SENSOR MEASUREMENT IN PROCESSING INDUSTRY: FROM QUALITY ASSURANCE TO QUALITY CONTROL

SENZORSKA MERENJA U PROCESNOJ INDUSTRIJI: OD OBEZBEĐIVANJA KVALITETA DO KONTROLE KVALITETA

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Paper presents sensor technologies, terminology and chronology of sensors development and describes their use, especially in the processing industry and measurements. The analysis of the sensor measurement parameters can obtain improvements in processing industry, especially through quality assurance and control. This important parts of quality management should serve as a basis to process improvement and saving costs of quality.

Key words: sensor measurement, quality assurance, quality control

Rad predstavlja senzorske tehnologije, terminologiju i hronološki razvoj senzora, kao i njihovu upotrebu u procesnoj industriji i metrologiji. Analiza parametara dobijenih senzorskim merenjem može se koristiti za unapređenje procesne industrije, posebno kroz obezbeđivanje i kontrolu kvaliteta. Ovi važni delovi menadžmenta kvaliteta mogu biti osnova za poboljšanje procesa i uštedu troškova kvaliteta.

Ključne reči: senzorska merenja, osiguranje kvaliteta, kontrola kvaliteta

1. Introduction

Dating back to the 19th century, it was Wilhelm Von Siemens who developed sensor for measuring temperature, based on copper resistor. Later, the sensors development was influenced by the advancement of materials technology [1].

This rapidly developing field is wide and imbued throughout most scientific and technical studies. This is why many formal definitions of sensors are ambiguous. The American National Standards Institute (ANSI) standard MC6.1 defines a transducer as "a device which provides a usable output in response to a specific measurand" [2].

By capturing and revealing real-world phenomena, sensors link the physical and the digital world. The phenomena are then converted into data that can be processed, stored and analyzed. The sensors provide a significant social contribution once incorporated into diverse environments and devices. With their use, a society is able to:

Steer clear of catastrophic infrastructure malfunctions; Savor precious natural resources; Boost productivity; Improve security; Activate new applications such as context-aware systems and smart home technologies.

To sense means to possess a technique with which one can collect data pertaining to physical processes or object, as well as the occurrence of events (for example, rise in temperature or pressure). And when you have an object that can perform this type of task, it is known as a sensor. Transducer is a synonymous term used for the aspect of sensing. A sensor is basically a type of transducer, which is capable of converting energy from one form to the next. And in case of sensors, they can be applied to convert physical world energy into electrical that can be transformed digitally to a particular system or controller [3].

The rapid progress in information processing has influenced and led to the most recent innovations in control technology. It is only when the time constant for the measurement and analysis is commensurate with the time scale of the process itself that real-time control is made possible. Process monitors in the past, on the other hand, were limited to measurements of primary parameters, such as temperature and pressure. However, with the capabilities of modern computing workstations (and the availability of appropriate sensor technology), massive computing power now enables in situ and real-time measurement of parameters that were

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not measurable before. And with the constant progress in terms of computing capabilities, the future carries the potential of ever increasing and precise real-time control as a standard practice [4].

In order to bring forth maximum process productivity and yield, one would have to create sensors that could carry the potential to guide a process to achieve desired properties.

2. Classification of sensors technologies

The physical property that is being monitored will be the influencing factor in choosing the right sensor for an application. Those influencing factors include: Temperature; Pressure; Light; Humidity.

In addition to these physical properties, there is a variety of other methods that can be used in the classification of sensors. The question of external power supply would be one such example. If external power is required by the sensors, they are then defined as active sensors. In other words, the active sensors can detect a change or trigger a response of the transmitted signal with by emitting a certain type of energy (light, sound, microwave etc.).

Opposite of that, we have passive sensors which derive their power from the energy input that they detect in the environment. A classic example of this can be found in passive infrared (PIR) sensors, which detect and measure the light radiating from close-proximity objects [5].

With the backup of modern advances, vast opportunities for research and development of Wireless Sensor Technologies (WST) are being created. Thus, we are entering a new phase in this area. All this is the consequence of the:

- continuous drop in costs of ownership
- engineering of progressively smaller sensors
- radio frequency technology innovations and development of digital circuits.

