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SELECTED ASPECTS OF SENSOR APPLICATION IN THE DESIGN AND IMPLEMENTATION OF INTELLIGENT INSTRUMENTATION FOR RECYCLING SYSTEMS

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ABSTRACT – The use of sensors in the development of laboratory equipment is widespread, and today there is hardly any modern laboratory device that does not rely on some form of sensor technology. Sensors are selected to meet specific characteristics of a given process. In the selection process, certain dominant features are typically considered; however, there are also specific sensor characteristics that are often overlooked, yet they can significantly impact the realization of the desired functionalities of the laboratory equipment. This paper highlights some of these aspects through a practical example.

Keywords: Control, Laboratory Equipment, Monitoring, Programmable Logic Controller, Sensors.

INTRODUCTION

Modern instrumentation, whether in scientific, industrial, or other application domains, regardless of complexity, inherently involves the use of some type of sensor, one or more, alongside various systems for data processing and display [1]. The indispensable role of sensors as vital components of any modern system lies in the necessity for a system component capable of providing sufficient information about various aspects of a process, whether pre-process, in-process, or post-process events [2].

Thanks to advances in material science, engineering, and technology, today we have a vast array of sensors of different types, constructions, characteristics, and application areas, making it difficult to establish a universal classification of sensors. Considering the complexity of sensors in current use, depending on the problem being addressed, both very simple sensing solutions and highly advanced sensors with exceptional complexity are employed. Although we may not always consciously consider sensor use in certain systems, many everyday devices perform basic functions precisely through sensor

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technology. Furthermore, due to their widespread usage, sensors may be referred to by other specialized terms depending on the field of application, technical discipline, or other specific perspectives [3].

In the past, the development of instrumentation often meant implementing so-called "dumb" instrumentation, which enabled only simple data acquisition, while further actions, such as processing the obtained data, relied on manual methods and human interpretation. Since the late 1980s, this landscape has changed. The development of instrumentation today focuses on achieving intelligent systems capable of performing a wide range of automated tasks after data acquisition, such as data filtering, processing, presentation, and correlation with other data [4]. Modern sensors are the backbone of such intelligent instrumentation systems, and modern instrumentation inherently includes the use of advanced sensors and sensing techniques.

As a result, special attention is now given to the proper selection and implementation of sensors. In this context, many primary sensor characteristics are carefully analyzed, such as measurement range, resolution, and response time, along with certain specific features like mechanical robustness, dimensions, and unique mounting capabilities. The increasing complexity of systems has also led to more complex criteria for selecting suitable sensors for specific instrumentation tasks. Often during system development, some sensor characteristics are overlooked or it becomes evident only during testing or actual operation that the chosen sensor solution is not optimally suited to the implemented system.

In the following section, an example of a testing system will be used to highlight some of the previously mentioned issues that may arise in practice. In accordance with standard manufacturing practices and the design of modern sensor systems, the term sensor as used in this paper will refer to the complete electronic assembly comprising the sensor module or the sensor device.

RESULTS AND DISCUSSION

To conduct the necessary analysis of the above-mentioned issue, we will assume, at a certain level of abstraction, that a given testing system consists of a gas chamber for sample testing, a PLC responsible for controlling the testing process, and a computer used for collecting relevant data related to the tested samples. One of the key aspects of such a system is the proper selection of sensors that will monitor the concentration of a specific gas within the chamber where testing is conducted. To develop a more universally adaptable system, let us assume that the chamber will be used for testing different gases independently or simultaneously. This implies that for each gas being tested, an appropriate sensor capable of accurately measuring its concentration must be used. For the sake of simplicity in further analysis, we will assume that the system is designed to test up to three different gases, which requires the use of three different sensors.

In the initial stage of sensor selection, attention must be paid to whether the sensors meet key performance characteristics of the system. Accordingly, the first parameters to be considered are whether the sensors can measure the required concentration range and whether they operate at the appropriate measurement resolution. For example, if we want to measure concentrations up to 50 ppm, we must select a sensor capable of measuring values beyond the target, such as a sensor with a range of 0–100 ppm, and at a suitable resolution. The next step in selecting suitable sensors would be to consider the response time. For gas sensors, this is typically expressed in seconds and denoted as T90 [5], which represents the time required for the sensor to reach 90% of the target gas concentration value (in some cases, T50 is used, indicating the time to reach 50%). Attention will then likely turn to the accuracy of the sensor readings, in accordance with the overall measurement accuracy required by the system. Further attention must be paid to various operational parameters that define the necessary conditions for proper sensor performance, such as operating temperature, humidity, pressure, and other similar parameters. These are joined by other important factors like the expected degradation of the sensor over time, its anticipated service life, and related considerations.

