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XR for Enhancing Supervision in Automated Production Plants

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ABSTRACT

Improved data acquisition capabilities and extended machine connectivity in industry, combined with rapid evolution of smart portable and wearable devices opens various opportunities for support of industrial plant operators on site. In this paper the authors propose a solution which allows to interactively support human operators on the shop floor by means of smartphones and Hololens, connected to the production line database. It is studied application of such system in the context of the hollow glass production line.

1 INTRODUCTION

Nowadays, industrial plants and production lines are typically equipped with advanced control systems that incorporate state-of-the-art technologies, including a variety of sensors and the ability to collect and transmit large volumes of reliable data. This data typically enables better process control and facilitates such services as overall production optimization, predictive and preventive maintenance. As a result, there is a growing demand for intelligent solutions that could acquire, store, filter, analyze and distribute this data in order to support and improve industrial plant operations. These capabilities, often associated with the concept of Industry 4.0, are essential for staying competitive in today's market.

Apart from productivity boost and operation cost reduction, such systems could help to improve safety of the human workers. Indeed, as presence of dangerous conditions could be detected or forecasted, it could be possible to guide operators towards most suitable preventive or remediation solution. For instance, it could be possible to aware them about occurred and potential leaks and discharges of dangerous materials, remind about necessary Personal Protective Equipment (PPE) required in certain areas, notify about abnormal conditions of machines.

Among fundamental technologies which play role of pillars of the whole Industry 4.0 it is necessary to highlight IIoT (Industrial Internet of Things). Indeed, it evolved jointly with the technological and methodological stack of Big Data, which is focused exactly on new ways to acquire, store and process previously unthinkable amounts of information. The availability of all this data from industrial production lines is the reason why nowadays it is common to introduce new solutions based on Artificial Intelligence (AI), Digital Twins, Augmented Reality (AR) and Autonomous multi-domain Vehicles (AxV) in industrial plants (Vignali et al. 2018, Bruzzone et al. 2017, Bruzzone et al. 2016). To highlight this considerations, the authors present a research project which lead to the creation of an innovative operator support system based on portable and wearable solutions, which takes advantage of all available information.

2 OBJECTIVES

As noted, the availability of information derived from omnipresent and reliable data sources offers numerous opportunities to improve various aspects of plant operations, ranging from performance and productivity enhancements to better work safety. In this specific research, the authors focus on addressing multiple factors, aiming to improve both safety and work optimization. For example, data related to the status of systems could serve as early warnings for potentially hazardous conditions and help reduce response times; additionally, new functionalities, such as remote assistance, are introduced. This capability, for instance, allows highly qualified personnel at headquarters to provide support to operators on the production floor in real time, regardless of the physical distance between them. This represents a novel service that guarantees expert remote support at any time, no matter where the operators are located.

To explore these aspects, the authors propose portable, mobile, and wearable solutions to assist operators with their daily tasks on the shop floor, along single production lines or in whole plant. Specifically, the research investigates the development of flexible solutions compatible with multiple platforms, ranging from HoloLens to smartphones and tablets. These devices are capable not only to display critical information but also to collect and to store data related to interventions and lessons learned. This work builds upon several industrial initiatives, notably the W-ARTEMYS project (Wearable Augmented Reality for Employee Safety in Manufacturing Systems), which explores how these innovative tools and technologies impact safety within industrial environments.

In particular, during the familiarization with the industrial context of chosen case study, following principal objectives were identified:

- Definition of Key Performance Indicators of chosen pilot plant. Identification of principal risks to the operators and ways to reduce them.
- Create a prototype system which includes modern portable, mobile and wearable solutions in order to verify their efficiency in the chosen context.

3 AUGMENTED PLANT OPERATOR

As mentioned, this research is focused on experimentation with innovative solutions to support supervision and maintenance of industrial production lines using Mixed Reality (MR) technologies, with particular emphasis on Augmented Reality (AR) to highlight critical issues and performance during plant operations. One key objective of the study is to evaluate the effectiveness of various wearable and portable hardware and software solutions, taking into account the unique challenges posed by different types of production lines. For example, certain environments may involve extreme temperatures, high noise levels, dust, or the presence of chemical agents. In other case there could be fixed and/or moving objects which hinder effective positioning inside the facility. The authors are specifically testing flexible, portable solutions compatible with different platforms, such as smartphones, tablets, and HoloLens.

