The development of CMMS platform incorporating condition monitoring tools in the advances of Industry 4.0

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Abstract

Computerized maintenance management software (CMMS) considered effective supporting tools to enhance the organisation and scheduling practices of maintenance tasks on manufacturing assets. Condition monitoring applications in the advances of Industry 4.0 applications enhances machines condition insight by utilising different sensing nodes to improve the optimisation of the scheduled maintenance tasks and support predictive maintenance applications. To overcome the disconnection between condition monitoring technology and CMMS software, the research presents a new generation of CMMS by integrating condition monitoring technologies with maintenance management functionalities under a single cloud-based platform. As an example, energy data from five-axis machine tools are included to show it is predictable and stable to be reliable for failures prediction applications.

1. Introduction

CMMS has increased in popularity amongst organisations(10) and currently is a common tool used within maintenance operations to schedule tasks and improve equipment availability. Alongside this increased use has come advances in sensors and Industry 4.0 applications(1) .Whilst many authors acknowledge the potential for these applications to improve diagnoses, scheduling of tasks and increases in equipment availability(1,10,6), there is little evidence of the integration of the two approaches. A potential reason for this may be the difficulty that systems and maintenance operatives have in interpreting signals from certain sensors attached to CNC machine tools[8] .As a result of this the authors have previously proposed that energy consumption may be used as an indicator of machine condition[8]. This research presents a cloud-based platform that integrates CMMS and Industry 4.0 enabled remote sensors to improve the functionality and efficacy of the maintenance function.

2. Literature review

It has been established that poorly maintained equipment is likely to consume more energy than equipment in better condition[5]. Whilst energy consumption can provide valuable intelligence regarding equipment condition, it is largely restricted to machines with a relatively stable duty cycle. Energy monitoring at machine level, in particular by Small to Medium Enterprises (SME) in the UK does not appear to be widespread and the adoption of I4.0 technologies is likewise poor. A recent survey by a sector body suggests that it is largely due to a misunderstanding of the advantages of I4.0[7]. In addition, Machining Centres have a number of factors that explain an increase in energy consumption that may not be linked to its primary function such as removing metal and much of the vibration analysis research has been aimed at the tooltip[2]. Ancillary equipment, such as coolant pumps and table motors could provide the necessary data to establish a link between higher or erratic energy consumption and machine condition. With the advent of Industry 4.0 sources of data that were previously disparate, such as vibration and temperature can be integrated with energy measurements using Industrial Internet of Things (IIoT) technologies. This can, in turn, be compared with data from Enterprise Resource Planning systems to allow for maintenance scheduling that is flexible and adaptive to production demands, equipment condition and efficiency. In order to make full use of these, a clear link to a CMMS is required.

Management of maintenance activities are considered a vital element of a successful maintenance practices within an organisation[3]. Different mechanisms exist to maintain such records and keep track of the maintenance activities carried out, scheduled tasks and failures records. Different mechanisms could be highlighted by using paper-based sheets, general purpose computerised spreadsheets, or tailored CMMS software. Each mode of use provides certain advantages that supports the company having improved insight and track record of machines maintenance and carried out activities. CMMS provide advantages in being targeted for maintenance activities, but they still suffer from certain drawbacks including limitation of key performance indicators (KPIs) and functionalities which companies can benefit from to improve their applications, the localisation of the software on certain computers to access or modify the required tasks and being isolated from the condition monitoring tools that might exists to provide actual insight of internal parts conditions. Such isolation forces the companies to utilise two different software, a CMMS and a condition monitoring software and carry out the migration of sensors data manually to the CMMS. such application compromises the validity of data and exhaust valuable time that could be spent to carry out more important tasks. The current research provides a unique platform that integrates CMMS applications with sensory data using the clouds to enable the accessibility of the data over the internet from any device with internet connection capability.

2.1 *Condition Based Maintenance (CBM)*

Advancements in technology using health indexes provided by sensory devices were developed to support improving the insight of machines internal components' conditions and performance(11).

