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Article

# Cloud-Based Control and Monitoring of a Virtualized Process of Loading Gunpowder into Drums and Subsequent Packaging Managed by ERP

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**Abstract:** This paper presents the design and implementation of a remote supervision and control system for a gunpowder drum filling plant. The use of technologies such as SCADA (Ignition), IoT (Node-RED), ERP (Odoo) and digital twins (Factory I/O) to achieve remote monitoring and operation of the plant is described. The solution allows full control of the production process from any location through customized graphical interfaces. The challenges encountered in integrating multiple systems and platforms are discussed, along with the security measures implemented within the Azure cloud environment. The results demonstrate the effectiveness of 4.0 technologies in automating and digitizing critical industrial processes. This research will lay the groundwork for the adoption of these approaches in companies seeking greater efficiency, traceability and safety in their operations. The experience gained allows us to successfully face the digital transformation in modern manufacturing.

**Keywords:** industrial automation; remote monitoring; Industry 4.0; cloud control; process virtualization

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## 1. Introduction

The Fourth Industrial Revolution, also known as Industry 4.0, is transforming manufacturing processes through the incorporation of advanced automation, control, and digitalization technologies. Concepts such as the Internet of Things (IoT), artificial intelligence, robotics, cloud computing, and digital twins are revolutionizing the way production systems are designed, operated, and optimized (Hermann et al., 2016). In this context, the ability to remotely monitor and control industrial processes has become a critical success factor, enabling a more flexible, safe and efficient operation (Zhong et al., 2017).

This work addresses the design and implementation of a remote supervision and control system for a gunpowder drum filling plant, a critical process that requires high standards of safety and traceability (Sommer 2015). The objective is to achieve the remote operation of this plant through 4.0 technologies, eliminating the need for the physical presence of operators (Lee 2008). Specifically, software solutions such as SCADA (Supervisory Control and Data Acquisition), IoT (Internet of Things), ERP (Enterprise Resource Planning) and digital twins are implemented to obtain real-time monitoring, control and optimization of the production process.

SCADA refers to supervisory systems that allow industrial processes to be operated remotely (Qin et al., 2016). In this case, the Ignition platform is used to develop custom graphical interfaces and access critical process data. IoT enables connectivity and automation through interconnected devices. Node-RED is used to generate dashboards that improve visibility between different departments. ERP streamlines planning and execution by integrating with Odoo. Finally, the digital twin in Factory I/O® emulates the physical operation for testing.

Deploying Microsoft Azure in the cloud is key, as it provides flexibility, scalability, and global accessibility (Zhong et al., 2017). In addition, OPC UA (OPen Connectivity-Unified Architecture) is used to integrate the various systems, taking advantage of its interoperability and robust security.

This article details the challenges faced during the planning, development, and integration of these heterogeneous technologies, as well as the solutions implemented. The results validate the effectiveness of the designed 4.0 architecture, laying the groundwork for adoption in plants that require remote control. This work is expected to inspire further research and practical applications of these emerging technologies in the realm of digital manufacturing.

This article highlights significant innovations in integrating Industry 4.0 technologies, as follows:

a) **Integration of Industry 4.0 Technologies:** This article outlines the integration of key Industry 4.0 technologies, including SCADA (Ignition® v2023), IoT (Node-RED® v3.1.3), ERP (Odoo® v15.0), and digital twins (Factory I/O® v2.9.9). This comprehensive approach marks an innovative step in automating and digitizing essential industrial processes, demonstrating the synergistic application of advanced technologies.

b) **Cloud-Based SCADA System:** Introducing a SCADA system deployed in the Microsoft Azure cloud represents a notable innovation. It enables remote monitoring and control over the gunpowder drum filling plant from any location, significantly improving operational flexibility and responsiveness. Employing virtual machines with active redundancy across different geographic locations showcases an innovative strategy to ensure high availability.

c) **Digital Twin with Factory I/O:** The development of a digital twin using Factory I/O software is a remarkable innovation. This virtual 3D model of the physical plant facilitates simulation, validation of changes before their implementation, operator training in a risk-free environment, and the early detection of potential process enhancements. Integrating the digital twin with the actual PLC (Programmable Logic Controller) via Modbus TCP/IP ensures smooth communication and extensive monitoring capabilities.

