Facilitation of tools inspection activities

Monitor and improve the efficiency of production processes.

The Challenge

Forecast of maintenance duration for production tools: Each incoming tool is inspected before the maintenance and repair activities begin. This is done by skilled workers. The inspection results are documented according to specific levels for certain specific categories (condition of paint, dirt, missing parts, etc.). To document the condition of incoming equipment photos are taken by the worker. In order to reduce the effort for inspection and enable even non-experienced workers to conduct this task it is intended to semi-automate the inspection activity by using photos of the incoming assets and to determine their condition automatically.

Industry Sector:
Provider and integrator of solutions for manufacturing and logistics

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

Time for Project Completion:
6 months

Main Requirements

- Optimize the production planning and scheduling;
- Optimize the maintenance operations based on ML and AI;
- Optimize number of operators based on performance.

Other Requirements

N/A

Key Performance Indicators

N/A

Other informations

What competence does the company have with this project?
Operational as well as technical know-how.

Use manufacturing execution systems (MES) or enterprise resource planning (ERP) systems?
No

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

Number of machines to be connected:
0

Configuration of each machine and the operation of each:
N/A

Machines are equipped with PLC/PAC or CNC controllers and can provide data?
0

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

Communication protocols, sensors or devices with which the solution needs to integrate?
Barcode readers indicating start and end of maintenance activities. Central database storing and providing further information related to incoming tools (condition, repairs, ...).

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. Should the proposed technological solution work even without connectivity in the industrial environment?
2. Should the condition of industrial equipment be monitored at any time, from any place, or should the data remain at the local level for security reasons?
3. What is your budget?
4. Is your system Cloud-ready or not?
5. What is the level of knowledge and skills of current employees?

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:

- Data Visualization Tools and Platforms
- K Nearest Neighbour (KNN)/Case-Based Reasoning (CBR) (Machine Learning)
- Deep Learning
- Computer Vision
- Cloud Data Storage and Computing
- Embedded Computing
- Connectivity (5G, WiFi, etc.)
- Augmented Reality (AR)
- AR and VR Software development, Platforms and Technologies

Sources of those technologies that best suit the challenge:

1. Mourtzis, D.; Boli, N.; Fotia, S. Knowledge-Based Estimation of Maintenance Time for Complex Engineered-to-Order Products Based on KPIs Monitoring: A PSS Approach. Procedia CIRP 2017, 63, 236–241, doi:10.1016/j.procir.2017.03.317.

2. Mourtzis, D.; Angelopoulos, J.; Panopoulos, N. A Framework for Automatic Generation of Augmented Reality Maintenance & Repair Instructions Based on Convolutional Neural Networks. Procedia CIRP 2020, 93, 977–982, doi:10.1016/j.procir.2020.04.130.

3. Remote Support | 4REMOTE | Zerintia Technologies. (https://zerintia.com/en/industry-4-0/4remote/)
4. Fieldbit - Fast AR and Spatial Computing for Remote Assistance Available online: https://helplightning.com/solutions/fieldbit-share-know-how-instantly/ (accessed on 18 June 2022).
5. Aschauer, A.; Reisner-Kollmann, I.; Wolfartsberger, J. Creating an Open-Source Augmented Reality Remote Support Tool for Industry: Challenges and Learnings. Procedia Computer Science 2021, 180, 269–279, doi:10.1016/j.procs.2021.01.164.
6. Richard, K.; Havard, V.; His, J.; Baudry, D. INTERVALES: INTERactive Virtual and Augmented Framework for IndustriaL Environment and Scenarios. Advanced Engineering Informatics 2021, 50, 101425, doi:10.1016/j.aei.2021.101425.
7. Masood, T.; Egger, J. Adopting Augmented Reality in the Age of Industrial Digitalisation. Computers in Industry 2020, 115, 103112, doi:10.1016/j.compind.2019.07.002.

