Automatization of colors manufacturing

Monitor and improve the efficiency of production processes.

The Challenge

Due to the recent increase in production volume, we want to implement a batch of manufacturing system in order to manufacture the product by recipes and improve the raw materials and the finished product.
Along with this change, the aim is to implement a production planning system capable of launching batches automatically and optimize manufacturing times and resources.

Industry Sector:
global color and specialty chemicals

Challenge classification:
Real-time process monitoring and optimization; Smart planning and scheduling of processes.

Time for Project Completion:
12 months

Main Requirements

- Monitor the production flow;
- Optimize the production planning and scheduling;
- Always-on process monitoring (Consumed Power, Temperature....);
- Create alerting and notification system;
- Optimize flow of material.

Other Requirements

N/A

Key Performance Indicators

N/A

Other informations

What competence does the company have with this project?
Define user requirements to contract the project to a system integrator specialist.

Use manufacturing execution systems (MES) or enterprise resource planning (ERP) systems?
I don't know.

Use of any existing cloud vendor (AWS IoT, Microsoft Azure, etc.)?
No

Number of machines to be connected:
15 reactors

Configuration of each machine and the operation of each:
Chemical reactors for the manufacture of colors

Machines are equipped with PLC/PAC or CNC controllers and can provide data?
15

Machines are not equipped with any digital controller (Legacy Machines)?
0

Communication protocols, sensors or devices with which the solution needs to integrate?
Modbus TCP

Research Phase

Taking into account the challenge description, its requirements and its information, elaborate at least 5 questions that can lead your research for a solution.

Research questions:

1. How can I be informed of any situations that could potentially require a response?
2. How can I visualize the production flow and basic KPIs?
3. How can I create production schedules and optimize them?
4. How can I launch (automatically or via an operator) new production batches?
5. How can I obtain and collect data from machines regarding the implementation of production and resource consumption?

Given the questions and the main requirements of the challenge previously listed:

- *identify possible technologies using the Planet4 Taxonomy Explorer;*
- *identify and analyze the sources (papers, articles, etc.) of those technologies that best suit the challenge;*

Technologies identified in the taxonomy:

- Big Data Frameworks (Apache Hadoop);
- Streaming and Messaging (Apache Kafka);
- Relational Databases;
- NoSQL Databases: Document databases (MongoDB), Time Series Databases (influxDB), Column-Oriented Databases (Apache Cassandra);
- Data Warehouses (Apache Hive);
- Data Analytics: Unified Data Analytics Engines, Unified stream-processing and batch-processing frameworks, Business Intelligence (BI) Tools, Data Visualization Tools and Platforms, Data Mining, Process Mining;
- Machine Learning: Supervised Learning, Unsupervised Learning, Deep Learning, Semi-Supervised Learning, Reinforcement Learning;
- Computer Vision;
- Intelligent Agents and Multiagent Systems
- Soft Computing: Fuzzy Set Theory, Neurocomputing, Optimization Techniques;
- Infrastructure as a Service (IaaS): Cloud Data Storage and Computing, Virtual Machines;
- Platform as a Service (PaaS): Device Management;
- Software as a Service (SaaS): IoT Analytics Software and Platforms;
- Container Technology (Container as a Service): Containerization Platform;
- Serverless Programming;
- Edge Computing;

- Fog Computing;
- Industrial IoT: Industrial Communication Protocols, Industrial (IoT) Gateways and Data Acquisition Devices;
- Physical Devices and Controllers: Embedded Computing (Microcontroller programming and RTOS, Microprocessor programming and embedded Linux), Sensors (hardware);
- Signal Processing: Software Defined Radio (SDR);
- Connectivity: Radio Communication Technologies, IoT Messaging Protocols (Message Queuing Telemetry Transport (MQTT)), Application Programming Interfaces and Programming Tools;
- Digital Twins: Computer-aided design (CAD) Software, Finite Element Analysis (FEA) Software, Simulation software, Digital twin Data Modelling;
- Industrial Robotics: Middleware (ROS (Robot Operating System));
- Virtual Reality;
- Augmented Reality: AR glasses, AR Software Development Kits;
- AR and VR Software development, Platforms and Technologies: Unity;
- Additive manufacturing: 3D Printers;
- Data Protection: Public Key Infrastructure (PKI), Encryption, Blockchain;
- Identity and Access Management: Authentication, Authorization;
- Foundational Security.