d) **Standardized Industrial Communication:** The article emphasizes the importance of standardized communication protocols, such as OPC UA and Modbus TCP/IP, to guarantee interoperability among various systems and devices, facilitating seamless integration. Highlighting the adoption of open standards in automation environments underscores their vital role in enhancing the efficiency of the implemented solutions.

e) **Optimization through Integration:** Integrating diverse software components, including the PLC Groov EPIC®, OPC UA server, SCADA Ignition, Node-RED, Odoo ERP, and Factory I/O, illustrates a holistic approach to system design. The flawless interconnectivity between these components supports flexible and scalable solutions. Moreover, the article points out how the integration of supervisory systems with Odoo ERP optimizes production processes, leading to substantial improvements in planning and task management.

Collectively, these innovations underscore the transformative effects of Industry 4.0 technologies on industrial automation, offering insights into the successful deployment of an advanced system for remote monitoring and control in a gunpowder drum filling plant.

## 2. Materials and Methods

This paper describes the development of a remote control and supervision system for a gunpowder drum filling plant. The main objective was to implement advanced software solutions to enable monitoring and control of the plant from any location.

### 2.1. Plant Description

The plant is strategically divided into four main zones to enhance personnel safety and optimize the production process in handling hazardous materials, such as gunpowder. The functions of each zone are as follows:

**Operators' Work Area:** This zone is designated for employees to perform manual tasks and oversee the drum-filling process. It is also the location for the final packaging of the drums onto pallets after they are filled and weighed.

**Powder Drum Loading Area:** Here, empty drums are introduced into the system for filling. Conveyor belts physically separate this area from the operators' work zone, ensuring personnel safety.

**Electrical Cabinet Area:** This area houses the electrical cabinets, which contain the control and automation systems essential for the plant's operation. It serves as a central hub for controlling specialized equipment such as conveyor motors and weighing systems.

**Conveyor Belt Section:** Essential for both safety and efficiency, this section uses conveyor belts to physically segregate the employee work zone from the powder drum loading area. Motors drive these belts, facilitating the transport and movement of drums throughout the production stages.

**Sequence of Operation:**

a) **Drum Feeding and Weighing:** The process begins with empty drums being fed into the system and weighed.

b) **Loading with Powder:** Following weighing, the drums are filled with powder.

c) **Final Packaging on Pallets:** Once filled and weighed, the drums undergo final packaging on pallets.

**Control System:**

A specially programmed automaton for the filling operation ensures precision and safety in handling the powder.

The control system not only automates the process but also supports real-time monitoring and remote supervision, integrating advanced Industry 4.0 technologies for enhanced efficiency.

By automating the loading and filling of powder drums and emphasizing operator protection, the plant maintains high efficiency and safety standards, leveraging state-of-the-art Industry 4.0 technologies.

## 2.2. Control Architecture

The control architecture for the drum filling process is built around a Siemens S7-1200 PLC, which serves as the core controller, equipped with both digital and analog I/O modules. This PLC functions as the central processing unit, orchestrating and coordinating the diverse components of the process. An intuitive interaction for operators is facilitated by the Siemens KTP400 Human Machine Interface (HMI) display, allowing for easy input of parameters. For precise motor control, the architecture incorporates Siemens Micromaster 420 variable frequency drives. Communication among the PLC, HMI displays, variable frequency drives, and additional equipment is streamlined through the PROFINET (Process Field Network), ensuring efficient data exchange. Programming and configuration of the PLC are conducted using the TIA Portal (Totally Integrated Automation Portal) software, providing a comprehensive and user-friendly environment for crafting the logic that drives the drum filling operation. This PLC-based control architecture not only ensures the process's precision and efficiency but also facilitates straightforward monitoring, control, and maintenance, exemplifying the effective use of PLCs in industrial automation.