WST refers to Wireless Sensor Networks (WSN) and radio frequency identification (RFID) based sensor devices. When it comes to revolutionary technologies in the 21st century, WSN is definitely counted among the very top. Although RFID was originally developed with a focus on identification purposes, alternative applications of it led to the a new series of wireless RFID-based sensor devices. And unlike a WSN system which allows various network topologies and multi-hop communication, RFID devices possess no cooperative capabilities.

And as a result of increasing maturity and adoption of standards such as Bluetooth [6] and ZigBee [7] for WSN, and various ISO (International Organization for Standards) standards for RFID (ISO 15693, ISO/IEC 18000, ISO 11784, etc.) [8-14], these technologies have been attracting a good deal of research efforts during the course of the last couple of years. At the moment, they are very promising in several fields, including: environmental monitoring, irrigation, livestock, greenhouse, cold chain control or traceability.

3. Selected sensor applications in manufacturing

Sensors have always been employed by manufacturers. An example of the very first sensor application can be found in the helpful eyes of a blacksmith as he would guide the shaping of steel into a weapon. Another example would involve a medieval artisan that used Vernier calipers to help him measure the dimensions of an architectural icon. Advancement befalls complexity, and the same has happened with manufacture. As the sophistication of a certain product increased, so did the complexity of the manufacturing process. In fact, one might even claim that manufacturing has been in the fore-front of incorporating advanced sensor technology, to a certain extent. For example, without advanced sensor technology, current revolution in computer-integrated manufacturing would not be possible. As the competitiveness of the global marketplace grows and expands, it also demonstrates the very high cost in “inspecting-in” quality (i.e. the expense to “fix” or remake certain parts of the products which do not meet the subscribed quality levels assessed for the product). And given that the manufacturing process focuses on quality as an integral element, the process itself has to be kept under control. This can be done through one of two options: using appropriate sensors to monitor the work at all times; inspect the product at intermediate manufacturing stages.

And when it comes to the best possible reliability and performance of a certain product today, it is exactly the manufacturing process sensors that provide a limiting capability for it all [15].

In the most traditional approach, calibrating the equipment at the very start of the manufacturing process would be essential, the expectation being that the operation would perform optimally for a certain duration of time. And the parameters that sensors monitor in such cases would be: temperature, gas, pressure and composition. And so, as the overall complexity of materials processing were to raise, sensors would have to be used to help monitor any modifications to the actual product. Such changes usually come down to: minimal growth during processing; nucleation sites location within the epitaxial grown thin films; chemical com-

position, morphology, and nanoscale thickness of fiber interface coatings for ceramic and metal matrix composites.

There are also cases when the manufacturing and use of toxic or hazardous chemicals is involved, at which point the concept of online control is very practical and even more so desirable. At certain times, reproducible manufacturing of extremely sophisticated components is not possible without the implementation of in situ sensors. Without them, providing specific online measurements and feedback for real-time process control would not be possible.

3.1. Intelligent processing

When it comes to priori processing systems, we use the results of a model to create a predictive schedule of variable process events, such as temperature and pressure – time-temperature profile. The model itself could be based on the results of empirical trials. On the other hand, posteriori processing systems focus all their attention on process monitoring for the purpose of gathering statistical data, to then be evaluated and used for eliminating or reducing unwanted variables. Once you have all the statistics and analysis, removing the variability comes down to making necessary modifications to either the process itself or certain product features that are causing the variables.

In order to avoid predefined process models and statistics, intelligent processing systems use sensed information to control and modify the process with an event-based control strategy. When we refer to “event-based”, we imply that certain predictions and occurrences of potential events are denoted with the application of sensed information (online decision making or conflict resolution being the example here), so a form of variability control may be necessary. For examples such as in situ material behavior, the use of sensed information to influence modifications to these types of variables is the very foundation of the term self-directed, as used and proven with intelligent processing [16].

Self-directed control can be used in conjunction with process models or in lieu of them if sufficient empirical information exists to construct the necessary rule-bases or neural networks [17].

To conclude, instead of using prescribed parameters, intelligent processing conducts process control via objectives.

