ISBN: 978-3-95450-238-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2023-TUMBCM039

ENHANCED MAINTENANCE AND AVAILABILITY OF HANDLING EQUIPMENT USING IIoT TECHNOLOGIES

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Abstract

CERN currently houses 6000 handling equipment units categorized into 40 different families, such as electric overhead travelling cranes (EOT), hoists, trucks, and forklifts. These assets are spread throughout the CERN campus, on the surface (indoor and outdoor), as well as in underground tunnels and experimental caverns. Partial access to some areas, a large area to cover, thousands of units, radiation, and diverse needs among handling equipment makes maintenance a cumbersome task.

Without automatic monitoring solutions, the handling engineering team must conduct periodic on-site inspections to identify equipment in need of regulatory maintenance, leading to unnecessary inspections in hard-to-reach environments for underused equipment but also reliability risks for overused equipment between two technical visits. To overcome these challenges, a remote monitoring solution was introduced to extend the equipment lifetime and perform optimal maintenance.

This paper describes the implementation of a remote monitoring solution integrating IIoT (Industrial Internet of Things) technologies with the existing CERN control infrastructure and frameworks for control systems (UNICOS and WinCC OA). At the present time, over 600 handling equipment units are being monitored successfully and this number will grow thanks to the scalability this solution offers.

INTRODUCTION

The Handling Engineering (HE) group plays a crucial role in ensuring the efficient handling and transport of equipment and materials at CERN, which are subject to regulatory constraints regarding maintenance, from equipment with unconventional shapes to extremely delicate detector parts. Their responsibilities include designing, and conducting feasibility studies related to transport and handling operations, as well as procuring, installing, and commissioning standard and custom-built equipment. The group also manages and maintains all industrial transport, handling, and lifting equipment to ensure optimal performance throughout its life cycle. This includes the purchase, installation, and maintenance of thousands of equipment such as lifts, cranes, forklifts, and custom-made transport machines. In this context, the HE group requires modern tools to streamline their tasks, reducing equipment downtime and maintenance expenses.

The handling equipment assets to be monitored and maintained are scattered across the CERN sites. These extends over a vast area, spanning across France and Switzerland with both surface and underground areas.

An optimal solution requires a system capable of efficiently acquiring geographically widespread data while minimizing installation costs and making the most of CERN's existing infrastructure, including communication networks, data acquisition and monitoring systems, and computerized asset management systems. Consequently, the desired characteristics for the final solution include interoperability and synergy with existing systems. A new system to manage handling equipment also needs to cope with a large variety of machinery that will be enhanced by a set of smart sensors to measure relevant data.

Hence, the adoption of a combination of IIoT (Industrial Internet of Things) technologies, industrial automation technologies, and computerized maintenance software suites appears to be the appropriate approach.

HANDLING EQUIPMENT SCOPE

The HE group identified two principal areas where introducing the previously mentioned technologies would prove advantageous for their tasks.

The first area concerns overhead lifting equipment, including EOT (Electric Overhead Traveling) cranes and hoists. An analysis made in 2020 concluded that important savings on preventive maintenance could be done by changing the actual strategy based on a fixed periodicity to a strategy based on the usage of each crane. To be able to implement such change, the usage of each crane has to be known and remotely communicated on a daily basis. Thus, the HE group aimed to cut down on maintenance costs and prevent equipment maintenance periods from impacting the runtime of installations like the LHC accelerator. Their approach involved monitoring both the number of lifts (i.e., how often the equipment is in motion) and the total working hours. Given that cranes and hoists require maintenance every 30 hours of operation, they proposed implementing an automatic system to trigger maintenance orders accordingly. Depending on the level of operational priority of the cranes, EN-HE has been scheduling preventative maintenance every 6 months or 1 year, harmonizing the CERN Safety Rule GSI-M-1 prescriptions and the recommendations of a multitude of manufacturers. This is confirmed and benchmarked with the industry, where usage-based maintenance is starting to be the standard in terms of good practice. With this method, maintenance teams would carry out maintenance only on assets that genuinely required it, rather than adhering to a fixed periodic maintenance schedule regardless of the crane's actual usage. Additionally, administrators would be able to identify assets that are either overused or underused compared to the average, allowing for better anticipation of when a crane should be replaced.

