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CLOUD BASED MAINTENANCE IIOT PLATFORM FOR SMART MANUFACTURING

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Abstract: *The main objective of CM4SMART project was to perform research, development, simulation and production implementation of a smart manufacturing maintenance solution based on cloud technologies. The result of the project will enable digital transformation of the production in the direction of smart maintenance and new data driven production efficiency models for the SME sector. Following the key Industry 4.0 design principles, the project has succeeded to interconnect business level software systems with operational data from the field thus aligning production schedules with maintenance activities. Innovative machine learning algorithms for predictive maintenance analyses data and propose both preventive and optimization actions before machine failures take place thus aiming at zero downtime, zero defected manufacturing and a greener enterprise.*

Key words: *big data, digital factory, IIoT, Industry 4.0, cloud computing, smart maintenance.*

1. INTRODUCTION

Industry 4.0 introduces what has been called the *smart factory*, in which cyber-physical systems monitor the physical processes of the factory and make decentralized decisions. The physical systems become Internet of Things, communicating and cooperating both with each other and with humans in real time via the wireless web. Industry 4.0 (the automation revolution) is the term used in the modern manufacturing world to denote the fourth industrial revolution, characterized by the widespread use of cyber-physical systems [1].

For a factory or system to be considered in Industry 4.0, it must include interoperability (machines, devices, sensors and people that connect and communicate with each other), information transparency (the systems create a virtual copy of the physical world through sensor data in order to contextualize information), technical assistance (both the ability of the systems to support humans in making decisions and solving problems and the ability to assist humans with tasks that are too difficult or unsafe for humans), decentralized decision-making (the ability of cyber-physical systems to make simple decisions on their own and become as autonomous as possible) [2].

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2. INFORMATION

The aim of the project was to develop a smart maintenance concept for the production enterprise that was implemented through an advanced predictive and preventive maintenance software system. This was achieved through utilizing the cutting edge technology available in Microsoft Azure Machine Learning combined with best software industry practices and Industrial IoT innovation. CM4SMART project specific goals are to improve productivity and resource utilization, reduce unplanned breakdowns and failures, reduce scrap and rework, save consumables, root cause analysis on failure or productivity, objective and immediate assessment with KPIs.

Figure 1 shows a data flow diagram, basically an overview image of the whole system and processes that where developed within the project. First layer (from the bottom to top) it represents the source of data and is located at the manufacturer (the factory where will be implemented the solution). The greatest challenge encountered was due to the fact that the platform was built with flexibility in mind and the cloud gateway adapters must understand the required protocols in order to successfully communicate data with machines. The types of machines from the pilot environments at HTS Maskinteknikk and ICPE were Mazak with Mazatrol controller, Fanuc Robot with Fanuc, Nakamura Tome with Fanuc, Hermle with Heidenhain, Dmg Mori with Heidenhain, Fanuc Robot with Siemens and OPCUA, Dmg Mori with Sinumerik and OPCUA [3].

The second layer it represents the cloud platform backend [4] that comprises hardware and storage and are located on remote servers. At this layer accessible

