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SENSORY TECHNOLOGY IS ONE OF THE BASIC TECHNOLOGIES OF INDUSTRY 4.0 AND THE FOURTH INDUSTRIAL REVOLUTION

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Abstract: Digital transformation of the production process or the entire value chain, from component to system and from supplier to customer, is the key to hidden value that can contribute to the company's productivity, compliance, profitability, and quality of the finished product. Connected production processes in the company are realized by converging information technology (IT) and operational technology into a single one, which results in the introduction of flexible industrial automation of production processes. These technologies connect the physical and virtual worlds with the Internet of Things (IoT) in order to better collect and analyze data, turning it into information that reach the decision–makers. All of the above cannot be achieved without the implementation of smart sensors that provide information at all times. Industry 4.0 can be implemented in production processes only by using smart sensors, and they, along with other technologies, are responsible for fully flexible automation of production processes, which brings a number of advantages such as shortening product development time and reducing manufacturing costs. The application of smart sensors makes production processes more efficient, and we have the ability to optimize them. The paper presents the basics of smart sensors, their role in Industry 4.0 as well as examples of their implementation in production processes.
Keywords: smart sensors, Industry 4.0, implementation, production system

INTRODUCTION

All companies in the world as facing global competition, and in order to keep up with the competition and meet the growing demands of the market, it is necessary to use new technologies in production processes, i.e. implement Industry 4.0. In other words, digital transformation is needed to make a connected company that enables production processes to discover new ways to increase productivity and improve overall business performance. Industry 4.0 helps to increase productivity as well as improve the company's overall business performance [1–3]. To ensure this, it is necessary to have a secure connection between the various production systems and processes throughout the company.

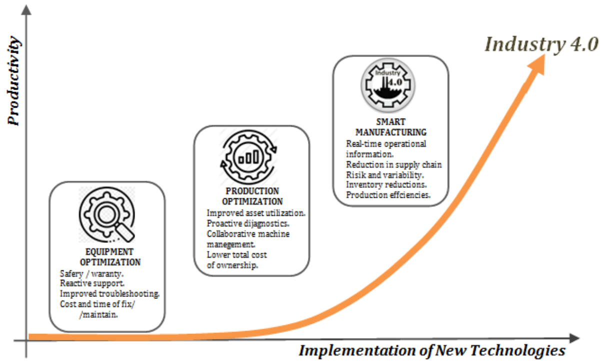
The new way of managing production processes aims to improve performance, make better use of data that already exist, and use a combination of tools that can improve the system or production process. The digitalization performed throughout the company, integration of processes, serial and discrete, drives, and movement into one connected infrastructure increases efficiency and productivity in all segments of companies. The access to production data in the production process at any time in real time allows us to monitor and improve the performance of the production process itself.

Many companies around the world have developed different sensor designs to measure different physical sizes [1,7–9]. Currently, great changes are happening every day in all industries, including the transformation of production processes, increasing flexible automation of production processes, new form of delivery of finished products, and a new way of consumption, all thanks to the implementation of Industry 4.0.

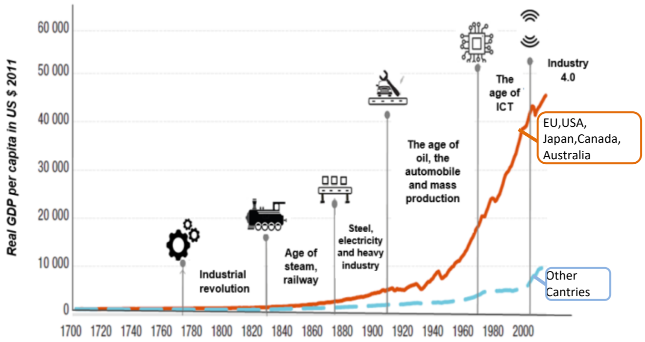
The basic technologies on which Industry 4.0 is based are: robotics and automation, smart sensors, Big Data, Internet of Things (IoT), 3D printing, radio frequency identification (RFID), virtual and augmented reality (AR), artificial intelligence (AI), advanced security systems, etc. [10–13]. The application of Industry 4.0 brings a number of advantages such as flexible automation, and bridging the physical and digital world through cyber physical systems (CPS). Greater and more open integration in manufacturing companies is enabled by cyber physical system (CPS) and Internet of Things (IoT) through horizontal integration (reflected in the exchange of information and data, networking of production processes, communication integration: procurement–production–logistics, and inclusion of customers in the production process), and vertical integration (connectivity in the company from the operational level to the production itself).