These are just some of the most critical parameters typically considered when selecting sensors for integration into a specific solution. However, they are not the only ones. Here, we highlight two additional parameters: proper connectivity and communication between the sensor and the rest of the system, and the sensor's broader integration capabilities. These parameters are often insufficiently analyzed, and as a result, certain limitations and shortcomings only become apparent during the testing phase or early in deployment at which point sensor replacement can present a significant financial burden and often a highly complex task.

As previously noted, it is assumed that the entire process will be managed by an appropriate control system based on the use of a PLC. Accordingly, it is expected that the initial choice would be a sensor that can be easily interfaced with the PLC system. In most cases, the typical choice for designing such a system would be a sensor that outputs gas concentration as a current signal in the 4–20 mA range. Figure 1 shows an example of such a two-wire sensor that detects a specific gas and uses a 4–20 mA output powered by a 24V DC supply [6].

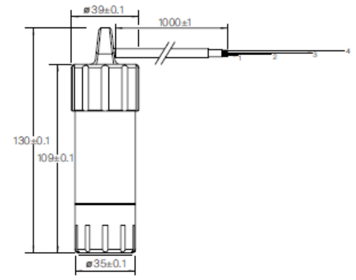
Figure 1 EC Sense 4-20mA Smart Gas Sensor Module TB420-ES1 [6]

These parameters are ideal for implementation using a PLC and its analog input capabilities [7]. Thus, when considering a straightforward implementation, this would likely represent the most optimal and simplest approach in terms of wiring and ease of system integration. From a control perspective, this is one of the most commonly used and effective methods for achieving reliable process monitoring and control.

Regarding the measured gas concentration values, they would need to be directly acquired from the PLC. This would involve the data acquisition software on the computer accessing the appropriate PLC register, performing the necessary value conversion (e.g., from hexadecimal to decimal), and then processing the data further in accordance with the system's processing tasks.

Additionally, in the context of PLC-based control, it is also possible to use a sensor solution that does not rely on analog interfacing, but rather on digital communication. One such approach is illustrated in Figure 2, where the connection is achieved using an RS485 Modbus RTU interface [8]. This solution, on one hand, increases the complexity of wiring and integration, since the PLC must support a sufficient number of RS485 communication ports. For example, in the case of using three sensors to measure the concentration of three different gases, three RS485 ports would be required, which in most cases entails additional costs in the form of expansion modules equipped with RS485 ports.

On the other hand, this approach allows for extended functionality, as it enables the retrieval of a broader set of data from the sensor device compared to the analog method. In most cases, in addition to gas concentration, additional parameters such as temperature and humidity can also be read. Thus, while this approach introduces an added layer of complexity in the implementation of the control system, it simultaneously provides enhanced capabilities.



Pin	Name	Color	Description
1	VCC	Red	Power Supply
2	GND	Black	Power Supply
3	485 A+	White	RS485 A+
4	485 B-	Grey	RS485 B-

Figure 2 Pinout of the EC Sense Stox Smart Gas Sensor Device [8]

However, it is important to note that this also leads to increased complexity in data acquisition from the PLC via the computer software. Since multiple registers need to be read, because each of them holding a single value, data retrieval becomes more intensive. In our case, with three sensors and expanded functionality (reading concentration, temperature, and humidity), the system would need to read a total of 3 × 3 registers i.e. nine registers in total. These values must then be appropriately read, converted, and further processed by the computer.

However, direct integration with the PLC is not the only solution available for addressing the described problem. The gas sensors considered in this context do not necessarily need to be connected exclusively to the PLC. An alternative approach involves connecting the sensors directly to a computer. Naturally, the previously discussed sensors are not suitable for this purpose; instead, a sensor such as the one shown in Figure 3a must be used.