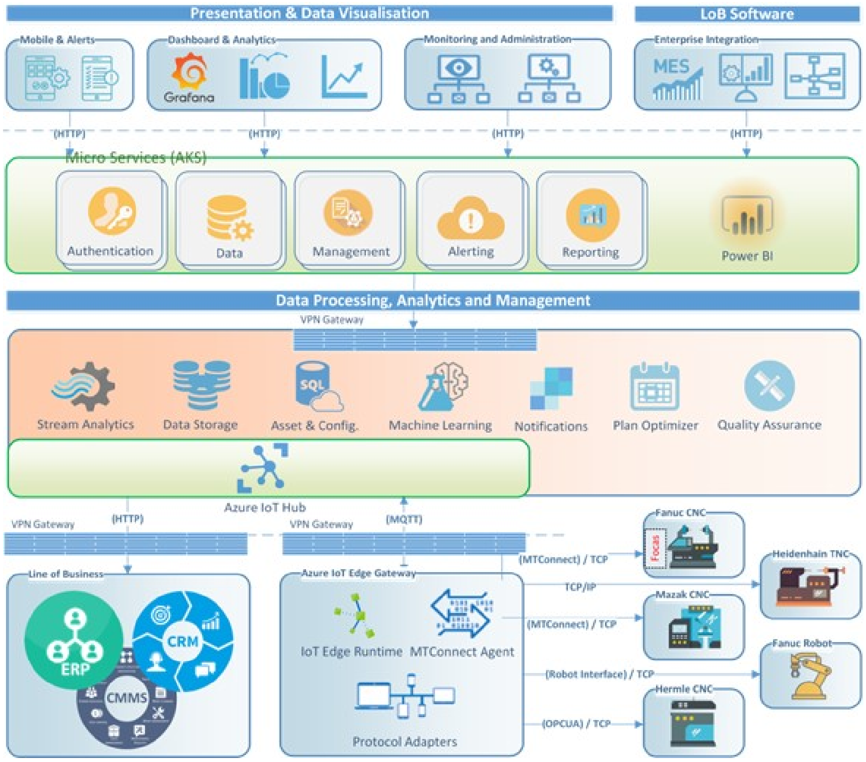

Fig. 1. CM4SMART data flow diagram.

through Azure IoT Edge gateway there are powerful applications such as Azure Machine Learning [5] (a cloud-based environment that can be used to train, deploy, automate, manage, and track ML model), Azure Stream Analytics [6] (complex event processing engine by Microsoft that enables users to develop and run real-time analytics on multiple streams of data from sources such as devices, sensors, web sites, social media, and other applications).

Access to that applications is made via PaaS (Platform as a service) which offers a complete development and deployment environment in the cloud, with resources that enable the user to deliver everything from simple cloud-based apps to sophisticated, cloud-enabled enterprise applications. The resources that are needed are purchased from the cloud service provider on a pay-as-you-go basis and can be accessed over a secure Internet connection.

The third layer shows microservices application deployed to Azure Kubernetes Service (AKS) [7]. Modern applications are increasingly built using containers, which are microservices packaged with their dependencies and configurations. Kubernetes is open-source software for deploying and managing those containers at scale. Kubernetes help to build, deliver, and scale containerized applications faster.

The forth layer is related with presentation and data visualization. Grafana [8] is one of the popular and leading open source tools for visualizing time series metrics. It was used to monitor Azure services and applications by leveraging the Azure Monitor data source plugin, built by Grafana Labs. This plugin enables to include all metrics from Azure Monitor and Application Insights in Grafana dashboards.

In relation to integration with software systems, data was successfully ingested through the Azure Edge Gateway from the SAP B1 ERP [9] at HTS Maskinteknikk and from the tailor made Microsoft Access based planning system at ICPE.

Within the project a cloud platform based on Azure PaaS [10] was created, which utilizes services like Azure IoT Edge, IoT Hub, Functions, Service Bus, Resource Manager, API Management, Logic Apps, Azure SQL, Azure Compute and Microsoft Power BI. Some open source tools and applications like InfluxDB and Grafana have also a key place in the architecture respectively for time-series data storage and visualization. Grafana was the selected customizable frontend for interactive and flexible dashboards. Features demonstrated include: status chart, downtime tagging input, gauges for productivity, workload and performance, line charts showing the fluctuations of a given machine parameter, tables with summary data of KPIs etc.

3. METHODS USED

The developed solution was implemented at two manufacturing facilities ICPE (Romania) and HTS Maskinteknikk (Norway). At HTS Maskinteknikk data from 5 cnc machines, 2 robots and one internal system of sensors were collected and at ICPE data from two cnc machines (Emco Maxxturn 65 [11] – Fig. 2,*a* and DMG Mori CMX600V [12] – Fig. 2,*b*, and an internal system of sensors were collected.

To achieve these objectives and connect the enlisted machines, 3rd party libraries for low-level communication to machines was used. As a result, Fanuc FOCAS library was obtained to connect to Fanuc

a b

Fig. 2. ICPE's CNC machines from pilot experimental model:
a – Emco Maxxturn 65; *b* – Dmg Mori CMX600V.