3.2. General sensor issues

According to the National Materials Advisory Board reports, sensors are still regarded as the weak link in intelligent processing. The basis of this belief is the potential lack of sensor capabilities to perform in a noisy or adverse manufacturing environment, backed by real-world constraints such as:

- *short time constants*: the ability to sense rapid, localized shifting in a material over the course of processing
- *monitoring chemical changes*: sensing the nonlinear behavior of one or more simultaneous chemical reactions and associated by-products;
- *point measurement*: sensing critical points, rates, and changes in rates within a complex three-dimensional product shape; and
- *inferred measurement*: sensing parameters of interest that are not directly measurable (i.e., inferred parameters require the establishment of constitutive relationships to those parameters that can be directly measured) [18]

4. State of the art in sensor technologies in agriculture and food industry

Agriculture

The progress WST applications development minimizes any potential impacts on wildlife and the environment of many agricultural production systems while at the same time maximizing productivity, efficiency and profitability. With the real-time information farmers receive from the fields, they will be able to act in time and adjust strategies accordingly. A precision farming approach can recognize differences that hypothetically-based opinions and decisions cannot, and it can adjust management actions accordingly. [19].

Food Industry

With a growing demand of larger diversity of high-quality standards food products, the food industry is forced to respond to consumer needs with critical changes, while having to consider health and safety concerns.

The quality of these products might change rapidly, because they are submitted to a variety of risks during production, transport and storage that are responsible for material quality losses. Parties involved need better quality assurance methods to satisfy customer demands and to create a competitive point of dif-

ference. Successful supply chain logistics calls for automated and efficient monitoring and control of all operations. The monitoring should allow establishing a better knowledge, detecting weakness, and optimizing the whole process, all things that potentially would have a significant impact on the supply chain [20].

Also, there is an increasing demand of traceability in the food chain, statutory requirements are growing stricter and there is increasing pressure to develop standardized traceability systems. From the raw material to the sale of goods, more and more information needs to be gathered and made available. In the next years, the lowering cost of WST will provide the opportunity to track and trace not only large and expensive products, but small and cheap ones, creating a new generation of intelligence products [21]. Moreover, the information gathered by the WST can be linked with a traceability system in each step of the life of the product, “from farm to fork” [22].

Products can be tracked and traced from the field to the industry. Anastasi *et al.* designed and implemented a WSN-based system for monitoring the productive cycle of high-quality wine in a Sicilian winery. Nodes were deployed both in the field and in the cellar, where wine aging is performed [23].

WSN was also studied for the supervision of temperature during assessment of canned food sterilization, developing a mathematical model analyzing wireless sensor nodes during the process [24].

Cold Chain Monitoring and Traceability

Vegetables, fruit, meat, fish and other perishable types of food need to be transported in climate-controlled conditions. Hence, the most important factor needed to prolong their shelf life is temperature. And it is the concern of the food industry to study and analyze the temperature variables that can occur within cooled rooms, containers, and trucks. On the one hand, we have the supply chain management which calls for swift action when it comes to the shipping of fresh food products from distribution centers. On the other hand, standard RFID tracking and tracing cannot provide all the necessary information required for detailed planning of this forwarding process with a time frame of several hours.

This is why any quality-related issues, such as temperature variables exceeding the prescribed limitation, should be detected and reported as quickly as possible. And even though we might not be able to directly gain access to the transport in question, there is such a contingency in place such as online notification, which offers new and improved means of transport planning and control.

The use of wireless sensors in refrigerated vehicles was proposed by Qingshan *et al.* [25]. The vehicles can host a variety of sensors to detect, identify, log, and communicate what happens during the journey, monitoring the status of perishable products in transport (see Figure 1). Ruiz-Garcia *et al.* studied and analyzed intermodal refrigerated fruit transport that integrated wireless sensor networks with multiplexed communications, fleet management systems, and mobile networks [26]. Also, the psychrometric data model was implemented for quick assessment of changes in the absolute water content of air. Thus it was possible to address water loss from the products, and also to detect condensation on the commodities [27].

Figure 1. A Review of Wireless Sensor Technologies and Applications in Agriculture and Food Industry: State of the Art and Current Trends (Basel, 2009).