The implementation of base technologies can optimize the following: equipment in the production process so that we have greater safety, improved problem–solving, equipment safety, improved maintenance, self–production so that we improve the use of tools, proactive diagnostics, collaboration and management machines, and lower total costs [14–19].

The goal of implementation of Industry 4.0 core technologies is smart manufacturing where we have real–time operational information, reduce supply chain risk, reduce inventory, achieve the efficient production (Figure 1.a), as well as growth of GDP (Figure 1.b). It is necessary to build a set of skills both inside and out. An illustration of how to achieve smart manufacturing using Industry 4.0 implementation in companies is shown in Figure 1.



a – application of base technologies of Industry 4.0 increases productivity



b – the impact of technological change on GDP growth

Figure 1. Implementation of base technologies of Industry 4.0 –a, and their impact on GDP growth – b [6]

A graphical representation of the implementation of base technologies in Industry 4.0, their impact on technological change and inequality over the centuries, and GDP growth are shown in Figure 1. The analysis of Figure 1.b) has shown that the biggest jump in living standards due to investment in research, development and the implementation of advanced technologies happened in the last fifty years. Worldwide, many leading companies are investing and implementing advanced technologies that are key Industry 4.0 technologies. These companies have made significant progress thanks to artificial intelligence, machine learning, and an increase in available data growing exponentially, as well as the improvement of statistical methods and advanced data analysis in digitization and automation in production processes. All this has been happening in the last ten years.

The accelerated implementation of advanced technologies in Industry 4.0 has been significant since 2016, when the Fourth industrial revolution was announced at the World Economic Forum. In order to survive and be present in the global market, it is necessary for companies to optimize equipment, which must be reliable and safe, minimize equipment downtime, and improve problem solving. It is necessary to optimize the production processes (as shown in Figure 1–a) that are active in companies through improving the use of devices and machines, collaborative management of machines, proactive diagnostics, and reduction of overall costs. By introducing the technologies that form the foundation of Industry 4.0, we have real–time operational information and can act instantly which makes production efficient, reduces risk and supply chain variability, thus reducing inventory. The implementation of advanced Industry 4.0 technologies would not be possible without the use of smart sensors, defined by the IEEE 1451 Standard. The enhanced development of robotic and sensor technology, supported by information and communication technologies, is moving in the direction of communication between robots and humans, and the machines themselves.

SMART SENSORS AND THEIR CAPABILITIES IN PRODUCTION PROCESSES

Companies in the world engaged in the research, development and production of sensors for measuring different physical quantities have developed different sensor designs. Today, companies are in the phase of transformation of production processes, because they want to achieve greater automation of production processes with greater flexibility due to the higher customer requirements and survival in the global market. The implementation of advanced Industry 4.0 technologies such as: Internet of Things (IoT), Big Data, 3D printing, robotics, smart sensors, artificial intelligence (AI), virtual and augmented reality (AR), etc., provided a new way of consumption and a new form of delivery to the customer, since the customer wants to be involved in the production process. The implementation of Industry 4.0 cannot be achieved without the implementation of all the above mentioned advanced technologies. However, we must single out the basic sensor technology, because without the implementation of various smart sensors we could not monitored parameters in real time [1,3,17,18,20–22]. Since there has been a development in all segments of society in all technologies, there has also been a historical development of sensors. The schematic representation of the development of sensor technology over time is given in Figure 2.