This type of sensor features a UART TTL 3.3V digital interface [9], which allows it to be connected to a computer using an appropriate converter module, such as the one shown in Figure 3b. This module enables the conversion of the UART digital signal to a signal compatible with standard USB interfaces on a computer [10]. In this setup, data is read directly from the sensor into the computer software via a serial connection. This approach provides easier access to sensor data for further processing, as the procedures for acquiring and handling sensor data are generally simpler and thus facilitate more straightforward data manipulation on the computer itself.

Figure 3a EC Sense NO_2 Gas Sensor Module TB600B [9]

Figure 3b 4-pin USB to TTL module [10]

This raises the question of how the control over the process is maintained, specifically, how the PLC obtains information on gas concentrations. In previous approaches, data was read from the PLC by the computer. Here, the direction is reversed: in order to provide the PLC with access to sensor data, the computer writes the relevant concentration values into predefined PLC registers, converting the data into a format suitable for the PLC (e.g., from decimal to hexadecimal).

Moreover, this approach also allows for extended functionality, as the connection between the sensor and the computer can support the transfer of multiple parameters, such as gas concentration, temperature, and humidity. Compared to the earlier method, this results in a reduced number of PLC register manipulations. Instead of performing 9 register operations (3 sensors × 3 values: concentration, temperature, and humidity), only 5 operations are required. Specifically, the system writes values into three registers for gas concentration (one per sensor), and one value each for temperature and humidity, these being the average values considered most relevant for process control.

Averaging is used here because writing three separate temperature or humidity values would not significantly enhance the control logic—particularly as the values typically differ only slightly and the PLC would not be capable of determining which one is most significant. Additionally, this approach offers enhanced diagnostic capabilities: for instance, temperatures and humidity values can be compared across sensors, and any significant deviation may indicate a fault, either in sensor performance or communication, an issue that is more easily identified in this configuration than when sensors are connected directly to the PLC.

APPLICABILITY IN RECYCLING SYSTEMS

The previous considerations were presented in a generalized manner, but they have wide applicability in the design of various aspects of recycling systems. This is particularly evident given the fact that intelligent systems can significantly improve recycling operations. For this purpose, a variety of sensor types are used, including optical, inductive, ultrasonic, infrared (IR), and others, serving different tasks such as material type recognition, metal detection, waste volume measurement, and more.

Gas sensors, in particular, play an important role in recycling centers during the processing of different types of waste, as the treatment of organic, electronic, or chemical waste can lead to the release of harmful gases. Accordingly, the previously discussed considerations find excellent application in the implementation of recycling systems, as the same system aspects are encountered as in the previously analyzed generalized solution: control, monitoring, management, and data acquisition.

These considerations can significantly contribute to a better understanding of the design aspects of recycling systems, as they can improve certain vital components and thus enhance the overall recycling process. For example, the previous analyses can improve ventilation automation through more accurate gas concentration analysis. Improved gas concentration analysis also enhances various aspects of alarm systems and helps prevent potential incident situations. Additionally, it opens the door to modern system integrations based on IoT solutions and provides the possibility to apply artificial intelligence algorithms to improve different parts of the recycling system.

It is important to emphasize that the improvements resulting from these considerations are not only of a technical or technological nature, but also contribute to safety, environmental protection, and other domains. They increase the safety of personnel in recycling centers, reduce the risk of explosions and fires, and allow for better monitoring of environmental parameters both within and around recycling facilities.

CONCLUSION

Connecting sensors directly to a PLC is not the only option in complex intelligent systems. While there are simpler cases of sensor-to-PLC integration, as well as more advanced configurations offering extended functionality, the possibility of connecting sensors directly to a computer should not be overlooked.

This method brings significant advantages to the overall measurement, control, and management process, offering broader functionality while simultaneously reducing the number of PLC register operations. However, it is important to emphasize that, from a control and automation perspective, this approach introduces additional potential failure points, due to the inherent hardware and software differences between PLCs and computers. As such, although this method is not without limitations, it should not be dismissed outright, as is often the case. In complex systems involving data acquisition, control, monitoring, and management, this architecture can offer substantial benefits that merit serious consideration.

When considering the application in the field of recycling, the approaches mentioned above enable the digital transformation of recycling centers through the introduction of modern, digitized intelligent recycling systems. This leads to improvements not only in recycling processes and facilities but also in the working environment and the broader ecosystem.

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