VerSatilE plug-and-play platform enabling remote pREdictive mainteNAnce

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Summary:

This document reports the stationing of the SERENA solution in the COMAU's use case. Moreover, it includes the experiment, the services, the requirements, and the consequent results from the testing procedures. All the aforementioned, along with the main outcome of the Robotics demonstrator, have been composed according to the end user's perspective.

Contents

List of Abbreviations

CEN	:	European Committee for Standardisation
CWA	:	CEN Workshop Agreement
ETL	:	Extract, Transform and Load
ICT	:	Information and Communications Technology
IIoT	:	Industrial Internet of Things
KPI	:	Key Performance Indicator
KPI	:	Key Performance Indicator
MOT	:	Mean Off Time
MRT	:	Mean Running Time
MTBF	:	Mean Time Between Failures
MTTR	:	Mean Time To Repair
OEM	:	Original Equipment Manufacturer
PLC	:	Programmable Logic Controller
RAM	:	Random Access Memory
RPCA	:	Robust Principal Component Analysis
RUL	:	Remaining Useful Life
SME	:	Small and Medium Medium-Sized Enterprise
SME	:	Small and Medium Enterprises
TRL	:	Technology Readiness Level
VR	:	Virtual Reality

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Executive Summary

The purpose of this manuscript is to describe the results achieved from the Robotics demonstrator. In particular, this demonstrator has been implemented, tested, and validated in the COMAU facilities and concerns an industrial robot correlated with the automotive industry. Furthermore, the main objectives, that will be extensively described in this report, are presented below:

- The overview of the demonstrator: A description related to the use case and the problem.
- The experiments: SERENA solutions are tested and validated via 3 (three) different scenarios.
- The end-user evaluation: The result and the KPI values are discussed, as well as the lessons that the end-user learned.

Subsequently, this deliverable reports, in the bellow sections, the deployment of the SERENA solution in the COMAU use case along with the impact and the results that have been achieved.

1 Demonstrator overview

1.1 Motivation and goals

IIoT (Industrial Internet of Things) solutions are becoming more and more important due to their effectiveness in process optimization as well as failures and production line stops predictive capabilities.

The two main aspects regarding an IIoT platform are collecting/storing and analytics pipelines; that is why the main goals for COMAU in participating in the SERENA project were to understand which solutions could be most effective in terms of ETL (Extract, Transform and Load) as well as to develop knowledge and methods regarding analytics solutions, to integrate that knowledge in the COMAU IIoT portfolio.

A COMAU's industrial robot has been chosen as the objective of the analytics pipeline since robots are the most common types of machinery in the COMAU's production lines. In the scope of the project, the analytics efforts have been focused on a precise component of the robot, which is common to many other industrial robots and has an important impact on both robot precision and capabilities, the transmission belt. As it is easily conceivable, having to deal with an industrial robot and its overall complexity is tricky, since there are many different physical and environmental conditions that all contribute in a different and not completely predictable way.

To deal with that complexity and with the fact that for having an efficient classification model a labelled dataset is strictly required (containing as well, fault data), it has been decided to focus the study regarding the transmission belt on a test-bed made of just one of the six industrial robot's axis, the sixth. As it is possible to see in Figure 1, a system that continuously changes the distance between the motor and the gearbox reducer has been designed and developed, simulating the changes in the transmission belt, tensioning from too low (simulating the loss in performance after too many working hours without maintenance) to extremely high (representing a wrong belt installation from the maintenance crew).