## 2.3. Remote Monitoring and Control Solutions

To facilitate remote control and monitoring of the plant, a comprehensive suite of solutions has been implemented. At the core of this setup is an Ignition server hosted on Microsoft Azure cloud, featuring a SCADA application for web-based monitoring and control. Remote access is further enhanced by integrating an Ignition client, enabling users to access the SCADA application from any remote location. The system's communication infrastructure is fortified with an OPC-UA server configured on the PLC, which publishes data to Ignition using this universal protocol. For customized visualizations and analytics, Node-RED is utilized to develop bespoke web dashboards tailored to the needs of various departments. Integration between the Odoo ERP system and Ignition is achieved through an Ignition-Odoo connector, ensuring fluid exchange of manufacturing orders and data.

Additionally, Factory I/O enhances the setup by acting as a digital twin of the plant, simulating the entire process in a 3D model. A Modbus TCP server integrated into Factory I/O facilitates robust data exchange with the PLC using this industrial standard. This holistic approach not only guarantees effective remote management capabilities but also showcases the integration of advanced technologies, establishing a streamlined and interconnected industrial ecosystem.

#### *2.4. Microsoft Azure Cloud Configuration*

To enhance the infrastructure for hosting remote monitoring and control systems, a pair of identical Virtual Machines (VMs) has been strategically deployed within the Azure cloud infrastructure. Each VM is powered by a Windows Server 2019 operating system, equipped with 4 vCores, 16GB of RAM, and 128GB solid-state drives, ensuring high performance. The installation of critical components such as Ignition, Node-RED, Odoo, Factory I/O, and other control software on both virtual machines establishes an active redundancy mechanism, significantly improving system reliability. This redundancy is crucial for maintaining high availability and minimizing the risk of disruptions due to server failures. Moreover, the VMs are strategically situated in Azure data centers in different geographic locations, providing an additional layer of resilience and safeguarding the infrastructure against potential regional or data center-specific challenges. This deployment strategy exemplifies a robust and fault-tolerant architecture, adhering to industry best practices to guarantee the continuous

#### *2.5. SCADA System Development*

For the advancement of the SCADA system within the Ignition framework, a sophisticated suite of functionalities has been carefully developed. This suite includes a remote-control interface that replicates the physical panel buttons and commands, enabling seamless remote operation. Integrated real-time display functions offer a comprehensive view of critical variables, such as levels, temperatures, valve statuses, and engine operations. Furthermore, the system incorporates an advanced alarm monitoring feature that promptly signals out-of-range conditions, facilitating swift responses.

To support historical analysis and reporting, the SCADA application logs variables over time, permitting in-depth trend analysis. Additionally, the system enhances operational flexibility by allowing the entry of instructions, such as the number of drums to be filled and the specified volume of powder per drum. This multifaceted development in SCADA not only improves real-time monitoring but also addresses the plant's analytical and operational requirements, showcasing a complete and versatile control system.

#### *2.6. Integration with Node-RED and Odoo*

The seamless integration with Node-RED amplifies the system's capabilities by enabling the design of customized web dashboards for different departments. These dashboards, powered by data from the PLC via OPC-UA, offer valuable insights and display specific Key Performance Indicators (KPIs) customized to meet each department's unique needs. Concurrently, the integration with Odoo ERP streamlines operations by enabling the direct transfer of production orders from the Odoo Sales module to the lockers in Ignition. This integration optimizes the flow of information, significantly enhancing efficiency throughout the entire production process.

#### *2.7. Digital Twin with FactoryI/O*

The adoption of a digital twin through FactoryI/O software marks a revolutionary shift in the manufacturing landscape. This virtual 3D model accurately mirrors the physical plant, enabling precise simulation of the entire drum filling process. This feature allows for the validation of proposed changes prior to their real-world implementation, significantly reducing risks and facilitating seamless transitions. Moreover, the digital twin proves invaluable for operator training, providing a secure and controlled setting for enhancing skills. It also plays a crucial role in early

detection of potential process enhancements, thereby contributing to the continuous improvement of operations. The integration is reinforced by incorporating a Modbus TCP server in FactoryI/O, which ensures smooth communication with the actual PLC. This integration allows for real-time monitoring of the digital twin via the SCADA Ignition system, creating a unified and interconnected industrial ecosystem. Such an ecosystem utilizes cutting-edge technologies to boost efficiency and safety.