AR and wearable technologies are particularly effective in alerting shift managers, supervisors and on-site operators about the need for immediate intervention. These technologies allow quick and intuitive access to key plant indicators and simplify the retrieval of information related to specific machines and production parameters. However, to enable these functionalities, it is essential to integrate portable devices that are aware of their location within the plant and could access common databases. Depending on the specific requirements, technologies like Indoor Positioning Systems (IPS) or QR codes attached to predefined locations can be employed. IPS is widely used for indoor and outdoor positioning, with GPS being common in many outdoor applications, but often unreliable in industrial environments due to weak signals, reflections and interferences. Fortunately, various tools are available today to help with accurate positioning using transmitters installed at fixed and known positions within the plant. For example, Wi-Fi and Bluetooth-based IPS systems could offer reasonably precise positioning with minimal infrastructure investment. For higher accuracy, systems using Ultra-Wideband (UWB) signals are typically preferred (Yang & Shao, 2015). In the case study presented, where average level of accuracy is sufficient, any of these systems could be used. Additionally, when absolute positioning isn’t required and it is sufficient to know what the operator has in front, QR codes offer a cost-effective solution.

In fact, QR code scanning could be an effective method for confirming an operator's or mobile device's location within the plant. All critical machines could be equipped with QR tags that help identify the device's relative position and orientation once the code is scanned. Furthermore, mobile and wearable devices are typically equipped with Inertial Measurement Units (IMUs), which are quite good in maintaining of position tracking even when tag are out of sight. Combining QR tags with IMUs often provides sufficient positioning accuracy for the proposed use cases.

Positioning solutions play a key role in enhancing operator efficiency and are integral to the effectiveness of wearable technologies. By tracking operators' locations and actions, these solutions allow real-time updates on the plant's status, such as alerts, abnormal machine behavior, and potential critical issues like performance anomalies or defect increases. Additionally, transmitting operator activity data to the control room, central office, or engineering department enables better remote supervision of operations. The synchronization of wearable devices with the control system ensures that remote supervisors know exactly where an operator is and what he/she is focusing on.

This approach could be further enhanced by creating a Digital Twin of the production line or entire plant, allowing operators to be virtually represented in a digital environment. In such a scenario, remote supervisors could access real-time plant data in a virtual 3D environment, providing remote support with the same view of the plant as the on-site operator (see Figure 1) (Bruzzone et al., 2019a). This synergy of technologies offers the potential for even greater operational benefits.

Figure 1: HoloLens for remote supervision, laboratory demonstration

4 SCENARIOS OF INTEREST

To study effective and efficient solutions based on this approach, the authors identified several potential application cases: one related to hollow glass production and another primarily focused on the food and beverage industry.

Glass Production Line

Hollow glass production line is a "hostile environment" due to the nature of the process, which involves melting raw materials in high-temperature furnaces, followed by hot and cold treatments along noisy production lines, and numerous control and packaging systems. In the early stages of the process, there is a significant presence of machines and materials exposed to extreme heat, while later stages, including control and packaging, handle highly fragile and consequently dangerous products, which often results in broken glass scattered around the area.

Additionally, automated packaging and transportation systems must be capable to manage properly the risk of collisions. Overall, these environments are considered to be quite hazardous (BLS, 2017). A notable characteristic of this environment is that the risks are not only posed by the machines but also by the products themselves.

Food and Beverage Production Line

The second case study focuses on a bottling line, which includes processes such as cleaning and sterilization, bottling, and sealing containers after they are filled with milk. In this case, the primary risk factors are associated with high temperatures and pressures in the machinery, as well as the presence of moving parts.

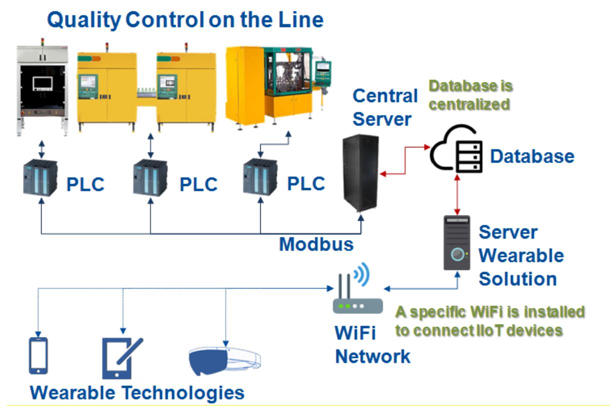

Figure 2: Architecture related of Quality Control along a Production Line

5 PROPOSED SYSTEM CONFIGURATION

To design and implement flexible solutions for the proposed case studies, it is essential to create an effective and robust support architecture that integrates various equipment, models, wearable technologies, and the operators themselves (Longo et al., 2012). A key challenge in this process is the need to develop reliable models of the production process, which must be effectively connected to the virtual representations of the machines and components. An example of this for online quality control in a production plant is shown in Figure 2.