Sources of those technologies that best suit the challenge:

[1] https://www.sciencedirect.com/science/article/pii/S2351978919303865?via%3Dihub

[2] https://link.springer.com/article/10.1007/s00170-020-06245-2

[3] https://www.sciencedirect.com/science/article/pii/S0166361518306808

[4] https://www.mdpi.com/2079-9292/9/8/1272/htm

[5] https://www.oracle.com/scm/manufacturing/

[6] https://www.topsoe.com/our-resources/knowledge/our-services/connected-services

In light of the discoveries made:

- *report the answers for the questions above;*
- *compare 2-3 of the more common solutions identified in the sources (how would they change the approach to the solution? What are the possible benefits/issues in such a use of these technologies?);*
- *draw initial conclusions on which path you want to take in proposing a solution.*

Answers:

1. Analyzing data from sensors using appropriate data analytics methods (knowledge discovery from databases); use of Business Intelligence tools (e.g., Microsoft Power BI) for data presentation and alerting.
2. Application of Manufacturing Execution System (MES) for KPI calculation; use of Data Visualization Tools and Platforms to present KPIs and SCADA systems to visualize the production flow.
3. Application of APS systems (Advanced Planning and Scheduling) to create production schedules; use optimization techniques from Soft Computing (e.g., meta-heuristic approaches) to optimize schedules.
4. Application of MES to launch new production batches.
5. Use of appropriate sensors (hardware) and Industrial Communication Protocols (Modbus).

Comparison:

There are several possibilities of presenting the data expected by the company (e.g., data on electricity consumption, temperature or KPI). The traditional way is to visualize it in the form of a dashboard, which is presented on a computer monitor or a TV screen. However, there are alternative ways, each one with its own advantages. In paper [1], augmented reality was used to present the above-mentioned data. The application proposed by the authors uses image recognition to identify workstations and, thanks to augmented reality, presents the calculated KPIs in real time. The advantage of this solution is the possibility of presenting other parameters (e.g. cycle times, and work in progress). In addition, the approach proposed in [1] fits the concept of Lean, in which the Go & See practice is well known. It assumes that managers go to the shop floor to be able to supervise production first-hand.

Another way of presenting data is described in [2]. The authors propose to use an application supported by smartphones, which presents selected data from the monitoring of production machines in real time. An additional advantage of this solution is the ability to control the operating parameters of selected machines.

In [2], attention was also paid to the importance of choosing the database system. The authors of [2] describe it as follows: "Regarding the choice of a database, there are two main alternatives described as relational and non-relational databases. These are sometimes referred to as conventional SQL (Structured Query Language), in which the data are related by tables, and NoSQL (not only SQL), in which the data are not modeled within the relational framework. Until now, SQL has provided a high level of efficiency for storing data. Given that this particular model has an established record of reliability, flexibility, robustness, and scalability, it is widely adopted. However, if the data is massive and unstructured, non-relational databases are usually chosen. For such a reason, the use of non-relational databases has seen a substantial increase in the past years."

Conclusions:

Monitoring energy consumption is an important element of production activities, because "energy consumption is one of the most important factors of sustainable machining and it enhances the competitiveness of corporations in terms of lower production costs, higher revenue and greener footprint", as stated in paper [3]. Likewise, it is important to monitor KPIs. Therefore, we need to develop a solution that will monitor KPIs and energy consumption using appropriate sensors. Data from sensors will be stored in the cloud continuously. Appropriate data processing algorithms should check whether the recorded data is free from errors that would distort the analysis results (ensuring data reliability). Appropriate parameters will be determined on the basis of the recorded data. The calculation of KPIs will be performed by MES. The KPI presentation will be carried out using an application for smartphones / tablets with the possibility of visualization in augmented reality. This is associated with the creation of a digital twin of each monitored workstation. The APS software should be used to create production schedules, while launching production batches will be possible thanks to MES.