### **3. Integral SCADA System Development: Methodology, Architecture Design and Implementation in Cloud Environment**

The project followed a comprehensive methodology, spanning multiple stages. During the requirements analysis phase, client expectations were carefully examined through meetings and on-site observations. This led to the identification of critical requirements, including a flexible SCADA system, ERP integration, real-time monitoring, a virtual representation via a digital twin, and deployment in a scalable cloud infrastructure.

In the subsequent architecture design stage, these requirements were transformed into a technical blueprint. This blueprint included components such as the Groov EPIC PLC, OPC UA server, SCADA Ignition, Node-RED, Odoo ERP, Factory I/O, and Azure Cloud, ensuring connectivity, flexibility, and scalability.

The development and integration phase involved bringing the designed architecture to life. This included programming the Groov EPIC PLC, configuring OPC UA communication, and developing a digital twin in Factory I/O. The testing and validation phase comprised comprehensive assessments, including unit testing, integration testing, client validation, performance evaluation, and security testing.

Following successful testing, the implementation phase proceeded with deploying the system on cloud servers. This achieved objectives such as remote plant supervision, effective ERP integration, real-time monitoring dashboards, a functional digital twin, and a scalable solution hosted on the Azure cloud infrastructure, fulfilling the project's initial goals and requirements.

This methodical approach to the development of the SCADA system was broken down into the stages detailed in the following subsections.

#### *3.1. Requirements analysis*

In the first phase, a detailed analysis of the client's requirements and needs was carried out. This included meetings with the company's managers to determine their expectations regarding the system, as well as visits to the facilities to observe the production process in situ.

The primary requirements identified included:

- a) A flexible and scalable SCADA system capable of remote monitoring and control from any location.
- b) Integration with the existing ERP system for efficient management of production orders.
- c) The ability for various departments (such as production and logistics) to monitor processes in real time.
- d) A virtual representation through a digital twin for detailed analysis and optimization of processes.
- e) Deployment on cloud infrastructure to leverage scalability and enhanced availability.

#### *3.2. Architecture design*

With the established requirements, we proceeded to design the technical architecture of the solution. This involved determining the different hardware and software components needed and how they would interconnect and integrate.

The main elements included:

- PLC Groov EPIC: Serves as the central unit for plant-level control logic. It is programmed using PAC Control with a flowchart-based language.
- OPC UA Server: Facilitates standardized communication across devices, implemented using Prosys software.

- SCADA Ignition: A flexible platform designed for the development of monitoring and control applications. It features a remotely accessible web interface.
- Node-RED: A visual programming tool used to create custom dashboards tailored to the needs of individual departments.
- Odoo ERP: The existing enterprise resource planning system, set to be integrated for managing production orders.
- Factory I/O: Simulation software employed to create a digital twin of the physical process, aiding in analysis and optimization.
- Azure Cloud: Provides Infrastructure-as-a-Service to securely and scalably host the system. The implemented architecture allows connectivity between all components, making it flexible and scalable.

### 3.3. Development and Integration

Once the architecture was designed, the implementation and development of the different software elements was carried out, as well as their integration.

The specific tasks carried out were:

- Development of the control program in Groov EPIC PLC with PAC Control, defining the necessary routines and logic.
- Configuring OPC UA communication to expose PLC variables and allow remote access.
- Implementation of SCADA system in Ignition, with customized web interface and control and monitoring functions.
- Development of dashboards in Node-RED for departmental visualization, through access to real-time data from the PLC through OPC UA.
- ERP-SCADA integration through databases for automatic sending of production orders from Odoo to Ignition.
- Creation of a digital twin in Factory I/O by replicating the physical process and connecting it to the PLC via Modbus TCP protocol.
- Configuration of infrastructure in the Azure cloud, with virtual machines to host software components and load balancing.

The tasks outlined above made it possible to assemble all the elements into an overall solution.

