available on the PLC.

The diagram in Figure 3 shows the basic chamber control algorithm. The operating parameters are initially set, including curing time, curing temperature, fan run time, and dead band. Consequently, the closed-door check is performed, followed by the emergency safety button check. If the checks are successful, the temperature in the chamber is measured. It is followed by a check of the elapsed curing time, and if the time has elapsed, the process ends, and the chamber performs a controlled shutdown. If the time has not yet passed, another temperature comparison occurs. Here are two options again; if the temperature is lower than the set curing temperature, the heating element is turned on with the fan to swirl the air in the chamber to homogenize the chamber temperature.

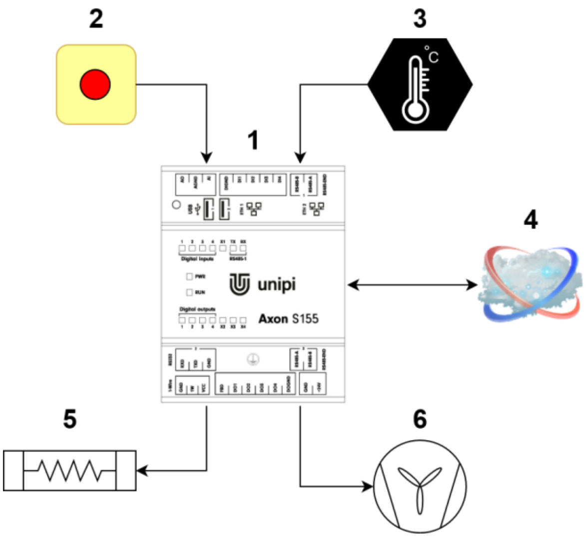

Figure 2. Block diagram of chamber components 1. PLC Axon S155, 2. An emergency stop button, 3. Thermometers, 4. Network connection, 5. Heating elements, 6. Fan.

However, suppose the temperature is higher than the set curing temperature. In that case, the heating element and the fan will turn off after the set cooldown time of the fan since the heater will not stop heating immediately after disconnecting. This process continues until the set curing time has elapsed.

The Node-RED solution (Node-RED, 2023) was chosen as an open-source control and data visualization solution. Node-RED is a tool for programming event-driven applications and provides interconnection between hardware, devices, APIs, and various online services. With the help of the extensive selection of nodes in the palette, Node- RED's browser-based flow editor makes it simple to link flows together. The event-driven, non-blocking paradigm of Node.js is fully utilized in the runtime's construction. Because of this, solutions can operate both in the cloud and at the network's edge on inexpensive hardware such as Raspberry Pi's already mentioned. It is simple to expand the selection of palette nodes to include new functions because the package repository contains more than 225,000 modules. Node-RED flows are saved using JSON format, which is simple to integrate and export for sharing with others.

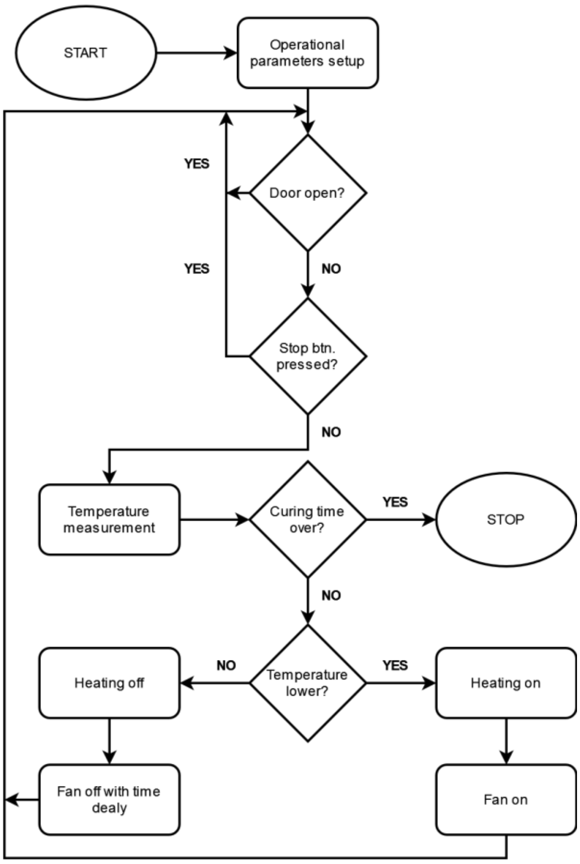

Figure 3. Chamber control flow diagram

Heating control utilizing electric heating elements according to the flow diagram is implemented in the Node-RED environment with the nodes shown in

Figure 4. It represents a typical two-position control implementation.