Quality monitoring of food logistics requires multiple measurement trials to be performed. And with specialized WST monitoring devices, the forwarding and handling of perishable products is on the verge of a breakthrough. The results of such a revolutionary step would benefit both suppliers and distributors in terms of constant and precise data during every phase of the distribution process. And with continuous and accurate automated readings, distributors and suppliers would be able to use the gathered and interpreted data to better coordinate and plan product inventories. This in turn would lead to a decrease in the number of rejected shipments, which would ultimately lead to intelligent goods management. So, in retrospect, WST sensors could resolve the issue head-on.

And as we already mentioned, even the lack of direct access to the means of transport can easily be resolved with the implementation of one of many new opportunities provided by online notifications. This

would all serve towards the improvement of transport planning, for time-efficiency is very important in cases where fixed delivery commitments require ordering a replacement.

5. Quality assurance and quality control

Each organization should clearly define the terms of Quality Assurance (QA) and Quality Control (QC). The fact is that both of these combined together present an integral part of an organization's quality management plan. And for both stakeholders and management to differentiate between the two terms can influence the effectiveness of delivery teams. The main difference to consider here would be the fact that effective quality systems can directly influence and contribute to the success of a project. The opposite scenario, where quality systems are misunderstood, can lead to an ineffective execution of the delivery in due time. And this difference can determine whether the system built by a team will remain within the allocated budget and satisfy the requirements of the customers [28].

This paper is here to ascertain the differences between Quality Assurance and Quality Control. To present the best analysis, both concepts are perceived from the guidance of key industry players

Even though both QA and QC are aspects of quality management and in close relation to each other, their core focus is fundamentally different:

QA presents the quality management process QC presents the verification of output quality. The ISO 9000 family of standards is a good reference point for understanding the difference between the two concepts. These standards focus on quality management systems and are used by organizations to tackle the needs of clients and stakeholders.

According to this standard, a quality management system is comprised of the following: Quality planning and improvement activities; Defining guidelines within an organization in the form of a set of quality policies and goals; QA and QC.

In the ISO 9000 standard, clause 3.2.10 determines Quality Control as: "A part of quality management focused on fulfilling quality requirements". Clause 3.2.11 determines the definition of Quality Assurance as: "A part of quality management focused on providing confidence that quality requirements will be fulfilled".

5.1. Assurance in the food industry– defect prevention

Quality assurance (QA) serves to ensure the quality of the product development processes through a set of activities. The focus of QA is to prevent any defective occurrences in the product making process. So, it can be said that QA is a proactive process which serves to test and prevent defects from arising during product development stages, thus improving development.

For an organization to achieve QA, they first need to implement and assess a good quality management system. The important thing to remember is that everyone involved in the product development process is held responsible for quality assurance [29].

5.2. Quality control in the food industry– defect identification

Quality control (QC) serves to ensure that the quality of the finished product through the identification of any defects. The process is reactive and aims to identify and correct any potential defect in developed products.

For an organization to achieve QC, they first need to identify and remove the cause of quality problems in the product, thus ensuring that the needs of the customers are always met. This is what one might define as the inspection aspect of quality management and is usually the responsibility of Traditional Quality Control or Real-Time Quality Control.

Traditional quality control eliminates defective products by inspecting the finished products, whereas real-time quality control eliminates defects in the product development stage by implementing corrective measures.

Figure 2 shows the steps involved in the traditional and real-time quality control approaches. As can be seen from the figure, real-time quality control strategy improves product quality by adjusting the manufacturing process parameters on-line. This, in turn, also leads to reduction in product wastage. However, online process monitoring and diagnosis are necessary in order to implement a real-time quality control strategy.

The real-time quality control strategy being developed in this research involves the following steps:

1. Identify the set of process input, output and state variables that have an influence on the product quality.
2. Employ suitable sensors or inspection methods to monitor the measurable process output and state variables.
3. Collect the sensor signals using suitable data acquisition systems.

4. Select an appropriate sensor data representation and feature extraction scheme.
5. Estimate the unmeasurable process states from sensor information.
6. Employ suitable diagnostic reasoning procedures to determine the causes for the deterioration of the product.
7. Employ suitable control schemes or corrective measures to maintain the required product quality.

Figure 2. Sensor Based Monitoring for Real-Time Quality Control in Manufacturing (PA,1994).