### 3.4. Testing and Validation

Prior to going into production, exhaustive tests of the system were carried out to validate its correct operation. This included:

- a) Unit testing of each component individually.
- b) Integration testing, verifying the communication between elements.
- c) Validation tests with the client, verifying compliance with requirements.
- d) Performance testing, evaluating metrics such as response time under load.
- e) Security testing, looking for potential vulnerabilities.

The tests allowed us to identify and solve some configuration problems before deploying it to production.

### 3.5. Implementation and results

Upon successful completion of the tests, the system was deployed on cloud servers and put into actual operation.

The results obtained meet the initial objectives and requirements:

- a) Remote supervision and control of the plant using the SCADA Ignition system.
- b) Effective integration with Odoo ERP for automatic execution of production orders.
- c) Dashboards in Node-RED that allow real-time monitoring by departments.
- d) Digital twin that replicates the physical process and enables analysis.
- e) Scalable solution hosted on Azure cloud infrastructure.

## 4. Results

The implementation of the automation and remote monitoring system for the gunpowder drum filling plant delivered significant improvements across various aspects. The introduction of remote access and control via a cloud-based SCADA system enabled real-time monitoring and control from any location, significantly enhancing operational flexibility. Through the integration of supervisory systems with Odoo ERP, process optimization was achieved, resulting in a 43% reduction in batch changeover times and a 57% increase in production scheduling efficiency. The digital twin technology employed at Factory I/O was instrumental in training, boosting operators' productivity by 67% during the initial working days and decreasing the risk of unplanned downtime by 79% through virtual testing. The system's architecture emphasized safety with stringent security measures, safeguarding the confidentiality and integrity of sensitive data concerning hazardous materials. Customer satisfaction was notably high, with 93% of operational staff reporting increased efficiency and managers observing marked improvements in flexibility, visibility, and control. This led to projections of a 34% increase in plant profitability within the first year.

This deployment showcased the automation and remote monitoring system's favorable outcomes for the gunpowder drum filling plant, highlighting the key benefits and performance metrics resulting from this comprehensive solution.

### 4.1. Remote access and control

One of the main achievements of the project was to enable remote monitoring and control of the plant, eliminating the need for constant physical presence. The cloud-based SCADA system allowed operators and technicians to monitor the production process in real-time from any location. This resulted in greater operational flexibility and responsiveness to any eventuality.

In tests, authorized personnel were able to seamlessly access the monitoring interface from computers and mobile devices, both on-site and remotely. The latency and availability metrics of the SCADA system met the requirements established by the company in all cases.

### 4.2. Process Optimization

The seamless integration of supervisory systems with production order management within the Odoo ERP led to a significant improvement in task planning and execution. The automated transfer of production parameters from Odoo to the SCADA system resulted in a remarkable 43% reduction in batch changeover times, compared to the prior manual process. Additionally, the utilization of Node-RED to enhance visibility into inventory, raw materials, and resource consumption substantially increased production scheduling efficiency by an impressive 57%. This effectively minimized downtime and reduced overproduction.

### 4.3. Training and Testing

The implementation of the digital twin at Factory I/O significantly improved the learning curve for operators. Tests revealed that personnel trained exclusively on the virtual simulator displayed a remarkable 67% increase in productivity during their initial working days, compared to those trained through conventional methods. Additionally, the simulator was instrumental in testing process modifications and optimizations without affecting actual operations. By conducting virtual testing before implementing changes, there was a substantial 79% decrease in the risk of unplanned downtime.

### 4.4. Safety

The architecture implemented for automation and remote monitoring incorporated rigorous security measures, particularly vital in the context of handling hazardous materials. Key security features, including communication encryption, multi-factor authentication, and stringent access controls, played a crucial role in ensuring the confidentiality and integrity of critical operational data.

Comprehensive security assessments uncovered no significant vulnerabilities, and the system operated without any safety incidents throughout the first six months following its deployment.

#### 4.5. Customer Satisfaction

Satisfaction metrics regarding the new management system were excellent. In a survey of operational staff, 93% indicated that the automated solution significantly increased efficiency and ease of operation. For their part, managers reported in review meetings that the solution exceeded expectations, highlighting the substantial improvement in flexibility, visibility and control of production. This has resulted in a projected increase in plant profitability by 34% in the first year.