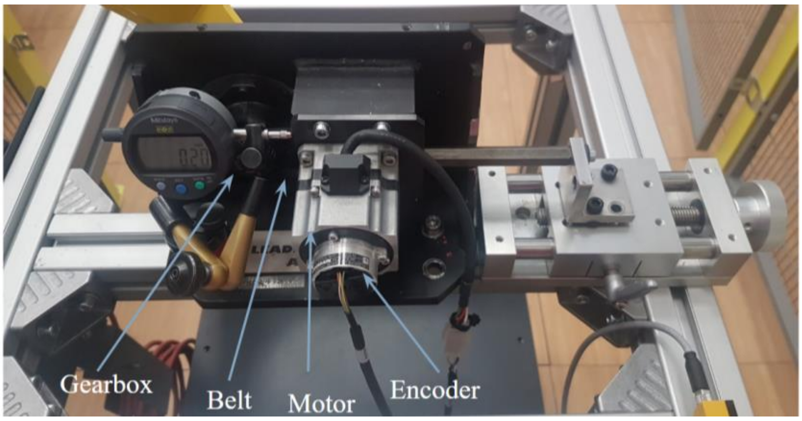


Figure 1: COMAU's testbed and its components

That system is made of a slider and a millesimal comparator to precisely monitor the actual distance and thus, the current class that the testbed is representing. A dataset is thus created, gathering data from two different testbeds, containing 5 comparable classes each, to test the model generalization capabilities.

In addition to the analytics results, in terms of both accuracy and generalization capabilities, maintenance instructions showed in VR (Virtual Reality) and a digital twin service, showing instant-by-instant the exact position of the physical testbed are included.

1.2 Testing environment and timeline

Initially, the testing environment regarding the COMAU use-case was the actual shop floor in an area dedicated to experimental solutions. Both testbeds were connected to the COMAU network as done for all the other machines and robots. The integration activities of the platform, in the current on-premises location, were started in the last months of 2019 and the entire setup was finished before the Christmas holidays. From that time on, the system ran and tested in the actual scenario, adding and upgrading new SERENA services, according to another partner's development plan. Currently, the entire system is integrated and working at its full potential.

The first test-bed has been developed in the second half of 2018 and used to better investigate the physical behaviour of the machine, how robot internal signals answer to different mechanical conditions, and what were the best features to extract in order, to sum up, all the information contained in the raw data. After the features' extraction, all the efforts were put into finding a way to simulate the behaviour of the transmission belt over time and to create a reference labelled dataset to feed the training phase of the predictive model.

In 2020, a second test-bed developed to test the generalization capabilities of the predictive model as well as to better understand the difference between the two testbeds signals even if they are made of the same components and assembled following the same process.

1.3 SERENA system deployment

In the scope of the COMAU use case, the entire SERENA platform has been deployed on-premises since this better represents the needs and requirements coming from the biggest COMAU's customers working in the automotive sectors. The entire platform was set up in hardware made of 8 physical cores and 32 GB of RAM. The overall system has been distributed in 4 VMs, three of them making the swarm, and the last one running the NFS (Network File System) which allows having shared and common access to stored data. On the boundary between the SERENA system and the COMAU network, the SERENA RPCA service guarantees that only trusted users or machines can effectively access the system and its services, making the SERENA system reachable from the entire COMAU internal network.