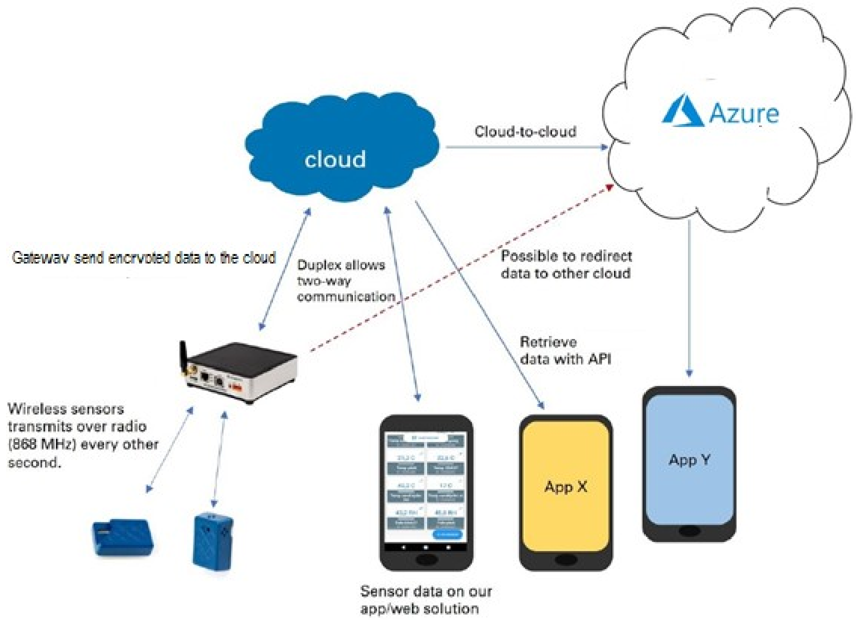

Fig. 3. Sensors data flow diagram.

machine controllers, Fanuc Robot Interface for connection to robots, open source OPCUA client library, open source MTConnect agent, a Heidenhain driver by Inventcom, RPC Sinumerik controller interface. This low level communication with the machines allows access to data from sensors that already equip the machines (ICPE's last generation DMG Mori belonging to CMX series is a high precision, high accuracy vertical milling center.

Also, during project implementation external sensors were mounted on machines in the environments – both for retrofitting older machines to which it cannot be established a communication way and to new ones, which do not provide required information, which may be useful to achieve project objectives (i.e. in-room temperature, temperature of cutting fluid, power consumption, vibration of specific equipment that are part of the machine (e.g. cooling system pump)).

ICPE identified a commercially available solution [15], an industrial grade IoT wireless predictive maintenance sensor that is equipped with 3 probes (an AC current range up to 100A RMS measurement probe, a 3-axis vibration probe with RMS, MAX and MIN and a thermocouple probe) having as a major advantage the capability to communicate data using its wireless mesh sensor network and the integration with Microsoft Azure using a dedicated micro gateway that reports all incoming IoT sensor telemetry as real-world values through the connected Device Twin, and/or Device to Cloud Messages. Other two commercially available monitoring solution was tested during project implementation in order to test their functionality and integration with the Microsoft Azure. All selected sensors from different manufacturers transmit data over radio (868 MHz) to a gateway that send encrypted data to the cloud (Fig. 3).

This option offers better penetration through walls, buildings, trees, and industrial equipment than 2.4GHz. The official line of site rating for 868 MHz transmission is 14.5 km using 2.1 dBi antennas.

All sensor additionally mounted are monitoring critical system area. As a general rule, the added sensor must have a noninvasive installation setup.

Figure 4 shows an indicative heat flow sensor, used for surveillance and alarms. It is simply mounted on the outside of the pipe (clamped-on outside pipes). The built-in data-logger and wireless radio makes it very easy to The built-in data-logger and wireless radio makes it very

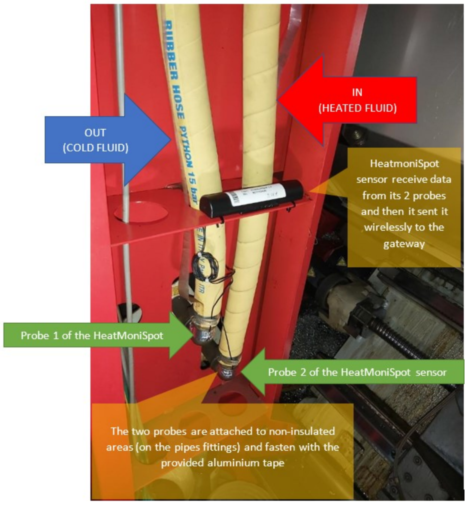

Fig. 4. Indicative heat flow sensor mounted in Emco Maxxturn 65 (cooling system).

Fig. 5. Indicative heat flow sensor mounted in Emco Maxxturn 65 (hydraulic system).

easy to install and setup for online monitoring. It measures pipe temperature values and gives an indication of heat flow he pipes of the main cooling system of Emco Maxxturn 65 machine.

Accurately measuring the refrigerant temperatures in a cooling system is of great importance in system diagnostics. Having inconsistent or incorrect temperature readings in the fluid and suction lines of an air conditioning system can lead to misdiagnosis and lower operating efficiencies. Cooling system problems and overheating can do a lot of damages and motor damages can occur on the first overheating situation. Failure of the cooling system of a CNC can have serious consequences on the machine and may require its immediate shutdown.