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. The proposed solution, to be reliable, should work with the same performance either in case of lack of connectivity or limited connectivity.
2. Managers should oversee the manufacturing system at any time and from anywhere, having applied the appropriate techniques for secure data transfer and minimization of cyberattacks.
3. The proposed solution should be characterized by the optimal trade-off between benefit and cost. That is a solution through which the goal will be achieved without requiring high operating costs or sufficient training time for this new operating mode.
4. No.
5. For non-skilled workers to be able to handle it, it must be user-friendly without the need to develop high-level skills such as computerized systems handling or programming.

Comparison:

Using the taxonomy, we identified various technological solutions for predicting the maintenance time of a failed production tool. The company's leading requirement was to create an AI-based system that uses photos of the incoming assets as input data. Therefore the basic technologies of all possible solutions are ***Computer Vision/Deep Learning***, which allows us to create knowledge-based models that can extract useful information from digital images, videos, and other visual inputs. Furthermore, all solutions use the ***Case-Based Reasoning (CBR) machine learning technique*** to estimate maintenance time.

The solutions' differences concern how the AI-powered system develops and the interaction between the worker and the system. For the development of the AI-powered system, two possible solutions were identified. The first one concerns the implementation of the system on a remote server (local or ***Cloud-based***). In this method, the worker captures the images and sends them (through ***IoT protocols*** or ***radio communication technologies*** such as ***5G*** or ***WiFi***) to the remote server for processing. Then the AI-powered system sends the output back to the worker. The second solution concerns implementing the AI-powered system in a local device (i.e., an ***embedded device***). The first approach is generally faster since it can process more data in less time due to the high computational power of the server and its ability to do several parallel computations. On the other hand, using a local device is more convenient and flexible, needing however lighter AI algorithms to be implemented efficiently; otherwise, both time and precision should be sacrificed.

Regarding the interaction, it is suggested to use ***Augmented Reality*** to take photos and display the results intuitively or use vision sensors (i.e., cameras) in conjunction with a web application (in which we have deployed the AI system) and ***Data Visualization Tools and Platforms***. However, using a web application requires more digital skills. On the contrary, Augmented Reality (AR) facilitates natural interaction between the worker and the system as it allows to send commands (gesture or vocal) and receive a fast response via an AR device (***AR glasses*** or ***mobile devices***), enabling an intuitive way to perform the inspection.

Conclusions:

The final choice of the solution is based on the comparison made before, the industry's requirements and the answers to the questions asked. Initially, we chose the computation platform (local server or Cloud-based server or local device) in which the AI-powered system will be developed. For the proposed solution to remain reliable even in the case of lack of connectivity or limited connectivity, we have to choose between a local server or an embedded device where the images of the failed production tool are collected and used to estimate maintenance duration. For this choice, the fact that the system is not Cloud-ready also played a role as the networking of the manufacturing ecosystem requires enough time. Although mobile devices have become more powerful to handle computations near real-time, the need to use a central database led us to decide not to use embedded systems but a ***local server/data center***.

Regarding the interaction, it is suggested to use Augmented Reality technology because non-skilled workers can operate the system without needing to develop digital skills. Finally, regarding the AR device used, although ***AR glasses*** are a relatively expensive choice, they combine smartphone features with a hands-free operating mode, thus ensuring the industrial task's fastest and highest quality execution.

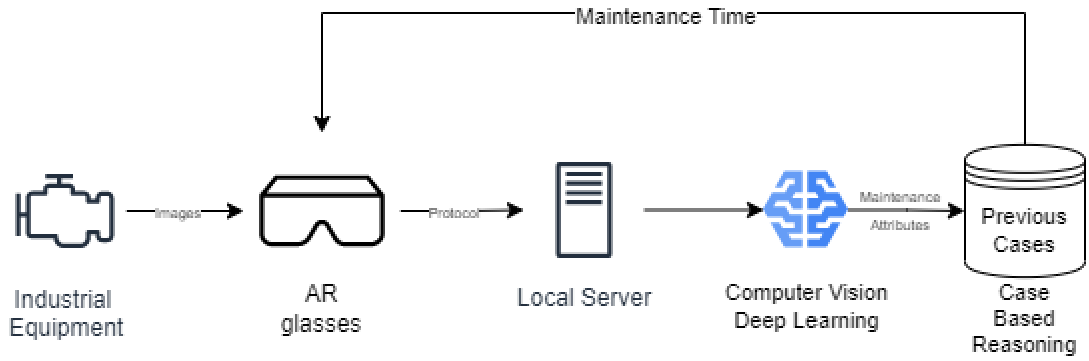
Proposed Solution

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)