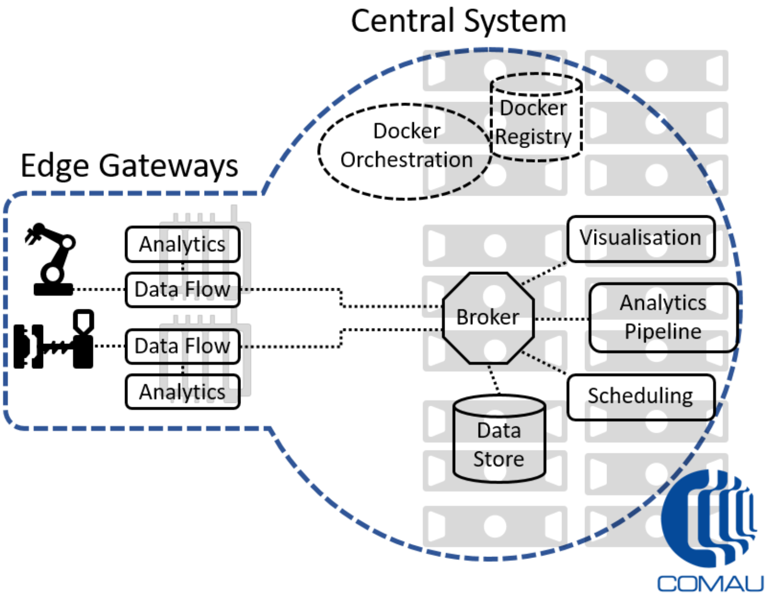


Figure 2: SERENA platform on COMAU premises deployment

Figure 2 shows all the components of the solution. Starting from the left, it is possible to recognize the industrial machinery, the two test-beds developed in the scope of the project and the edge gateway which is in charge of both generating the feature as well as classify the current data and predicting the RUL of the machine. Gateway information is then sent to the central broker, which stores data and propagates the information through all the other services, such as, analytics pipeline, visualization, and scheduling. Additionally, the central system oversees the distributed solution. Managing is made by the Docker registry and orchestration, which guarantees scalability, resilience, reliability but also load balancing throughout multiple replicas of the same services.

2 Experiments

2.1 Testing Objectives

The COMAU use case has as objective not only its own most complex industrial machine, but also the one most common in the production lines delivered to customers, the robot. Precision, repeatability, and speed are the three main indicators most relevant from the technical point, concerning robots, whose performance are the result of many components and physical dimensions and interactions. Robot complexity is the reason that they are so flexible and widely used. On the other hand, that means the need for a strict maintenance schedule to keep everything at its potential and that is not always simple to identify the component which is in charge of a not nominal behaviour. The main objective, in participating in the SERENA project, is to work on some algorithms which have the potential to foresee future anomalies of the robot due to component faults or prematurely degradation.

Table 1: COMAU robot KPI values

Metrics	Explanation	Current state	Notes
MTBF	Mean Time Between Failures	≈ 65000 h	The average interval between two different failure events of the robot.
MTTR	Mean Time To Repair	≈ 1 h	The average duration of the maintenance activities.
MRT	Mean Running Time	≈ 80000 h	The average duration of the productive periods of an individual component of the robot.
MOT	Mean Off Time	≈ 2 h	The average duration of all downing events of an individual component of the robot.

As shown in Table 1, the KPIs regarding the COMAU robot indicate how much the machinery is robust and designed to last. All characteristics necessary to work in the context better explained hereafter in section 3.1. The MTBF means an amount of time above 7 years which becomes more than 9, if considered the single component and thus the MRT. The value of the MOT represents robot component's failures that occur between the preventive maintenance activities, which unfortunately lead to expensive losses in term of missed production. Applying an analytics pipeline to robot components can enable a scenario where a sudden failure is early predicted and a special maintenance activity scheduled during the production stop time, increasing both the MTBF and MRT, reducing the MOT. Having detected the exact component, which is going to fail, allows, also, to cut the time regarding the diagnostic, reducing the MTTR significantly.

To start nearly approaching such a complex machine, the entire system is then split into components and the analytics efforts are thus focused on a precise component, the transmission belt, as described in section 1.1.

2.2 SERENA features to be tested

The entire SERENA platform provides a complete full-stack IIoT platform, covering all the needs and requirements of its industrial use cases. In the context of the COMAU use case, the overall platform has been deployed on-premises, leveraging on the COMAU internal network and satisfying all the legacy network and security policies.

The test-bed developed in the scope of the COMAU use case, described in section 1.1 uses the entire SERENA pipeline, testing the following features and services:

- the flow of gathering data and extract its features using a Node-Red flow installed on the local gateway;
- the collection and storage of the data in the central platform via the ingestion service;
- the model prediction in terms of current behaviour and estimated RUL (both in cloud and edge level);

- the propagation of the RUL in both the visualization and then the scheduling service;
- the self-assessment and then self-labelling services;
- the digital twin service which shows instant-by-instance the position of the testbed;
- the VR maintenance procedure for replacing the transmission belt.