To succeed in this task and avoid potential pitfalls, it is critical to define the entire architecture that supports the system, ensuring is capable to perform all required activities while maintaining high reliability, efficiency, as well as cybersecurity levels. For instance, to facilitate access to machinery data and to ensure consistent, efficient data acquisition, it is advisable to have a single access point for such information — such as a web API (Application Programming Interface) or direct database access. This centralized approach eliminates the need to redesign data extraction modules for each individual client device, which is especially important given the variety of access modes and data formats typically found in production lines with multiple machines from different manufacturers. Moreover, a centralized database allows for the easy introduction of new functionalities and extensions to existing ones, and the system could be easily adapted for other production lines or sites. This approach simplifies data access, ensuring that the project's server and clients are largely agnostic to the specific requirements of the different machines, while maintaining the highest possible level of security (Tanenbaum & Van Steen, 2017).

In summary, the proposed solution involves extracting data and storing it in a centralized database, which is periodically retrieved by the server and then sent to the clients. The server also performs data analysis, processing alerts and suggesting possible explanations and corrective actions.

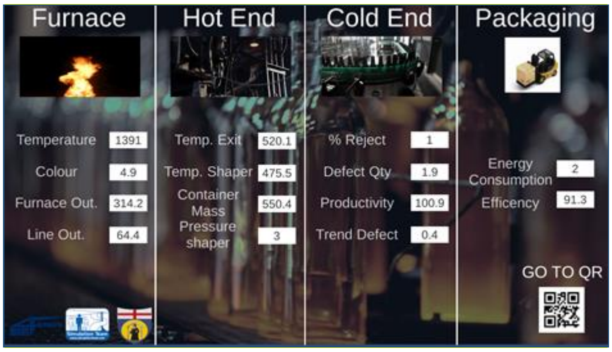

Figure 3: Mobile application displaying main plant indicators

The functionality of the server could be further enhanced by incorporating an Artificial Intelligence (AI) module, which would not only identify critical situations but also anticipate them, thereby reducing risks for both operators and the plant.

As previously mentioned, a crucial aspect of the project is ensuring safety of operators while providing security of the sensitive information. In particulat, production line data is retrieved directly from the company's servers. While the highest level of security would be achieved by isolating all systems from one another, this approach would make integration, centralization, control, and remote maintenance impossible. Therefore, compromises between safety and efficiency must always be considered. To address these challenges, the case study relies on portable solutions that operate in isolated network and are connected only to the plant database, which allows to maintain high level of data protection. From the proposed architecture, it is possible to identify the most critical points regarding data protection and access control. For instance, given that the main server could have access to certain parts of the production line's control system, controlling access to sensitive data is essential. This is partially addressed through read-only access to some of databases, which significantly reduces the possibility of unauthorized modifications to machine configurations. Additionally, security access measures are implemented to avoid unwanted data exchange.

Another cybersecurity concern arises from the use of wireless networks (Wi-Fi) to support the new system. To ensure data protection and integrity, it is essential to implement robust encryption measures. For example, WPA2 protection should be used for Wi-Fi connections, and all connected devices must operate within a secure Virtual Private Network (VPN) (Nguyen, 2018). Portable devices should be restricted to using only the dedicated wireless network.

Finally, security and safety are closely tied to human factors (Bruzzone et al., 2019b). Security measures will be ineffective if end users access external or mobile networks, create bridges between networks, or install unauthorized applications. To mitigate this risk, it is essential to implement strict access controls on devices, enforce policies, and apply encryption techniques to safeguard the system.

6 USE MODE AND EXPERIMENTATION

The authors have identified several potential use cases for these new systems in industrial plants. One key application is to directly support operators on the plant floor. In this context, AI and wearable technologies assist operators in quickly identifying problems and critical issues, guiding them to the right solutions. Additionally, these solutions could enable remote assistance, helping operators resolve more complex situations with support from experts located elsewhere. Another significant use case involves adopting Mixed Reality (MR) solutions for operator training, both online and offline, to improve their problem-solving skills and familiarity with production line interventions. For example, the combined use of smartphones and HoloLens could be employed to monitor the plant's status in real time, while headsets or CAVE (Cave Automatic Virtual Environment) systems could be used for remote assistance and training. One practical application might involve using a tablet to assist operators during maintenance tasks by providing real-time data on machine alerts, instructions for required actions, and components that need to be checked (see Figure 3).

CONCLUSIONS

The authors conducted research on modern mobile and wearable technologies and their potential integration within industrial plants and production lines. The study proved successful, working effectively with both Industry 4.0 machines and older components across various types of production lines.

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