As mentioned above, this methodology showing that step 1 depends on the nature of the process and step 2 depend mostly on reliable sensors to monitor the desired process output. Step 3 is really an easy task because data acquisition is a well-developed technology [30].

In turning process, on-line monitoring plays a dominant role whereas in powder injection molding, on-line diagnosis plays a dominant role in implementing a real-time quality control strategy. In turning, on-line monitoring refers to sensing process states that affect the quality of workpiece while material removal process is in progress. In powder injection molding, on-line diagnosis refers to the identification of the possible process disorders that are responsible for manifested process quality factors and process states.

6. Conclusion

The quality system is defined as "a set of interrelated or interacting elements which is using a variety of resources to achieve objectives related to quality." These objectives are focused on fulfilling and overcoming user's requirements [31].

ISO 9000:2015: Quality management systems—Fundamentals and vocabulary defines quality as the: "degree to which a set of inherent characteristics of an object fulfills requirements."

Simply stated, quality means to meet customer requirements.

All activities that determine the quality policy, objectives, responsibilities, and their implementation (as part of the overall management function) are parts that make up a system of quality management. And in accordance with ISO 9000, it is the management system that provides the means to establish and achieve a policy and its objectives.

When it comes to quality management, the impact of a structured approach should not be neglected. With a combined application of quality control (QC) with quality improvement measures, a team can achieve higher levels of quality through isolation of quality problems and resolution of those same problems [32].

With the successful formulation and execution of a quality management plan, a company can expect the following benefits:

- Increase in customer satisfactions, which can easily lead to an increase in business and referrals.
- A motivated team with a clear understanding of the quality management plan objectives, as well as the participation in the completion of those very objectives.

- Elimination of waste through the discovery and resolution of any potential defects, that is in accordance with meeting customer requirements.
- Improved and advanced planning activities due to the risk of failure otherwise.
- Income boost for the company due to the increase in business through new projects and referrals, as well as expense reduction saved on the potential need for re-work tasks.

As the company's quality management plan matures, so will the confidence of all stakeholders grow accordingly.

By using quality system tools defined by established standards (primarily ISO 9001), the above-mentioned benefits can be achieved. This bears a significant influence for process industries, especially when we discuss sensor systems. As we already discussed, sensor technology enable real-time monitoring, alarm and warning measures, prevention of harm and discovery of defects during the development process or after.

A quality management system also includes managing data gathered from sensor measurements, as well as the security of that data. It enables us to gain better control over processes and managing them, which leads to an increase in company profit and overall quality, which reflects to other stakeholders as well. Sensor technologies also secure quality assurance and quality control, because they function alongside project management and the processes it includes. And they are also used to test and control processes as well as products.