Proposed Solution

Making use of the technologies identified after the analysis of the sources, describe a possible solution to the challenge. Also, do not forget the constraints (time, number of devices to produce/connect, etc.): the solution must be applicable to the real context of the company that commissioned the challenge.

Solution Summary

Brief description of the solution (1-2 paragraph + 1 image)

The proposed solution consists of three layers:

1. **The layer of monitoring the production process and data storage.**

The monitoring layer of the production process should include appropriate sensors monitoring selected parameters at work stations (e.g. temperature, energy consumption). The data recorded by the sensors should be saved on the server (in the cloud). The server part of the solution is shown in Figure 1. As suggested by the authors of paper [4]: "The tools, which are implemented on the server side [...] can be run on practically any Linux-based operating system. [...] The MQTT broker (mosquitto) runs on the server and serves as the main central point through which all communication between the mobile device and the currently recognized mechatronic system takes place. Messages are sent to the broker using publish-subscribe communication on undefined topics. It is therefore not necessary to define them in advance, but the application that wants to obtain data from the address must be subscribed to receive this type of message.
Node-RED consists of a runtime based on Node.js and a visual editor. The program is created in the browser by dragging functional nodes from the palette into the workspace. Then it is necessary to interconnect these nodes. The application is then deployed to production automatically using the deploy button. Additional nodes can be easily added by installing new nodes created by the programming community. Flows that are created in the workspace can be exported and shared as JSON (JavaScript Object Notation) files."

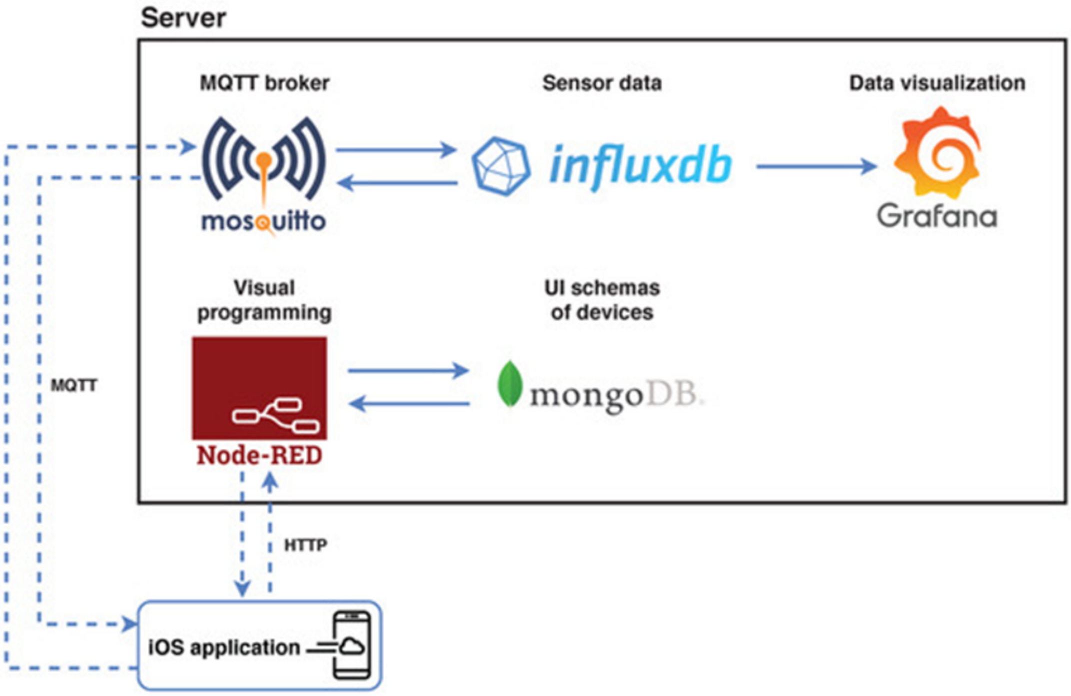


Figure 1. Server part of the solution. Source: [4]