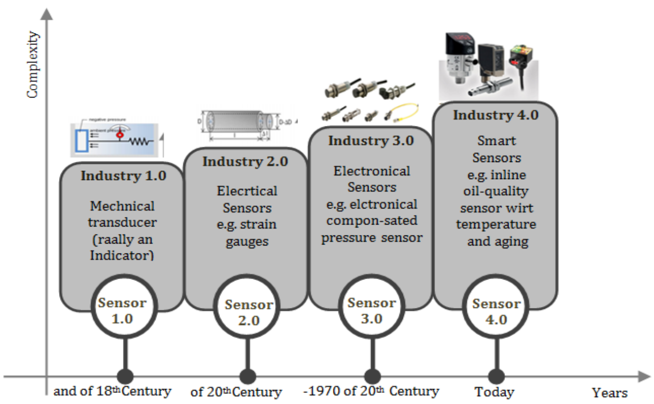


Figure 2. Schematic representation of the development of sensor technology over time

Based on Figure 2, we can conclude that sensor technology has had continuous development from the first mechanical sensors, electrical sensors, and electronic sensors. Today smart sensors are being researched, developed and implemented to support the implementation of Industry 4.0 in production processes. By implementing smart sensors in all processes, as well as in production processes, we can monitor and obtain a large amount of data on the basis of which we make decisions.

Given that the world's leading companies are in the process of implementing Industry 4.0, and they are trying to follow other companies in the world to remain in the global market, the possibility of increasing the use of sensors, and thus improving the manufacture of products is reflected in the following [1,3]:

≡ Sensors help to detect defects, allowing quick adjustment of settings and change of parameters to prevent downtime in future production processes.
≡ Based on data provided by smart sensors and insights gained from production to the delivery process, the entire supply chain is managed much more efficiently.
≡ Scheduled machine maintenance allows companies to more effectively plan downtime and prevent downtime or breakdowns during the manufacturing process.
≡ Increases efficiency and productivity by integrating smart sensors.
≡ We are able to quickly change the production process of one product to the production of another product.
≡ Adaptation of the production process for another product is simulated practically before it is physically implemented in order to adequately assess the impact and reduce the chances of errors.
≡ Implementation of smart sensors leads to smart machines and devices.
≡ Analysis of data obtained through smart sensors helps to identify and prevent dangerous situations, and thus improves the health and safety of workers.
≡ Their implementation ensures planned maintenance and quality control.
≡ Energy consumption can be optimized by using advanced analytics, because we can monitor energy consumption and make decisions by using smart sensors.

We can maintain optimal productivity and efficiency at all times if we have information about what is happening on machines that are installed in production processes minute by minute. We are also able to avoid unplanned downtime and losses that occur in the production process. The integration of smart sensors provides us with all the necessary data to create a comprehensive image of the production process at every moment. The implementation of smart sensors enables the introduction and operation of smart machines that increase the productivity and efficiency of the production process. Their installation in the production process enables all possible parameter: temperature, pressure, flow level, movement to distance, control of the accuracy of the performed operation, monitoring of the production process, and many other parameters that we have not listed. We are able to have a comprehensive overview of the production process. By knowing the current situation in the production system and the state of the sensor, we can ensure and timely identify any type of potential malfunction in the production process, as well as the sensor itself. The installation of smart sensors in the production process with other necessary equipment is shown in Figure 3 [3]