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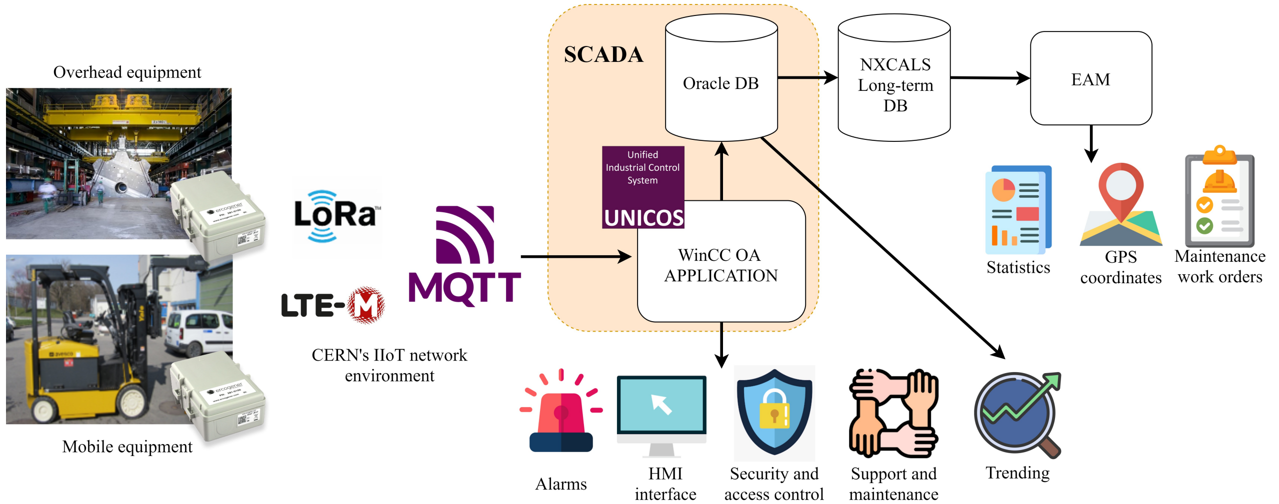

Figure 1: Technical solution overview.

The second area of focus was mobile lifting equipment, specifically forklifts and lifting platforms. For this category of equipment, precise asset management required the ability to locate these assets accurately. Prior to this development, technicians often spent a considerable amount of time searching for the location of these assets due to the absence of available information. To address this challenge, a user interface was suggested to help technicians pinpoint the precise geographical location of these assets across the CERN campus by tracking their coordinates. This approach would enable operators to prepare more efficiently for interventions.

TECHNICAL SOLUTION

In this section, a detailed description of all the components that compose the new system is provided. Figure 1 depicts these components.

Communications Infrastructure

CERN users have been connecting all kind of devices for several years via Ethernet, Wi-Fi, cellular networks or even home-made solutions. However, they were lacking the capabilities of LPWAN (Low-Power Wide-Area Network) networks to easily deploy battery-powered sensors at any location and at an affordable price. LoRaWAN was chosen because of its maturity, good radio and capacity properties, availability of devices and chips, backend features and its facility of integration with other services [1].

CERN's IoT infrastructure consists of the gateways deployed throughout the campus, the servers that allow to manage IIoT applications (add, delete and modify connected devices) and communication mechanisms such as Kafka (a distributed data streaming technology) and MQTT (Message Queuing Telemetry Transport) brokers facilitating efficient and reliable communication.

In this project, the LoRaWAN infrastructure was chosen for surface communications because the assets to be dealt with do not require the transmission of large or frequent data packets. While its performance in indoors environments is limited, future plans involve the deployment of LoRaWAN gateways underground at CERN, ultimately leading to a homogeneous solution for all upcoming IoT projects. Given the absence of LoRa coverage during the study period, LTE-M emerged as the preferred alternative for underground areas. LTE-M, a cellular network dedicated to the IoT, offers a higher data throughput compared to LoRa. Its selection primarily stemmed from the necessity for reliable underground communication. However, it's worth noting that LTE-M devices entail a monthly fee, which adds an additional cost to the project. LTE-M devices transmit data directly through the MQTT protocol, whereas LoRa frames are received by LoRa gateways and subsequently routed to the MQTT broker.

MQTT brokers offer a lightweight and efficient messaging solution for IoT, allowing for reliable, scalable, and secure communication while minimizing resource consumption.

End Devices

To identify the suitable set of IoT devices that align with the project's requirements, a market study was conducted. The chosen set of devices run on a 6Ah lithium battery and are IP67 rated (Fig. 2). Overhead surface assets were equipped with devices based on LoRa technology, while underground assets were outfitted with devices based on LTE-M technology.

These devices were seamlessly integrated by connecting their inputs to an auxiliary contactor, enabling precise recording of working hours and the number of completed lifts. Furthermore, for tracking mobile handling equipment, LoRa-based devices were employed alongside GPS trackers, facilitating near real-time location updates. The device payload was transmitted via MQTT topics, allowing the data to be forwarded to the control system that subscribes to. Additionally, the device only transmits data when the asset is in motion, which leads to substantial power savings.