2.3 Experiments & Results

<table>
<tr><td colspan="3">Data ETL (from the testbed through a gateway to the central platform)</td></tr>
<tr><td colspan="3">Description: This experiment wants to demonstrate that the ETL process can reliably gather, process, and storage data coming from the actual field without stops, in a resilient and fault-tolerance environment.</td></tr>
<tr><td colspan="3">Expected result: No lack of data and platform stops due to bugs or internal errors.</td></tr>
<tr><td colspan="3">Quantified outcome: No malfunction or error registered in 14 months.</td></tr>
<tr><td rowspan="9">Scenario 1</td><td colspan="2">Scenario description</td></tr>
<tr><td colspan="2">The entire architecture (the two testbeds, the gateway, and the central platform) was deployed on-premises over the COMAU network according to its security policies.</td></tr>
<tr><td>Features to be tested</td><td>Target result</td></tr>
<tr><td>Availability, reliability, data integrity</td><td>No data loss or stops/errors</td></tr>
<tr><td colspan="2">Results</td></tr>
<tr><td colspan="2">The entire platform has been running correctly for 14 months.</td></tr>
<tr><td colspan="2">Feedback/Comments</td></tr>
<tr><td colspan="2">The platform has demonstrated not only its technical strengths in terms of scalability, availability, and fault tolerance but also a flexible deployment, ranging from on-premises, hybrid-cloud and remote cloud solutions.</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="2">Achieved Metric/KPI value:</td><td>0 stops/errors</td></tr>
</table>

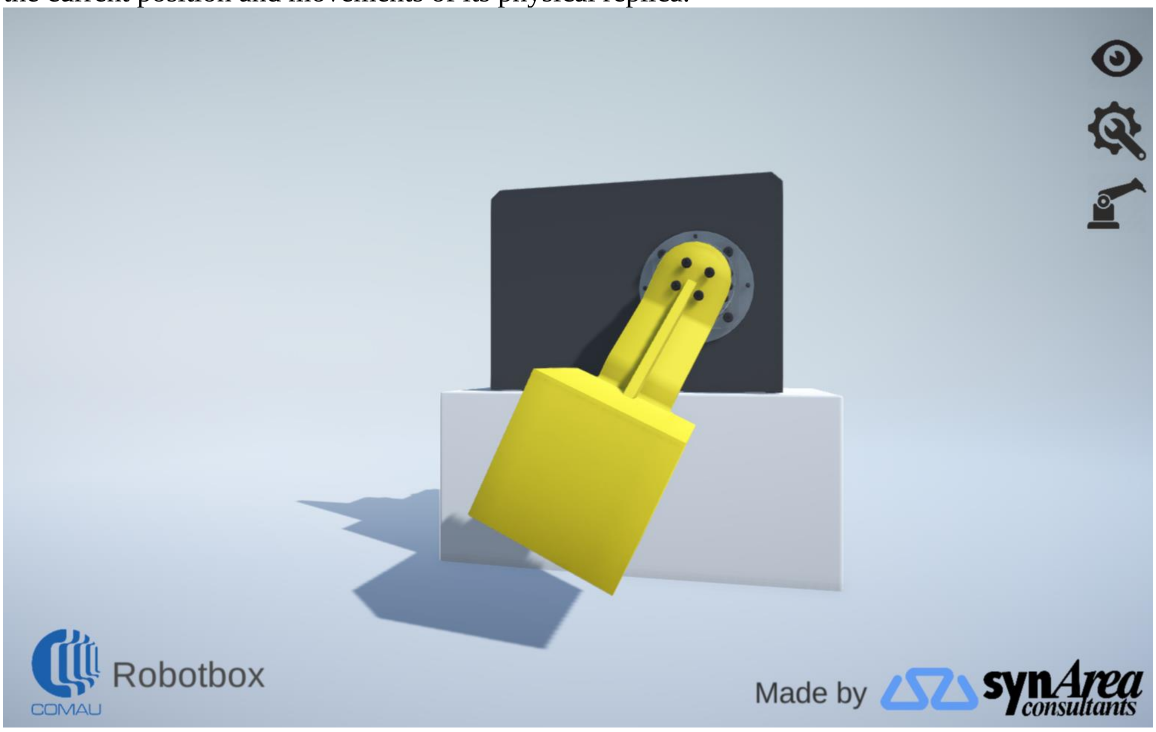
<table>
<tr><td>Digital twin</td></tr>
<tr><td>Description: The signals which the platform gathers from the test-bed are not only used as input for the analytics pipeline but also to feed a real-time digital twin, which can show instant-by-instant the current position and movements of its physical replica.