2. **The layer of presentation of monitored parameters and KPIs with the use of augmented reality.**

The presentation layer is based on the mobile device and augmented reality application. The authors of the work [4] describe this part of the solution as follows: „The mobile application includes the Wikitude SDK, which provides methods and algorithms for recognizing 3D objects in a real environment using a mobile device camera. A software package in Unity engine format (.unitypackage) is available on the official website of this tool.

Real-world 3D objects are detected by Wikitude by trying to match pre-created references in video streams from mobile device's camera. Such a prepared reference is called Object Target. It can also be understood as a SLAM map. Object Target is created using input images of a real model (mechatronic device). These are then converted into the so-called Wikitude Object Target Collection, which is saved as a .wto file. The procedure for creating a collection is as follows:

1. Creating photos of an object from different angles (up to 30 photos can be inserted)
2. Convert photos to Wikitude Object Target Collection (.wto)
3. Use of the .wto file in the project in the Unity 3D engine

[...] The generation of a dynamic graphical user interface takes place at the Unity engine level via a definition scheme."

3. **The layer of scheduling and production optimization.**

One of the commercial software available on the market can be used for production scheduling. An example is Oracle Fusion Cloud Supply Planning with the Production Scheduling module. This solution ensures maximization of production efficiency, optimization of resource use, reduction of costs related to production, increased productivity, and reduction of production waste [5].

Solution Description

Describe the solution and its details

The authors of the work [4] propose the concept of the system presented in Figure 2 (in the place of the mechatronic device there is a work station for which relevant parameters are to be monitored). The authors describe the operation of the system in the following six points:

1. "**The software application analyzes the image from the camera of the mobile device and recognizes the mechatronic system.** The augmented reality mobile app recognizes a real mechatronic device using a camera and a 3D map created in the Wikitude Studio. The 3D map of the mechatronic device is created using photographs of the device taken from several angles. Subsequently, the Wikitude SDK (software development kit) augmented and mixed reality library can interpret this 3D map from a database. The database is stored in a software application on an Apple iPad tablet. The advantage of this method is the ability to recognize the object from any angle. Consequently, even with less visibility tracking does not have to be interrupted as Wikitude can also store close surroundings of the object. Thus, the implementation of the proposed solution can do without conventional methods of recognizing objects relying on QR codes.
2. **The mobile device connects to the server and the mechatronic system's device twin in the cloud.** The mobile device is connected to the cloud where the recognized mechatronic system has its digital copy (device twin).
3. **The data from sensors of the mechatronic device is sent to the server, and the device twin in the cloud is synchronized.** The mechatronic device automatically sends data under its identifier from sensors to the server where the data is also stored. For this purpose, the InfluxDB database is used, designed for time-dependent data which can then be visualized in the Grafana environment. At the same time, the digital copy of the mechatronic device is synchronized at the level of the Microsoft Azure Device Twin, which ensures the visibility of current data even in the cloud environment.
4. **The application obtains information about the type of the mechatronic device, downloads the definition of the user interface and draws a graphical interface for control and monitoring of the system.** The proposed system works in such a way that the mobile application recognizes the mechatronic device and — according to its identifier— obtains a unique definition scheme of the user interface for the needs of its monitoring and control. The concept of definition schemes for a dynamic generation of a graphical user interface in augmented reality is one of the pillars of modularity of the implemented solution and at the same time one of the application benefits. The mobile application has access to these definition schemes due to the connection to the database. The connection is realized by means of visual flow-based programming in the Node-RED environment, where a suitable scheme is obtained based on the parameter.
5. **The user interacts with the mechatronic device through a graphical interface in augmented reality—a new form of HMI.** Based on a unique definition scheme, the mobile application displays a graphical user interface in augmented reality consisting of two parts. The first part is diagnostics and displays current data from available sensors. The second part is control and shows the control elements directly designed for the mechatronic device. Subsequently, the user is allowed to interact with the mechatronic device through a graphical interface in augmented reality, which is one of the

new modern forms of human-machine interface (HMI).