ICPE research team has considered that the hydraulic system is another critical system whose failure can lead obviously to downtime of the machine. Knowing what is the hydraulic system's normal operating temperature and rigorously collecting data was in the purpose of CM4SMART project. An indication of a possible malfunction can allow programming an intervention which, as far as possible not to interfere with the production schedule or this intervention have as few negative effects as possible. Figure 5 shows the probes of the sensor attached to the pipes of the hydraulic pump of Emco Maxxturn 65.

Fig. 6. Vibration sensor mounted on the cooling system pump.

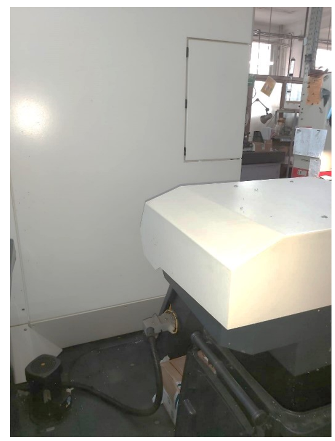

Fig. 7. Vibration monitoring of the emulsion pump (Dmg Mori CMX600V).

ICPE research team has considered appropriate, due to repeated failure situations, to monitor the vibration level of the cooling system pump of Emco Maxxturn 65.

Figure 6 shows the vibration probe of the industrial IoT wireless predictive maintenance sensor attached on the main body of the cooling pump.

Figure 7 shows the vibration and temperature probe that was attached to Dmg Mori CMX600V CNC on the main body of the emulsion pump. Cutting fluid system failure could also have serious consequences on the machine and may require its immediate shutdown.

4. RESULTS

Vibration monitoring has its roots in maintenance engineers inspecting machines during their traditional walk around. It attempts to formalize an instinctive understanding that a machine is vibrating unusual.

Time waveform is the raw data generally acquired by the analyzer and also plays a vital role in the analysis process. The amplitude units and the acceleration peak to peak values will be the initial focus for the analyst. The amplitude reflects the severity of the vibration against time domain. This is also known as the machine raw data, as it vibrates while running. The time waveform contains very important information. The time waveform data is the source that is used to generate the spectral data and trend data that are commonly used for fault detection [27].

Acquisition and subsequent processing of vibration data for rotating machinery fault diagnosis can be quite intricate; as data are usually required in three mutually perpendicular directions for accurate fault diagnosis. Several vibration monitoring approaches and data processing techniques for condition monitoring have been explored [28–30].

Figure 8 shows a sample of the recorded vibrations related to Dmg Mori CMX 600V. Based on the recommended vibration standards the equipment is in good condition, no action being required. Because they are new we do not have experimented during the project implementation abnormal behavior from any of the pilot machines but the recorded data is valuable because it will train the machine learning algorithm regarding witch are good or which are wrong vibrations.

Table 1 shows the recorded vibration data of the main body of the Dmg Mori CMX 600V and the body of the emulsion pump. The position no. 13 correspond to the highest peak that can be visualized on Fig. 8, 0.2 g, and witch indicate a normal operation of the machine.

On the online platform it could be manually entered threshold values based on recommended vibration standards. Some of them are as follows:

- 0.01 g or Less – Excellent condition, no action required;
- 0.35 g or less – Good Condition, no action required unless the machine is noisy or running at abnormal temperature;
- 0.5 g or less – Fair Condition, no action required unless the machine is noisy or running at abnormal temperature;
- 0.75 g or More – Rough Condition, possible action required if machine is noisy and also check the bearing temperature;
- 1 g or More – Very Rough Conditions, further analysis and see if its doing this continuously. Also check for noise and temperature;

Table 1

Recorded vibrations related to Dmg Mori CMX 600V

No.	Date, time	Vibration [g]
1	2020-11-11T09:41:42+02:00	0.071
2	2020-11-11T09:43:39+02:00	0.035
3	2020-11-11T09:45:36+02:00	0.035
4	2020-11-11T09:47:32+02:00	0.001
5	2020-11-11T09:49:29+02:00	0.008
6	2020-11-11T09:51:26+02:00	0.132
7	2020-11-11T09:53:23+02:00	0.022
8	2020-11-11T09:55:20+02:00	0
9	2020-11-11T09:57:16+02:00	0.002
10	2020-11-11T09:59:13+02:00	0.018
11	2020-11-11T10:01:10+02:00	0.057
12	2020-11-11T10:03:07+02:00	0.057
13	2020-11-11T10:05:04+02:00	0.221
14	2020-11-11T10:07:00+02:00	0.021
15	2020-11-11T10:08:57+02:00	0.011
16	2020-11-11T10:10:54+02:00	0.08
17	2020-11-11T10:12:51+02:00	0.023
18	2020-11-11T10:14:48+02:00	0.043
19	2020-11-11T10:16:44+02:00	0.005
20	2020-11-11T10:18:41+02:00	0.011
21	2020-11-11T10:20:38+02:00	0.057
22	2020-11-11T10:22:35+02:00	0.011
23	2020-11-11T10:24:32+02:00	0.08
24	2020-11-11T10:26:29+02:00	0.036
25	2020-11-11T10:28:25+02:00	0.007
26	2020-11-11T10:30:22+02:00	0.056