Figure 3: The digital twin of the testbed</td></tr>
</table>

<table>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3">Expected result: Always aligned and synchronized digital twin.</td></tr>
<tr><td colspan="3">Quantified outcome: N/A</td></tr>
<tr><td rowspan="8">Scenario 1</td><td colspan="2">Scenario description</td></tr>
<tr><td colspan="2">Using the SERENA digital twin tool, it is possible to see the industrial testbed’s synched movements and position.</td></tr>
<tr><td>Features to be tested</td><td>Target result</td></tr>
<tr><td>Real-time position gathering, visualization</td><td>Perfectly synched digital twin</td></tr>
<tr><td colspan="2">Results</td></tr>
<tr><td colspan="2">The digital twin showed has been always aligned with the real one, with no delay.</td></tr>
<tr><td colspan="2">Feedback/Comments</td></tr>
<tr><td colspan="2">This first feasibility test could be even more useful if extended to entire robots, production stations or plants. Another improvement is to gather process data also (e.g., cycle time).</td></tr>
<tr><td colspan="2">Achieved Metric/KPI value:</td><td>N/A</td></tr>
</table>

3 End-user evaluation

3.1 KPIs/Metrics

For the time being, the COMAU reference market is automotive, which is a sector characterized by an impressive volume of production and high level of optimization, since the millions of products made per year are a big multiplier of even the smallest inefficiency. On the other hand, industrial types of machinery, robots first, are designed and developed to be as much robust as possible, guaranteeing a long working lifetime (in some cases up to 20 years) coupled with strict preventive maintenance, to minimize the probability of production line stops, which are extremely expensive in terms of production missed.

Until recently, the COMAU business model regarding robots consisted of just selling them as equipment, without any kind of service (exception made for the maintenance one). That is why the step towards implementing a complete predictive maintenance tool in the actual production lines is not simple and it has to be incremental due to the types of machinery (in the biggest COMAU production lines there are hundreds of robots) and the strict efficiency and reliability requirements. That is why it is not possible today to provide a reliable KPI impact of the SERENA solution on the actual production lines.

Nevertheless, the project has a big impact internally since it has contributed to pushing the data-driven approach next to the classical model-based, highlighting the need of not just a digital transformation in terms of technologies and platforms but also about the creation of a knowledge base to tackle problems which are not predictable by physical models. Although the predictive approach, and more in general the digital transformation, are likely going to take some time before spreading out in the production environment, in COMAU is clear that it will have a disruptive impact.

3.2 Overall assessment of the SERENA system and its features

The SERENA platform has been working on the COMAU's premises for more than 14 months, demonstrating its architectural capabilities in terms of distributed computing, reliability, and security since it is working according to the COMAU's internal network and security policies.

The knowledge and the technologies used to develop the SERENA platform have raised an internal interest in COMAU, which has led to the re-use and extension of many of the SERENA concepts in the COMAU's IIoT offering. The analytics pipeline has been proved effective not only from the prediction point of view but also from the architectural deployment, giving the possibility to train the model in the cloud and then decide if keeping the prediction as well hosted in the cloud or if deploying it to the edge level. This is a key feature since it gives the possibility to choose time by time what is the best way to deploy the intelligence, not only from a technical point of view but also from business, enabling, as an example, analytics as a service scenario. As happened for the knowledge build, thanks to the SERENA architecture, most of the analytics ideas and procedures were the starting point of COMAU internal integrations and extension.