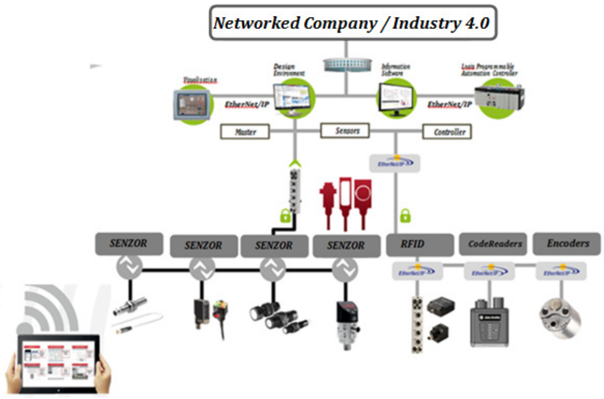


Figure 3. Scheme of installation of smart sensors in the production process with accompanying equipment

The continuous flow of valuable process and diagnostic data, and the visualization system are enabled by smart sensors with informative software and programmable controllers, as shown in the configuration diagram in Figure 1. In this way, the company is connected, which provides efficiency and other advantages. Creating a connected company using smart sensors and smart machines reduces the complexity of production processes and errors [23–25]. They simplify access to available data that can help achieve overall equipment efficiency and average time between failures. Real–time diagnostics optimizes preventive maintenance and problem–solving that arises in the production process, which enables us to reduce the solution time by about 90 % [28]. The change time for each sensor is reduced, and there is the possibility of automatic device configuration to reduce the error when replacing the sensor.

Within each production process there are many operations such as: material handling, material transport, execution of certain operations, assembly, packaging, varnishing, sorting, etc., which require smart sensor so that we can have data on the smooth performance of the operation.

When implementing sensors, we must identify key operations within the production system and define the area of focus in which we need to verify the conditions. We need to know what the system is doing or what we want it to do, such as counting products, performing quality checks, orienting parts, etc. [28–30]. We need to know what the feedback is for each function, as well as what conditions must be met after each function to confirm that the function was performed correctly. When we have identified the areas in which the action takes place in the production process, it is necessary to make an analysis of whether each area is so important from the point of view of automation of the production process and monitoring data important in the production process.

As we have seen, the application of smart sensors can occur in any production process. We need to choose the parameters to be monitored, make the right decision to install the appropriate smart sensor with other selected technology and continue to monitor the performance of appropriate tasks in the production process on mobile devices, as shown in the example in Figure 4.

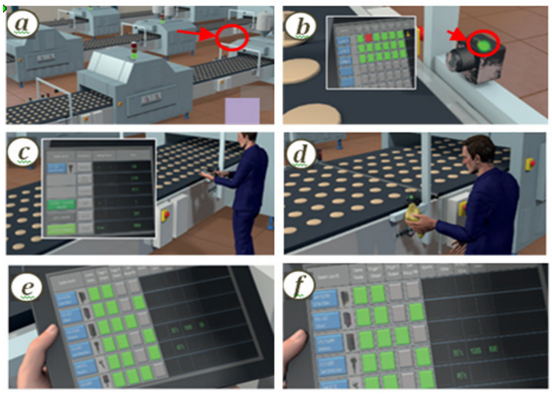


Figure 4. Implementation of smart sensors for collecting information in the production process

As Figure 4 shows, we are able to obtain information about performing operations on a mobile device. For the sake of illustration, Figure 4 shows the production process in which real–time data is monitored. The machine works normally (Figure 4.a)) and is monitored by mobile devices using smart sensors. Data is processed and monitored including activated output and measured data, the accuracy of the sensor, the state of communications, as well as data flow. It is observed that the sensor detects dust accumulation (Figure 4.b)). The operator has information about the type of sensor and where it is placed in the production process (Figure 4.c)). He provides information for maintenance, which act in a timely manner and eliminate the malfunction (Figure 4.d)), thus returning safe operating parameters (Figure 4.e)). Therefore, the monitoring of the production process can continue (Figure 4.f)). In this way, we can monitor the operation of all parameters of the production process that are important for that process at any time, so that we can take necessary measures and eliminate the shortcomings and allow the production process to work without errors. By implementing smart sensors in the production process, we are able to quickly adjust the production process for the production of another product, i.e., the transition from the production of one product to the production of another is very simple, as shown in Figure 5.