Based on the analysis made in the previous two sections, the following solution is proposed:



The worker captures images of the failed production tool by exploiting ***AR glasses*** (which are equipped with vision sensors) and sends them (through ***IoT protocols*** or ***radio communication technologies*** such as ***5G*** or ***WiFi***) to the remote server for processing by the AI-powered system. This system consists of a ***Computer Vision***/***Deep Learning*** model which extracts the values of the maintenance attributes (MA) from the images of the failed production tool (these are the condition of the paint, dirt, missing parts, etc.). These attribute values are input data on the ***CBR*** procedure, which will estimate the maintenance time of the newly entered case. Finally, the AI-powered system sends the output back to the worker's glasses.

Solution Description

Describe the solution and its details

When a production tool fails, a worker captures images of it through ***AR glasses*** (equipped with vision sensors) and sends them (***IoT protocols*** or ***radio communication technologies*** such as ***5G*** or ***WiFi***) to the ***local remote server*** for processing by the AI-powered system [3]. There, the ***Computer Vision***/***Deep Learning*** model extracts the maintenance attributes (MA) from the images of the failed production tool (e.g., condition of the paint, dirt, missing parts, etc.) [2]. These attributes are qualitative and quantitative (i.e., linguistic and numerical variables). In order to avoid text processing, the qualitative attributes are encoded. Furthermore, based on the feedback we take (from semi-structured questionnaires and interviews) and the knowledge of expert engineers, a weight for each MA is assigned. These weights represent the relative impact of these features on the maintenance time (i.e., the higher the weight value, the higher its impact). Having completed this procedure, the newly entered maintenance task is compared through a similarity mechanism against previously solved cases retrieved from the ***central database***. Except for MA values, data regarding actual maintenance time are available for the past cases. The actual maintenance time for each task has been calculated with the help of ***barcode readers***, indicating the start and end of maintenance activities. The comparison is performed by calculating the distance of the attributes using specific equations [1]. As a result, the most similar past case, as well as the similarity degree between the new task and the past one, are identified. In the final phase of the CBR methodology, the resulting similarity degree is adopted to estimate the maintenance duration of the failed production tool. This methodology has presented promising results since the maintenance time has been estimated accurately based on past knowledge reuse [1].

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).

The development of the proposed technological solution requires implementing the AR application, the connection establishment between the AR glasses and the local server, and developing the AI-powered system (the Computer Vision/Deep Learning model and the CBR Classifier).

<u>AR application</u>:

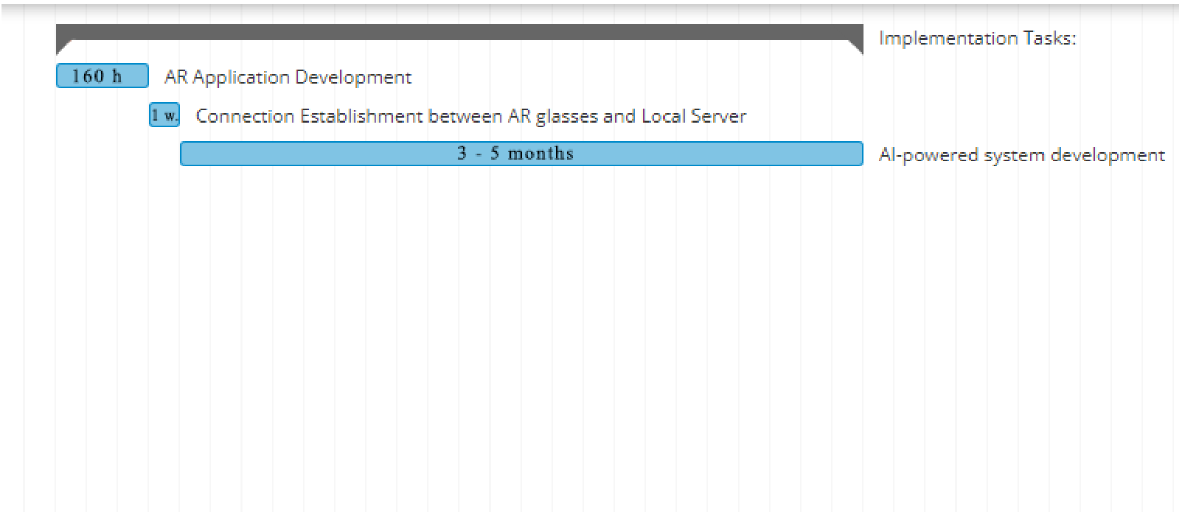
As previously mentioned, production tools are equipped with barcode readers indicating the start and end of maintenance activities. These barcodes can also be used as markers to track the tool in place and capture images. For such a marker-based AR technology, developers need about **40-160 hours** to implement. However, this approach has limitations because the technology may start losing track once that barcode is out of view (**Issue 1**). In order to address this limitation, we can use a model tracker where the 3D CAD data of the tool and the physical one are aligned, thus, allowing the user to recognize the actual object and then trigger different events (e.g., taking photos).