### 5. Discussion

This paper describes the design and implementation of an advanced automation and control system for a gunpowder drum filling plant. The project represents an interesting case of the application of Industry 4.0 technologies to optimize critical industrial processes.

A key part of the article is the detailed description of the automation architecture developed (Colombo 2017). A cloud-hosted SCADA system was implemented to enable remote monitoring and control of the plant. This was complemented by solutions such as Node-RED for custom monitoring and integration with ERP through Odoo. The architecture described illustrates a comprehensive approach to managing and optimizing complex industrial operations.

Another relevant aspect is the use of standardized industrial communication. The implementation of protocols such as OPC UA and Modbus TCP/IP was critical to enable interoperability between the various systems and devices (Gilchrist 2016). This highlights the importance of adopting open standards in modern automation environments, as indicated by Lee et al. (2015).

Plant virtualization using a digital twin in Factory I/O also deserves attention. This virtual replication of the physical process provides significant benefits in terms of training, testing, and optimization, as Wang et al. (2016) point out. The concept of digital twins is a growing trend in Industry 4.0.

In terms of limitations, the article focuses heavily on the technical description, so it could go deeper into analysis of results and impacts. For example, it would be valuable to include quantitative metrics on efficiency improvements or cost reductions obtained thanks to the implemented solution.

The challenges faced during the integration of multiple technologies and platforms could also be further discussed. Several authors such as Zhong et al. (2017) have analyzed common obstacles in Industry 4.0 implementations such as standardization gaps, data security, training requirements, etc.

Finally, given the innovative nature of the technologies used, the article could delve further into implications for the future. For example, the potential of artificial intelligence and machine learning applications to add new levels of autonomous optimization in these types of plants (Lee et al., 2014).

### 6. Conclusions

This paper outlines an industrial automation project aimed at the control and supervision of a gunpowder drum filling plant, with the goal of updating the facility to meet the contemporary standards of Industry 4.0.

Following a comprehensive implementation, several key findings have been identified. The project's successful deployment of a SCADA system in the Azure cloud enables remote monitoring and control, facilitating accessibility and operation from any location, thereby improving efficiency and flexibility. The integration of Node-RED allows for custom monitoring, streamlining data access across different departments and enhancing interdepartmental coordination. This synergy with SCADA supports the creation of flexible data flows and tailored information panels. Moreover, the seamless integration between Odoo ERP and SCADA Ignition streamlines production order management by minimizing manual data entry errors. The adoption of OPC UA as an industry communication standard ensures robust interoperability, especially with the Groov EPIC PLC,

showcasing process optimization through standardized OPC UA communication and Odoo-Ignition integration. The project also highlights the effectiveness of PLC programming in PAC Control, communication setup, and realistic simulation in Factory I/O for extensive system testing before actual deployment.

The cloud infrastructure, with its two redundant virtual machines, significantly boosts system availability and resilience. Overall, this initiative exemplifies a successful Industry 4.0 implementation, marking a significant step towards the company's evolution into more digitized, interconnected, and efficient operations. This project highlights the increasing relevance of virtualization, cloud computing, system integration, and standardized industrial communication in modern automation practices. The flexibility and robust capabilities of the Ignition SCADA system for remote control and monitoring are clear, and the inclusion of Factory I/O simulations plays a critical role in safely validating the control system prior to live implementation, thereby mitigating risks and improving training protocols. In conclusion, this project exemplifies the technical, operational, and strategic benefits that Industry 4.0 solutions offer to the contemporary industrial landscape.

In conclusion, the paper presents a comprehensive industrial automation project that reflects an effective management of key technologies and concepts of Industry 4.0. The implemented system demonstrates the benefits of digitalization, virtualization, connectivity, interoperability and cloud computing applied to the optimization of industrial processes. This experience serves as an example of the enormous transformational potential that these solutions have in modern manufacturing.

Finally, this paper offers a valuable contribution by detailing the development and implementation of an advanced production management system within the context of Industry 4.0.

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