If the production process is set to manufacture one product, e.g., product (A) which we monitor using smart sensors, the setting of all parameters is defined for product (A), as shown in Figures 5.a and b). If we want to stop the product (A) and switch to the production of the product (B), we must give the command for that product on the mobile device, as shown in Figure 5.c).

The production of product (B) is initiated (Figure 5.d)) and profiles for four sensors that monitor the parameters in the production process (Figure 5.e) are downloaded. Smart sensors set new parameters for product (B) so that the machine is ready to manufacture another product. By implementing smart sensors in the production process, we can supervise, monitor, and control certain parameters when performing tasksat any time, all depending on which parameters are necessary for the production of the finished product to run smoothly.

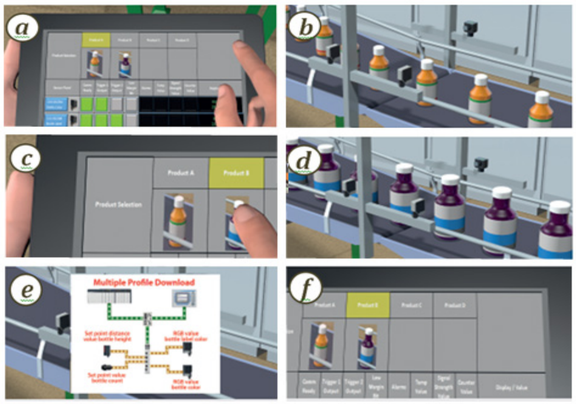


Figure 5. Adjusting the production process to manufacture another product using smart sensors

For the sake of illustration, an example is given in Figure 6.a). If we want to have information on which product is currently on the production line,we can obtain this information by implementing a radio frequency identification RFID sensor, since it is connected to PLC Logix controllers (Figure 6.b)) through a set network [30–32]. The control, information and monitoring of the current product packaging on the packaging section is shown in Figure 6. c, d), whereas the monitoring of products and raw materials at each stage from entry, production and shipment to the end customer is shown in Figure 6.e, f). We can achieve increased productivity and production efficiency by implementing smart sensors. We can also achieve detailed monitoring of products, as well as the visibility of the supply chain in order to make the right decisions on time. An example of monitoring certain positions in the production process by implementing smart sensors is shown in Figure 7. Depending on the production process, there are different positions for the application of smart sensors. In addition, the choice of information we are interested inwill influence the choice of smart sensor that will be placed to monitor and obtain information [31,32].

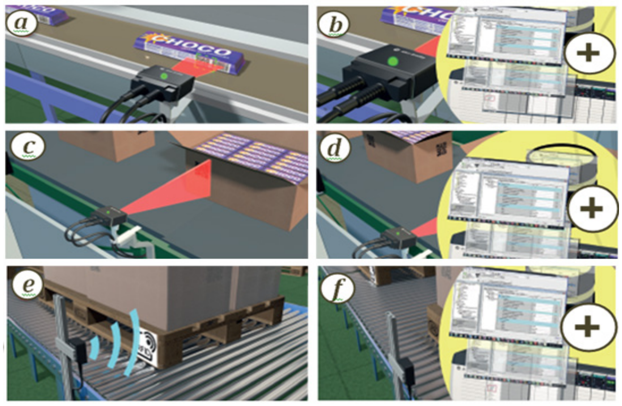


Figure 6. Monitoring of certain parameters with smart sensors in the production process

Figure 7 shows an illustrative example in which the temperature is monitored in the production process. There is a sensor that shows that the temperature is 45∘C, while the second position displays the application of pressure sensor which shows a pressure of 50 bars. In the third position, there is a proximity sensor that registers the positioning of the product on the 750 mm conveyor belt, while the power signal is 500 units. At the end of the production process, a sensor for counting parts was installed, which is now active and providing information that there are 1284 units of elements.