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Figure 2: IoT device.

Acquisition, Operation and Monitoring Layer

Once the assets are equipped with IoT devices and connected to the CERN communication infrastructure, a system capable of acquiring, archiving, and displaying the data becomes essential. This system should possess trending and alarming capabilities and, in the case of mobile access, location-based synoptics. Fortunately, these functionalities align closely with the existing industrial control tools available at CERN [2].

WinCC OA, a commercial product supplied by SIEMENS, serves as the standard SCADA (Supervisory Control and Data Acquisition) suite at CERN. Data is archived in an Oracle Database. Moreover, a standard control systems framework is already deployed in other installations at CERN, such as cryogenics, gas, and electricity. This standard is called UNICOS [3], the Unified Industrial Control System. Figure 3 depicts a classic HMI (Human Machine Interface) of UNICOS with an operational faceplate allowing operation and diagnostics.

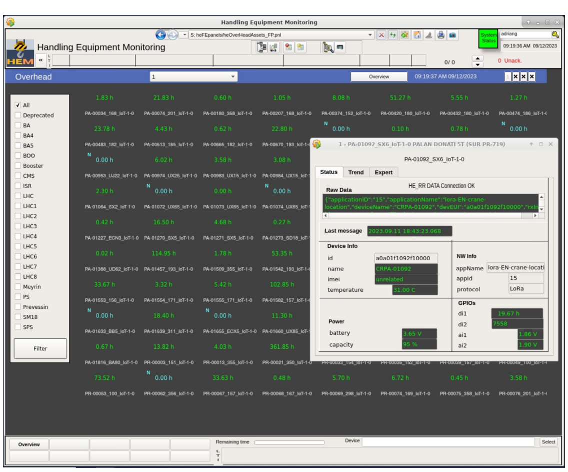

Figure 3: SCADA's HMI.

Striving to reduce cost and development time, the system design leverages existing tools and frameworks to create a cost-effective solution which will incorporate features as security, central alarming and long-term data archiving.

To successfully complete this project, several key development areas were identified, including the design of new software devices (corresponding to the new assets) to enable their operation and diagnostics. Additionally, a new communication front-end based on MQTT and geolocation capabilities was implemented to facilitate the tracking and visualization of assets on a geographical map.

Two use cases were covered concerning the integration of GPS coordinates within an interactive map. Through the integration of GPS coordinates within an interactive map assets could be visualized within a so-called geofenced zone (Fig. 4), with the possibility to know which assets are available within a given geographical area.

Figure 4: Geofencing.

Tracking of assets is achieved by applying time range filters to display the path the asset has travelled over a given period of time. From this one can see where, and how often, the asset has been used helping to perform asset management (Fig. 5). An HMI was customized to embed virtual devices and maps within navigation panels with which clients and operator could interact.

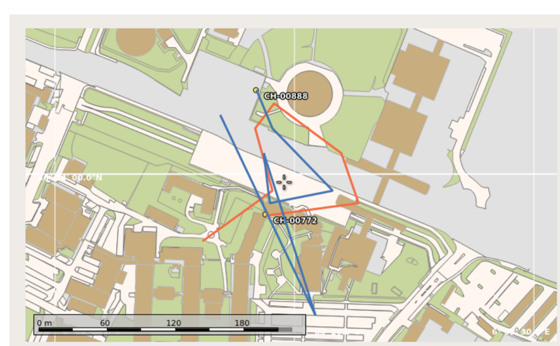

Figure 5: Asset tracking by time-range filtering over the CERN campus.

After the development phase was completed, validation tests were conducted to ensure the proper functioning of the application and IoT devices, including both overhead and mobile equipment. These tests also verified interaction with

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third-party software. Following successful validation, an application was deployed on a high-availability production machine, which receives central support and maintenance.

The final result is not only the design and development of the new system but also the enrichment of the UNICOS framework with MQTT communication capabilities via a new MQTT front-end. It manages the connection between the control application and the MQTT broker and ensures the right functioning of the system by running periodic checks and firing alarms to users in case a problem arises. The second enrichment is the capability of showing devices on CERN maps. All these are now available for other projects which uses the UNICOS framework.

Computerised Maintenance Management

Up to this point, with the described components in place, experts have the capability to interact with the system, visualize assets, receive alarms, and track trends on the devices. The subsequent phase is making the data accessible to a system designed to optimize maintenance operations.

At CERN there is a standard maintenance suite: Hexagon EAM (Enterprise Asset Management). It supports the implementation of preventive maintenance strategies to minimize unplanned downtime and extend asset life. It allows CERN users to create maintenance work orders and trigger maintenance tasks based on predefined criteria, such as usage, time intervals, or condition-based monitoring.