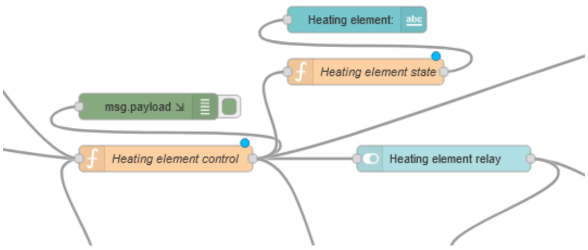

Figure 4. Heating control-related nodes

The fan speed control is implemented using PWM on the digital output of the PLC. The PWM settings are not directly available as a node and must be accessed via the MODBUS PLC registers. The method of setting the PWM parameters can be seen in the right part of Figure 5. through the nodes Set value, Modbus Flex Write and Modbus Response.

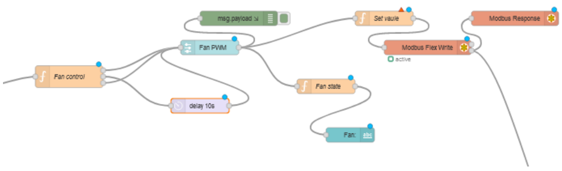

Figure 5. Fan control-related nodes

The MODBUS frame sent to the PLC to set the PWM parameters via node *Set value* has the following format,

```
msg.payload = {
     'quantity': 1,
     'value': msg.payload,
     'count': 1,
     'fc': 06,
     'address': 18,
     'unitid': 1
}
return msg;
```

where *value* represents set PWM duty, *fc* preset single register, *address* MODBUS register and *unitid* connecting route.

Figure 6. shows the implementation of the operating parameters settings, which include curing time, curing temperature, fan run time, and dead band. All settings are user configurable in the UI dashboard through input boxes.

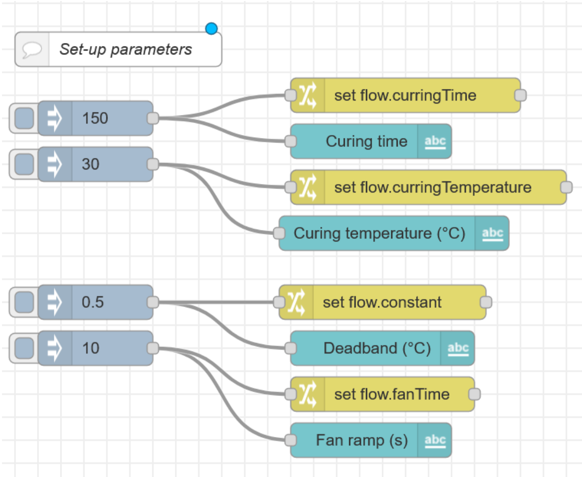

Figure 6. Set-up related nodes

Figure 7 shows the measurement and processing of temperature values. First, values are read from connected digital thermometers, then converted to °C values. Consequently, they are split and formatted for individual temperature values.

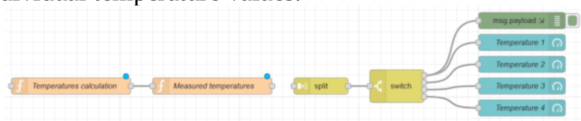

Figure 7. Temperature-related nodes

A simplistic visualization of the climate chamber control process is depicted in Figure 8. In the first column are used defined operating parameters, and in the second column are shown other operating parameters. The chamber graphical visualization is shown in the middle with possible visual alarms on a specific location according to error causing part. On the very right are displayed measured temperature values from connected digital thermometers.

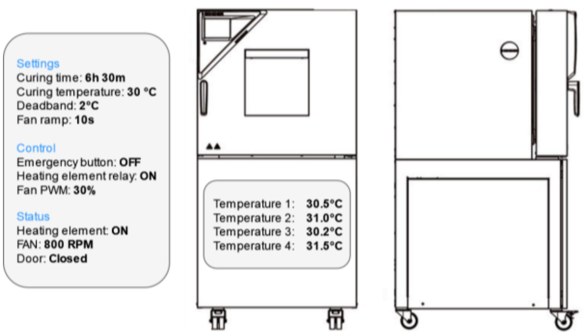

Figure 8. Dashboard example

5 Conclusions

Nowadays, open-source solutions are indisputably part of the toolbox for practical automation tasks. These tasks include building automation, sensor systems, industrial applications, and many others. The area of upgrading existing equipment is proving to be an interesting one. Such equipment does not have the technical level to meet the requirements placed on current equipment. Despite their reliability and the possibility of even longer use, other solutions often replace them.

The proposed solution uses open-source tools that allow fully-fledged upgrade of existing devices for Industry 4.0 requirements with commonly available components such as PLCs, sensors, and others. Node-RED, a tool for programming event-driven applications, provides interconnection between hardware, devices, APIs, and various online services. After programming the basic functionality, the solution fully replaces the legacy control system while providing options for low-cost additional hardware and software extensions.

Despite the limited scope of this work, its outputs can form the basis for deploying similar solutions in complex tasks.

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