7. References

- [1] *** National Academy of Sciences, Expanding the Vision of Sensor Materials, Committee on New Sensor Technologies: Materials and Applications, Commission on Engineering and Technical Systems, (1995).
- [2] *** Instrument Society of America, Electrical Transducer Nomenclature and Terminology, ANSI Standard MC6.1. Research Triangle Park, North Carolina: Instrument Society of America, (1975).
- [3] *** Waltenegus Dargie and Christian Poellabauer, Fundamentals of Wireless Sensor Networks: Theory and Practice, John Wiley & Sons, Ltd, (2010).
- [4] *** National Academy of Sciences, Expanding the Vision of Sensor Material, Committee on new sensor technologies: materials and applications national materials advisory board commission on engineering and technical systems national research council, Washington, D.C. 20055, (1995).
- [5] **Luis Ruiz-Garcia, Loredana Lunadei et al**, A Review of Wireless Sensor Technologies and Applications in Agriculture and Food Industry: State of the Art and Current Trends, Basel, Published online 2009 Jun 16. doi: 10.3390/s90604728, (2009).
- [6] **Dursch A., Yen D.C., Shih D.H.**, Bluetooth technology: an exploratory study of the analysis and implementation frameworks. *Comput. Stand. Interface.* 2004;26:263–277.
- [7] **Baronti P., Pillai P., Chook V.W.C., Chessa S., Gotta A., Hu Y.F.**, Wireless sensor networks: A survey on the state of the art and the 802.15.4 and ZigBee standards. *Comput. Commun.* 2007;30:1655–1695.
- [8] *** ISO 11784, Radio frequency identification of animals – Code structure. 2004.
- [9] *** ISO 11785, Radio frequency identification of animals – Technical concept. 1996.
- [10] *** ISO 14223, Radiofrequency identification of animals – Advanced transponders. 2003.
- [11] *** ISO/IEC 7816, Identification cards – Integrated circuit cards. 2008.
- [12] *** ISO/IEC 14443, Identification cards – Contactless integrated circuit cards – Proximity cards. 2008.
- [13] *** ISO/IEC 15693, Identification cards – Contactless integrated circuit cards – Vicinity cards. 2008.
- [14] *** ISO/IEC 18000, Information technology – Radio frequency identification for item management. 2008.
- [15] *** National Research Council, Expanding the Vision of Sensor Materials, Selected sensor applications in manufacturing, Washington, DC: The National Academies Press. doi: 10.17226/4782, (1995).
- [16] **LeClair, S.R.**, Self-directed process control: Can we build material processing systems that know better how to process a material than we do? *Concurrent Engineering Journal* 1(2):13–22, (1991).
- [17] **Gillham, J.K.** Formation and properties of thermosetting and high Tg polymeric materials. *Polymer Engineering and Science* 26 (20):1429–1433, (1986).
- [18] *** Committee on microwave processing of materials, Microwave processing of materials, Committee on microwave processing of materials: an emerging industrial technology national materials advisory board commission on engineering and technical systems national research council, Publication NMAB-473 National Academy Press, Washington, D.C. (1994).
- [19] *** USC Precision Agriculture. <http://www.gpoaccess.gov/uscode/index.html> (accessed 14 February 2009)
- [20] **Vervest P., Van Heck E., Preiss K., Pau L.-F.**, Smart Business Networks. Heidelberg, New York, USA: 2005.
- [21] **Meyer G.G., Främling K., Holmström J.**, Intelligent products: A survey. *Comput. Ind.* 2009;60:137–148.
- [22] **Ruiz-Garcia L., Steinberger G., Rothmund M. A.**, Model and prototype implementation for tracking and tracing agricultural batch products along the food chain. *Food Control.* 2009 In press.
- [23] **Anastasi G., Farruggia O., Lo Re G., Ortolani M.**, Monitoring high-quality wine production using wireless sensor networks. 42st Hawaii International International Conference on Systems Science (HICSS-42 2009); Waikoloa, Big Island, HI, USA. 2009.

- [24] **Marra F., Romano V. A.**, Mathematical model to study the influence of wireless temperature sensor during assessment of canned food sterilization. *J. Food. Eng.* 2003;59:245–252.
- [25] **Qingshan S., Ying L., Gareth D., Brown D.**, Wireless intelligent sensor networks for refrigerated vehicle. *IEEE 6th Symposium on Emerging Technologies Mobile and Wireless Communication*; Shanghai, China. 2004.
- [26] **Ruiz-Garcia L., Barreiro P., Rodríguez-Bermejo J., Robla J.I.** Monitoring intermodal refrigerated fruit transport using sensor networks: a review. *Span. J. Agric. Res.* 2007;5:142–156.
- [27] **Ruiz-Garcia L., Barreiro P., Robla J.I.** Performance of ZigBee-based wireless sensor nodes for real-time monitoring of fruit logistics. *J. Food. Eng.* 2008;87:405–415.
- [28] **Brett Arthur, Senior Consultant**, The Difference Between Quality Assurance and Quality Control, Open dialog article, *Dialog IT*, (2012).
- [29] **Christy Draus**, Quality Control or Quality Assurance in the Food Industry – X-ray Inspection Equipment Ensures Both, *Eagle.Quality.Assured*, (2017).
- [30] **Soundar R. T. Kumara Sagar V et al**, Sensor Based Monitoring for Real-Time Quality Control in Manufacturing, Department of Industrial and Management Systems Engineering, The Pennsylvania State University University Park, PA 16802, (1994).
- [31] **Filipović J., Đurić M.**, Quality management system, Faculty of Organizational sciences, Belgrade, (2010).
- [32] *****ASQ Audit Division and J.P. Russell**, “Appendix E: History of Quality Assurance and Auditing,” from *The ASQ Auditing Handbook*, ASQ Quality Press, pages 299-301, (2012).