CBM generally focuses on scheduling maintenance activities based on real-time collected data from the field using condition monitoring tools. CBM mainly eliminates the unnecessary maintenance tasks that could be scheduled to take place where the current state of the machine's measurements in real-time indicate it is unnecessary to carry out the planned maintenance tasks, which, in return, has a high impact on saving cost that is associated with spare-parts replacement labour costs and costs incurred due to machine stoppage(8).

Another main benefit for CBM is that it helps in reducing machine breakdown rates and downtime. CBM can provide a safety measure to warn the operators and stop the machine when it reaches certain predefined levels of vibration or noise parameters, for example, which in return, helps the maintenance team take the necessary precautions to avoid the machine's breakdown.

CBM is associated with three main aspects that are the central pillars in defining the necessary maintenance tasks and schedules[(2)].

1- Failure Diagnosis

2- Failure Prognosis

3- Maintenance Optimisation

Failure Diagnosis is the stage that associates the failure detection and the allocation of the irregular behaviour with identifying its cause and the related parts in the equipment.

Failure Prognosis is the prediction of the future state of the equipment and provides an estimation of the predicted failures times.

Maintenance Optimisation as a critical part of CBM and is related to establishing the connection between the expected failure times and maintenance schedule and determine the necessary types of maintenance to take place with each expected failure.

The opportunity to make use of large-scale implementations of embedded linked sensor technologies generating vast amounts of data is tantalising and well within the reach of most manufacturing organisations. Recent developments such as those from the Advanced Manufacturing Research Centre (AMRC) in Sheffield have demonstrated that capturing significant amounts of useful data is possible via a network of low-cost sensors linked through the Industrial Internet of Things (IIoT). Whilst Industry 4.0 cannot be boiled down to the use of linked sensors to provide data in a timely and intelligent fashion to assist managers in their decision making, it does provide a suitable and in many ways appropriate starting point for hard pressed manufacturing managers with a constant eye on costs. literature provides a useful review of available technologies[(15,5)]. Vibration analysis is used to diagnose both the seriousness and potential source of a problem. However, due to noise within the system one or more of several signal processing techniques may be employed to diagnose issues. However, due to the speed at which data may be acquired and analysed, it provides a very useful indicator of machine condition. A demonstration took place to show that it is possible to collect energy data and analyse these to infer machine condition and indeed to indicate where any problems may be about to create a breakdown[(10)]. The average power consumed during a specific time period was collected along with the peak power consumed during the same period. The output of these activities was used to create plots or traces shown in figure 1.

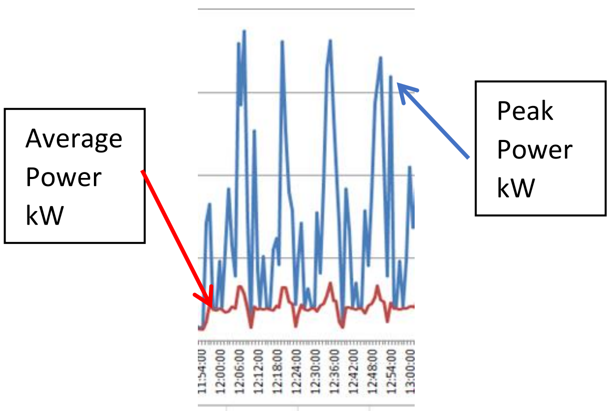

Figure 1. The energy consumption plots collected during a machining cycle

A typical repeating energy consumption pattern may be seen in figure 2.

Figure 2. Repeating pattern of energy consumption created by machining the same component

Furthermore, it was shown that the data were in statistical control allowing for inferences to be made from patterns and trends observed.