Furthermore, the SERENA platform has successfully proven that the platform-as-a-service is as efficient as flexible guaranteeing the interworking between services, developed from different companies/universities, just relying on the common data model and REST calls. Indeed, data collection, model prediction, visualization, and then maintenance schedules are all strictly linked together, with consistent and always updated data overall the platform. Finally, the VR maintenance procedure has demonstrated the supposed effectiveness, providing augmented and immersive instructions to perform tasks, even by non-expert personnel. Besides, the digital twin service has proven the technical feasibility of gathering robot real-time data and showing it remotely.

Pros	**Cons**
Container-based architecture, which means flexible deployment, scalable, reliable, distributed, and fault tolerance architecture.	The visualization tool should be more optimized to deal with a huge number of devices and a user management system has to be added.

Pros	Cons
Effective analytics pipeline in terms of RUL prediction, self-assessment and self-labelling, cloud training, and edge/central model deployment.	An automated way to manage the analytics component (model training, self-assessment, self-labelling) should be added.
Self-assessment notifies you when the model is not predicting effectively anymore (robot working cycle, payload or other conditions may change in the actual production field).	Not simple and user-friendly platform installation procedure.
Self-labelling enables the human-in-the-loop to leverage model and expert capabilities to have an always updated and continuous learning approach.	
The digital twin can show instant-by-instant the actual machine movement and position.	
The VR maintenance is an immersive and effective way for training and remotely help maintenance crew.	
The scheduling service digests the analytics RUL prediction and schedules the maintenance accordingly, without interrupting the production.	

3.3 Lessons learned

The SERENA project has provided a deep dive into an almost complete IIoT platform, leveraging all the knowledge from all the partners involved, merging in the platform many competencies and technological solutions. The two main aspects of the project for COMAU are the container-based architecture and the analytics pipeline. Indeed, those are the two components that more have been leveraged internally, and which have inspired COMAU effort in developing the new versions of its IIoT offering portfolio. The predictive maintenance solutions, developed under the scope of the project, have confirmed the potential of that kind of solutions, confirming the expectations.

On the contrary, another takeaway was the central need for a huge amount of data, possibly labelled, containing at least the main behaviour of the machine. That limits the generic sense that predictive maintenance is made by general rules which can easily be applied to any kind of machine with impressive results.

More concretely, predictive maintenance and, in general, analytics pipelines have the potential to be disruptive in the industrial scenario but, on the other hand, it seems to be a process that will take some time before being widely used, made not by few all-embracing algorithms, but instead by many vertical ones and applicable to a restricted set of machines or use cases, thus the most relevant.

4 Conclusion

The SERENA project has started almost concurrently with the COMAU decision of making an IIoT, offering and a complete platform with compatible objectives and requirements with the SERENA ones. This project has thus allowed COMAU to share important knowledge with the project partners, as well as showing the effects of different design choices taken in the project and the COMAU solution.

From the architectural point of view, nowadays the COMAU product has been more than just inspired by the SERENA platform since it has completely embraced the micro-service and container-based approach. The same parallel approach and techniques mixture has been taken as well about the analytics components and, first, the knowledge developed about the robot transmission belt. Current COMAU development is currently focusing on extending that knowledge and procedures to address other robot mechanical problems (such as the backlash of the gearboxes) as well as extending the test-bed prediction model to be effective on the entire robot and its kinematics chain instead of just one isolated axis.

Unfortunately, not just from the business point of view but also from technical passion, automotive and in general automation are sectors where the main mantra is not to stop production for any reason, since it means huge losses in terms of production missed. Having said that, it leads to the fact that preventive maintenance is nowadays essential and not practical nor feasible proposing to substitute it with the only predictive one. Nevertheless, predictive maintenance potential benefits are so promising and business effective which has all the factors to become in the next future a real disruptive methodology. To sum up, likely the predictive maintenance will take some time before supplanting its preventive version, but use case by use case the first one will take more and more space, establishing itself as standard the facto, supported as well by continuous improvements in the field of data science and artificial intelligence.