EAM maintenance database is fed with handling data from the SCADA application and its Oracle database, via the CERN long term archiving database NxCALS [4]. The mapping between NXCALS measures and EAM meters is done by a *SCADA-IIoT Bridge* provided by the EAM team at CERN. Each meter defined in an asset (e.g. EOT crane, hoist) will be mapped so EAM can generate the desired maintenance work orders (Fig. 6).

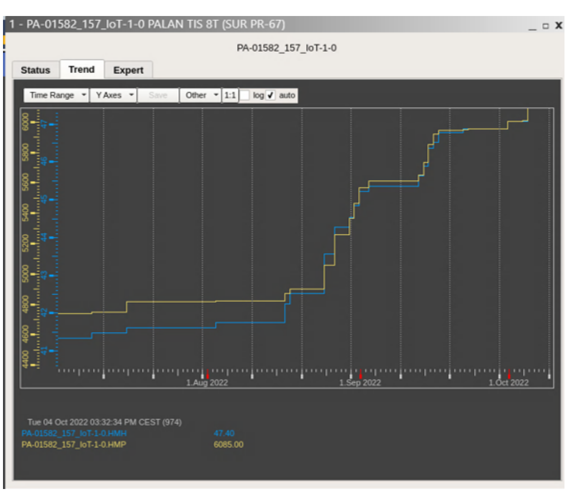

Figure 6: Working hours and number of lifts of a hoist during the validation phase.

DEPLOYMENT AND COVERAGE CONSIDERATIONS

The CERN IT department played a pivotal role in providing the necessary resources for data access and transmission. This included deployinga LoRaWAN gateways across the CERN campus, supplying SIM cards for sensors operating on GSM networks, technical support and providing the IoT network. Given CERN's extensive territory, comprising numerous buildings, warehouses, surface areas, and underground facilities that span both Switzerland and France, the deployment phase was instrumental in identifying regions with poor or nonexistent network coverage.

Where LoRaWAN sensors installations were not possible due to low coverage, LTE-M sensors were used. The devices exhibited a limited tolerance to electromagnetic disturbances, particularly because they operate within electric cabinets where electromagnetic noise can be substantial. Additional measures were taken to mitigate these challenges. This included shielding the cables and enhancing the installation process to the greatest extent possible to minimize the impact of electromagnetic interference.

CONCLUSIONS

With over 600 handling equipment units now being monitored and tracked, the project has proven to be a resounding success. The HE group can now precisely target overhead equipment that requires maintenance, and operators can easily locate mobile equipment for commissioning tasks. As of the completion of this paper, the project has been operational for more than a year. Based on the data collected during this time, a reduction in downtime has been observed, resulting in substantial savings on maintenance costs, amounting to several tens of thousands of Swiss Francs annually. The maintenance cost has been confirmed to be 70% less with respect to data from previous years. EOT cranes and hoists that are underused are no longer subject to maintenance unless they exceed 30 hours of operation, allowing the maintenance team to concentrate their efforts on heavily utilized cranes with higher load demands throughout the year. The time spent by operators in locating mobile equipment has been reduced, and operational tasks now require less time than before, further enhancing efficiency.

In terms of system and data processing, the two primary focus areas were reliability and the quality of processed data. The chosen approach for the project was to leverage existing services to meet these two essential criteria. The utilization of the existing SCADA-oriented framework added robustness and harnessed the inherent properties of industrial applications. This framework offered features such as data archiving, reporting, trending, alarms, troubleshooting, and the ability to seamlessly integrate with Enterprise Asset Management (EAM) software. The deployment of the system proceeded smoothly, and the established procedures for maintenance and support are straightforward, ensuring the system's reliability. This is because the knowledge and software generated have been fully assimilated by the framework

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and the engineers in charge of the development, contributing to the system's stability and longevity.

The IoT devices showcased several advantages, including cost-effectiveness, lower cost of installation due to their battery-powered nature, and compatibility with the existing Internet of Things network at CERN. The synergy of IoT sensors with the control system framework broadens the scope of UNICOS applications, introducing a new range of capabilities through the integration of modern products beyond PLCs (Programmable Logic Controllers) and traditional industrial components. This expansion diversifies the available solutions to cater to the requirements of forthcoming projects. As an illustrative example, the MQTT front-end that was designed has recently found application in the Science Gateway project at CERN, specifically in the context of an upcoming educational lab's control project. In this new project, once again, a SCADA application takes center stage, with the objective of creating a software-based control interface for monitoring and controlling telescopic robotic arms. This highlights the versatility and adaptability of the solution, demonstrating its re-usability across different projects and applications.

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