2.2 CMMS and CBM drawbacks

Major drawbacks with CMMS are the isolation from the actual machines condition and the entire reliability on the data records by staff. The programs do not have actual link between the machines to support decision making process. Even with the integration of CBM technologies, readings require collection, analysis and migration to the adopted CMMS program. The process compromises the data to being lost, wrongly migrated and causes losses in time. Another drawback of CBM using time-based interval for data collection is the possibility of higher deterioration level to the machines' components when applied on longer intervals.

2.3 Industry 4.0

A new paradigm developed to introduce advancements in technology to support the manufacturing industry**.** Industry 4.0 presents areas of interaction within the manufacturing process in different areas including the introduction of Cyber-Physical Systems (CPS), Industrial Internet of Things (IIoT), Big Data, Cybersecurity, Clouds and Additive manufacturing and Augmented Reality.

2.4 Industrial Internet of Things (IIoT)

IIoT technologies focuses on the connectivity between different devices and programs through the internet. Such advancements facilitated the introduction of Continuous monitoring applications to support machines condition monitoring. Continuous monitoring targets the fixation of different sensing nodes on machines' parts, streaming data continuously to a centralised system for data collection, analysis and visualisation. On the other hand, the technology enables the CMMS platforms to be accessible through the internet[14]. Such advancements eliminate the need for the presence and utilisation of single computing devices that host the programs and provides a continuous insight into machines condition remotely.

3. Developed platform

The current research presents a unique platform that utilises the advancements of Industry 4.0 to support maintenance practices. The developed platform tackles multiple issues that exists with the current CMMS and continuous monitoring programs including;

1- The isolation between the two platforms. The system integrates the sensory data collection, analysis and visualisation with alerting and maintenance tasks assignment for relevant engineers.
2- Online availability using the clouds for platform's data security and accessibility through the internet.

3.1 Platform features

The developed platform provides a range of functionalities to support the elimination of the barriers between IIoT technologies and CMMS applications. Features includes the following

3.1.1 IIoT technologies

In terms of products, there was a focus on the delivery of IIoT technologies for real-time machine monitoring and interaction aligned with an adequate management system that provides the necessary tools to deliver optimum advanced maintenance practices. From the IIoT side, a range of wireless sensory devices were developed to operate as performance indicators of key machines' parts. The wide range of sensors provided, ensures the compatibility and coverage of the different types of machinery and their different parts. Wireless sensory devices include the following;

1- Vibration monitoring sensor

Vibration is caused by imperfection in the machines that could be caused by

- Parts Misalignment
- Unbalance
- Worn belts & pulleys
- Bearing Defects
- Bent Shafts
- Rubbing

All the mentioned imperfections could be monitored by vibration monitoring tools, which could help in the early detection of failures before they take place. such applications could prevent failures from occurring and escalating to affect different machines parts and production quality.

2- **Temperature monitoring**

   Many failures are preceded by rising temperature, making temperature monitoring an extremely cost-effective, valuable diagnostic tools in many diverse applications. Components in various states of failure will emit more heat as a direct result of more energy dissipated into the component. This extra energy is caused by increased friction in mechanical devices, and higher resistance in electrical devices.

3- **Gas level sensors**

   Different sectors and ranges of production machinery generates certain level of exhaust gas due to the interactions with various materials. gas level monitoring provides an insight of the quality of ventilation systems that exists within the systems to improve surrounding air quality from toxic gas that could have major effect on workers and production quality.

4- **Power consumption sensor**

   Manufacturing machineries are designed to consume certain amount of power for operation. When consumption increases, it indicates certain parts are not functioning as expected and are applying more force to complete their intended tasks, which causes the extra use of power. Another utilisation of power consumption is the ability to indicate that the machine is operating.

5- **Maintenance call button**

   Machinery experience minor stoppages that could occur due to various reason. The research highlighted high waste level in waiting time for maintenance staff to attend to the required machines. Delays usually causes by difficulties to reach the required staff instantly on time to rectify the stoppages. A wireless button developed to be able to be installed on any machine. The button function as a call button that when pressed, a notification is sent to the assigned staff for immediate attendance. The developed system decreases the waiting time dramatically and increases machine’s availability.