<u>Connection between AR glasses and the local server</u>:

Most AR glasses support WiFi, and thus the connection between them and the local server can be established very quickly, which is a clear advantage (**Benefit 1**). A wireless connection allows it to conveniently update the software, download information content, and control the support system from a central server. However, interference from industrial assets can disturb wireless signals, thus, affecting the reliability of the local network (**Issue 2**). One proposal that addresses bandwidth constraints and latency fluctuations is installing many access points on the shop floor.

<u>AI-powered system development</u>:
In this phase, data related to maintenance tasks are collected for at least **three months**, and then the AI model is developed to create a database of past cases. According to Algorithmia's "2020 State of Enterprise Machine Learning", 50% of respondents said it took **8–90 days** to deploy an AI model. Thus, the development time of the AI-powered system lies between **3-5 months**, a logical fact as the AI-powered system is the core of this technological solution.

Gantt Chart:



<u>High-level cost analysis</u>

Regarding the proposed solution's cost, there is no established methodology for pricing, but only estimations are available. Initially, AR app development prices vary widely depending on the app type. For example, an application produced in 160 working hours costs **$5,000-$10,000** [8]. Regarding the required hardware (i.e., AR glasses, its cost varies greatly depending on its capabilities. Models with digital displays are often more costly, beginning at around **$500**. However, most general-purpose glasses with displays are more expensive, with prices ranging from **600$** to **1000$** (*Vuzix Smart Glasses, Epson Moverio BT-35E*). Smart glasses for businesses are often more expensive, starting at around **$1,000** (ODG R-9, Google Glass Enterprise) and rising to over **$5,000** (*Microsoft Hololens*) [9].

At the same time, the cost of a custom AI project is determined by the effort required to build a model. Typically, AI development work is divided into six phases [10]:

1. *Discovery & Analysis Phase*
2. *Prototype Implementation and Evaluation Phase*
3. *Minimum Viable Product (MVP)*
4. *Product Release*
5. *Maintenance and Support*

Prices for each case individually are often:

1. Prototype development starts from **$2.500**
2. MVP starts from **$8.000** and usually costs up to **$15.000**; it depends on the project size, complexity, and involved team)
3. The complete solution may cost from **$20.000** and up to **$1.000.000**

In summarizing, the minimum cost for the proposed technological solution is:

Augmented Reality application	$5,000-$10,000
AR glasses	$500-$5,000
AI-powered system development	$20.000-$1.000.000
TOTAL	**$25.500-$1.015.000**

8. Estimating Augmented Reality Costs in 2021 - Invisible Toys Available online: https://invisible.toys/create-augmented-reality-apps/augmented-reality-app-development-cost/ (accessed on 9 August 2022).
9. Rakver, M. How Much Do Smart Glasses Cost? (11 Examples) Available online: https://smartglasseshub.com/smart-glasses-cost/ (accessed on 10 August 2022).
10. How Much Does Artificial Intelligence (AI) Cost in 2020? Azati: Uniting experts to fulfil important projects 2020.