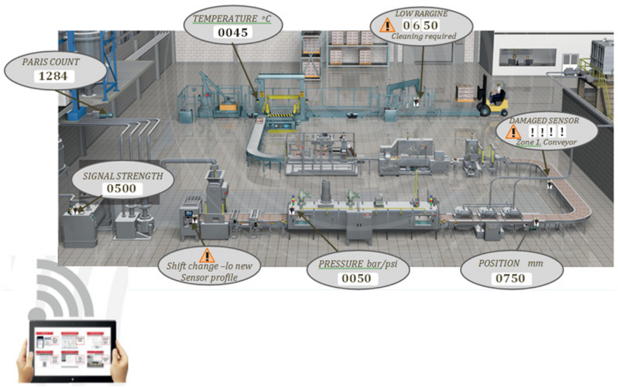


Figure 7. Mobile monitoring of production process parameters using smart sensors

Monitoring of the production process can take place on different devices, static screen or mobile device. In this particular example on the mobile device we have information about the problem on three sensors that we need to eliminate. The sensor in zone 1 is loaded on the conveyor belt, the second sensor needs cleaning, and the third sensor shows a warning that we have to change the sensor profile, i.e., we have to adjust the new sensor profile. When we have complete information given to us by smart sensors from the production process, we can act in time and eliminate errors so that the production process works normally. As we have seen in the concrete example on mobile devices in Figure 7, we can monitor the information in the production process, as well as problems on sensors that we need to eliminate. After analyzing the obtained information, we can make a decision on what actions need to be performed, such as cleaning or changing the sensor profile. In other words, we need to adjust the new sensor profile. When we have complete information given to us by smart sensors from the production process, we can act in time and eliminate errors so that the production process works normally.

CONCLUSION

Industry 4.0 is the one that provides relevant answers to the fourth industrial revolution. It is already present in all industries, from production to sales of finished products. By introducing technologies that form the basis of the fourth industrial revolution or Industry 4.0 such as: smart sensors, robotics and automation, big data (Big Data), Internet of Things (IoT), 3D printing, radio frequency identification (RFID), virtual and augmented reality, artificial intelligence (AI), advanced security systems, etc., we can change processes and technologies as well as the organization of production and sales. The fourth industrial revolution brings disruption to almost every industry in the world, because it has a greater impact than we think. The impact is reflected on all sectors and companies, including large, medium and small companies. Industry 4.0 relies on advances in the use and sharing of information, and has such potential to connect almost anything and everything on the web, thus drastically improving the company's business performance. Small and medium enterprises can benefit from what Industry 4.0 has to offer, because by using the technologies mentioned in this chapter, they can more efficiently process and store data, and improve the way they design, manufacture and deliver their products. Currently, small companies can compete with big companies in a way they never could before. It is impossible to implement Industry 4.0 without smart sensors. They are the ones that give the first information about monitoring parameters in the production process. Their implementation provides the company with advantages, some of which are:

- lower operating costs
- improved business communication processes
- increased productivity of companies
- access to the world economic market is expanding (wide user base)
- provides companies of all sizes with greater outsourcing opportunities (external associates)
- thanks to the availability of new communication tools the cooperation of company departments and individuals is easier
- advanced achievements, such as blockchain technology, greatly increase the security of business and personal data
- reduced downtime in the production process,
- rapid adaptation of the production process to the production of another product

As we have seen, advanced technologies that include: IoT (Internet of Things), robotics, cloud computing, smart sensors, radio frequency identification, cyber–physical systems and big data, are key in the application of the Industry 4.0 concept, because they imply full digitalization of all production processes, as well as creating an idea about a product, product engineering, production organization, process control, and the provision of industrial services. Based on all this, we can conclude that new constructions of smart sensors will be developed in the future, and their implementation in production processes, as well as in all segments of the human environment, will increase on a daily basis.

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