6. **Control commands are sent to the server which sends them to the connected mechatronic device.** Control commands are sent from the mobile device to the server using the MQTT communication protocol. On the server, they are processed and executed. The software application on the mechatronic device listens on the MQTT topic and subsequently sends these requests to sensors and actuators via serial communication."

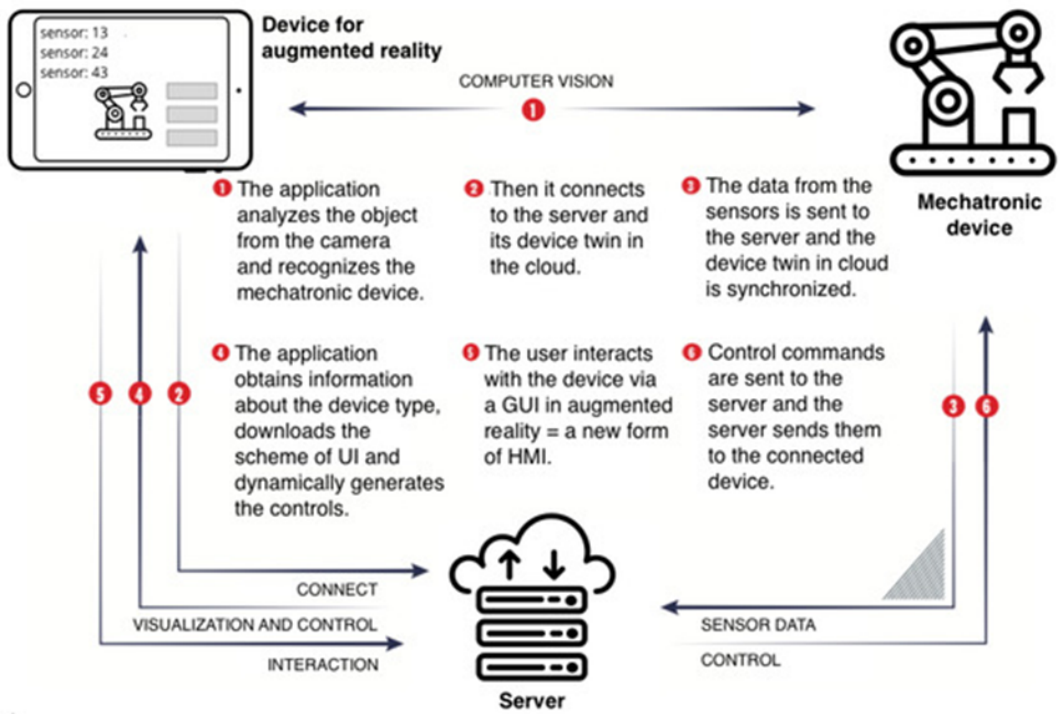


Figure 2. Proposal of a monitoring system using augmented reality. Source: [4]

In addition, it will be necessary to implement MES and APS systems to set KPIs and launch production batches.

Implementation Plan

Describe the solution implementation plan considering among other things: gantt chart with milestones, high-level cost analysis, possible difficulties (at least 3 major issues or difficulties) and additional opportunities (at least 2 extra benefits).

Implementation plan:

1. Analysis of the specificity of the production process and development of the hardware and software architecture of the system.