- 1.5 g or More – Danger Level, there is definitely a problem in the machine or installation. Also check the temperature Log;
- 2.5 g or More – Shutdown the Machine and look for possible causes. Strong recommendation to call a technician for immediate repair [34].

ISO 10816 establishes the general conditions and procedures for measurement and evaluation of vibrations from the non-rotating parts of machines [35]. Standards provide guidance for machines operating in the 10 Hz to 200 Hz (600 RPM to 12,000 RPM) frequency range. Examples of these types of machines are small, direct-coupled, electric motors and pumps, production motors,

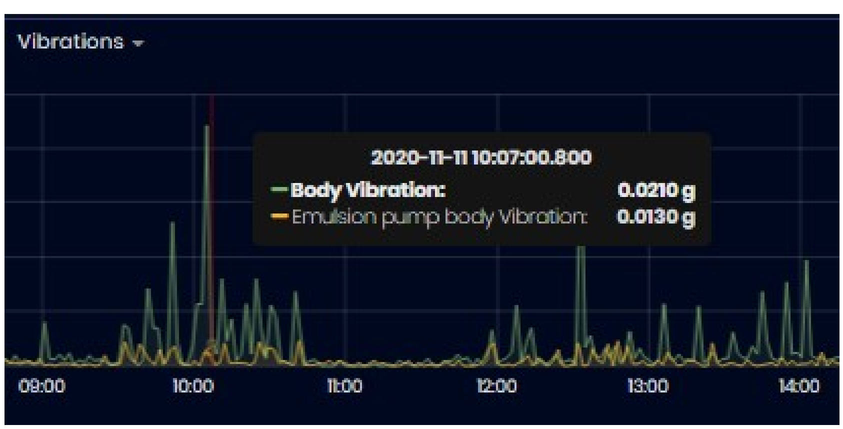

Fig. 8. Vibration monitoring of the emulsion pump (Dmg Mori CMX600V) and machine main body.

medium motors, generators, steam and gas turbines, turbo-compressors, turbo-pumps and fans. ISO 10816-3 defines four groups of machines, ranked according to size, base and purpose. It separates the working conditions into four zones: zone A green: vibration values from machines just put into operation; zone B yellow: continuous operation without any restrictions; zone C orange: condition is acceptable only for a limited period of time; zone D red: dangerous vibration values - damage could occur at any time.

Also on the online platform, threshold values can be manually entered for other type of sensors (temperature, current, etc.)

5. FURTHER RESEARCH

In a future study the shift from experimental model scale to the scale of the most of ICPE factory's machines (which will include an augmented reality for maintenance approach based on an immersive mixed reality experience (e.g. HoloLens)) will be developed and a separate and dedicated article will present its findings.

6. CONCLUSIONS

The project combines deep IIoT technology understanding and project experience from the leading partner ICN Interconsult Norway, strong R&D capacity from NTNU (Norway) and practical knowledge and real manufacturing challenges coming from two production enterprises – ICPE (România) and HTS Maskinteknikk (Norway).

CM4SMART differentiates from its market competitors by implementing high level of predictive maintenance where equipment is measured continuously to assess the likelihood for it to fail in the near future and take actions to avoid consequences of failures and that integrate also the proactive maintenance approach that concentrates on monitoring and correction of the root cause for equipment failures, self-learning surveillance solution as a service delivered at a reasonable cost that is targeting explicitly small and medium enterprises.

The scalability of the developed solution is a strong advantage that is in line with the Industry 4.0 concept. When fully applied on all levels, Industry 4.0 creates autonomous factory networks that can implement physical tasks and instantly correct imperfections without (or with a minimum involvement) the involvement of human hands or minds.

By utilizing the predictive and preventive maintenance functionalities enterprises will be able to improve production planning schedules and machine utilization by implementing proactive corrective and preventive maintenance activities, reduce the unplanned breakdowns in production, caused by unpredictable machine failure, produce correct parts first time (reduced scrap), extend machine and cutting tools life, save on water, lubrication, energy and other production materials consumption by implementing smart quality measurement algorithms.

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