Milestone 1: Hardware and software architecture

2. Development and implementation of a system for collecting data from machines.

Milestone 2: Data collection system

3. Implementation of Manufacturing Execution System.

Milestone 3: MES software implemented in the company

4. Implementation of Advanced Planning and Scheduling system.

Milestone 4: APS software implemented in the company

5. Development of the data analysis layer and KPIs.

Milestone 5: Defined KPIs

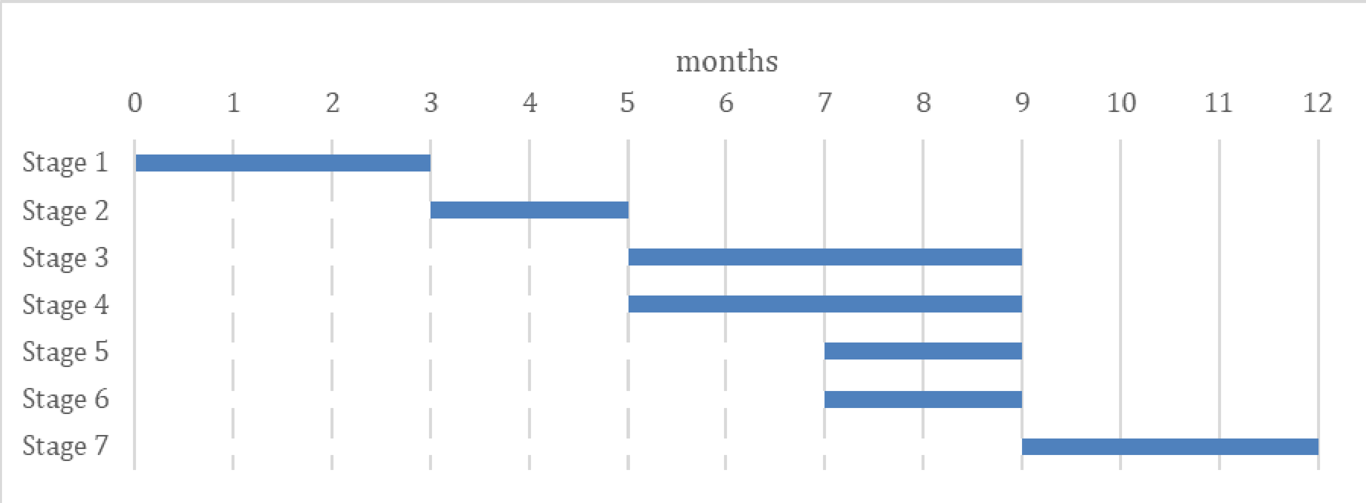
6. Development of an augmented reality layer for data presentation.

Milestone 6: Augmented reality system

7. Testing the proposed solution.

Milestone 7: Successful completion of the tests

Gantt chart:



High-level cost analysis:

Implementation of the stage 1 – labor costs (3 employees x 3 months)	18900 €
Implementation of the stage 2 – labor costs (2 employees x 2 months)	8400 €
Implementation of the stage 3 – labor costs (3 employees x 4 months)	25200 €
Implementation of the stage 4 – labor costs (3 employees x 4 months)	25200 €
Implementation of the stage 5 – labor costs (2 employees x 2 months)	8400 €
Implementation of the stage 6 – labor costs (3 employees x 2 months)	12600 €
Implementation of the stage 7 – labor costs (8 employees x 3 months)	50400 €
Server and network infrastructure	55000 €
Data analytics software	30000 €
Augmented reality system	85000 €
MES	40000 €
APS	40000 €
TOTAL	399100 €

Additional benefits:

- Meet performance targets for the entire plant with actionable insights and recommendations based on up-to-date, accurate data. [6]
- Reduce the risk of unplanned shutdowns by receiving early warnings regarding issues you can remedy before they become real problems. [6]
- Besides providing real-time monitoring information, the solution may assist in predictive machine maintenance, once historical data is combined with artificial intelligence and machine learning techniques. [2]

Possible difficulties:

- Problems with communication between machines and the data collection system.
- Difficulty in adapting existing APS systems to the production process.
- Necessity to modify existing production processes.
- Reluctance of the company's employees against modifying production methods and implementing new technologies.