The developed platform provides the necessary tools to interact between sensors reading and planned maintenance automatically without the interaction of the user. The system can have set points for each sensor, which when exceeded, the system generates a maintenance task automatically to the assigned member of staff.

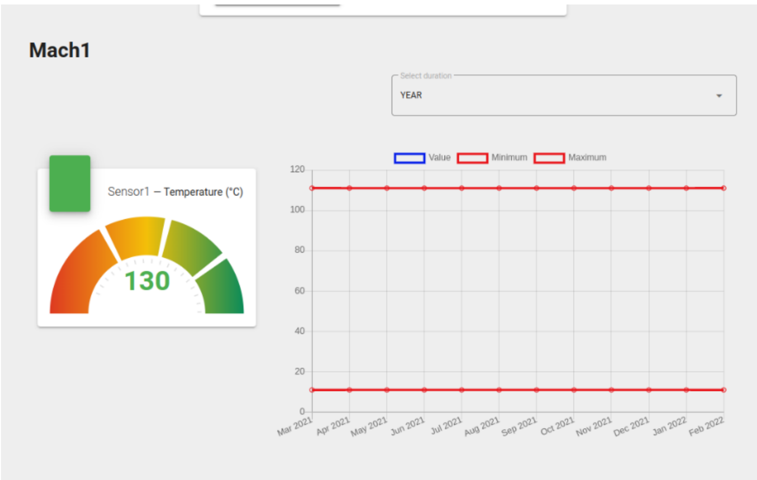

Figure 3. Real time temperature reading

3.1.2 Online management platform

From management aspect, the developed platform provides the necessary tools for adequate maintenance applications. the platform is designed to include different sites, facilities, machines, and submachines and provide visual tools to present the different sensory devices for different machines on a real-time basis. The system provides visualisation of historical data and the ability to extract the data required.

1- **Maintenance planning**

Planned maintenance is responsible of 70% reduction in machine failures through planned repeated simple tasks. The platform provides adequate maintenance planning mechanism with ability to assign repeatable tasks to individual users automatically. The system provides a monitoring tool of each users' performance and completion of their tasks on time.

2- **Failure recording and visualisation**

Failure recording in a timely and accurate manner is essential to monitor machines performance over time. This provides an insight into how the system reacts to an existing maintenance plan and what may need to be adjusted to increase their efficiency. The platform provides a user-friendly mechanism that allows users to report any failures that takes place on the machines.

3- Workorders management

Work orders management provides an organised mechanism for different work orders to carry out on different machines. the developed platform provides an insight of each user's performance and responding to work order with visual tools to monitor each user's performance and the state of their individual work orders.

4- Spare parts management

The platform provides a list of all the existing spare parts and their relation to each machine, with full details of their manufacturers, quantity, and cost. The system assigns a QR-code for each new part enters the system.

5- Cost analysis

The platform monitors the cost of labour, machine downtime and spare parts for each individual machine for better assessment of investment viability and how to adjust operations to reduce expenses. The system provides the necessary visual tools to evaluate and study the total cost of different maintenance aspects and their impact on the entire operation.

6- Reliability analytics and performance indicator

The platform provides different performance analytics derived from the existing advanced maintenance strategies, Total Productive Maintenance (TPM) and Reliability Centred Maintenance (RCM). The platform utilises the use of Overall equipment Effectiveness (OEE), for performance indication of the machines. Failure Mode Effect Analysis (FMEA), as one of the most effective tools to diagnose and study the different failures that could take place and their effect on the system. From RCM analysis the system provides Mean Time Between Failures (MTBF), Mean Time To Repair (MTTR), Mean Time To Failure (MTTF) analysis as a strong tool for maintenance optimisation and planning through the study of the machine performance against planned maintenance applications and the ratio of breakdowns and their intervals.

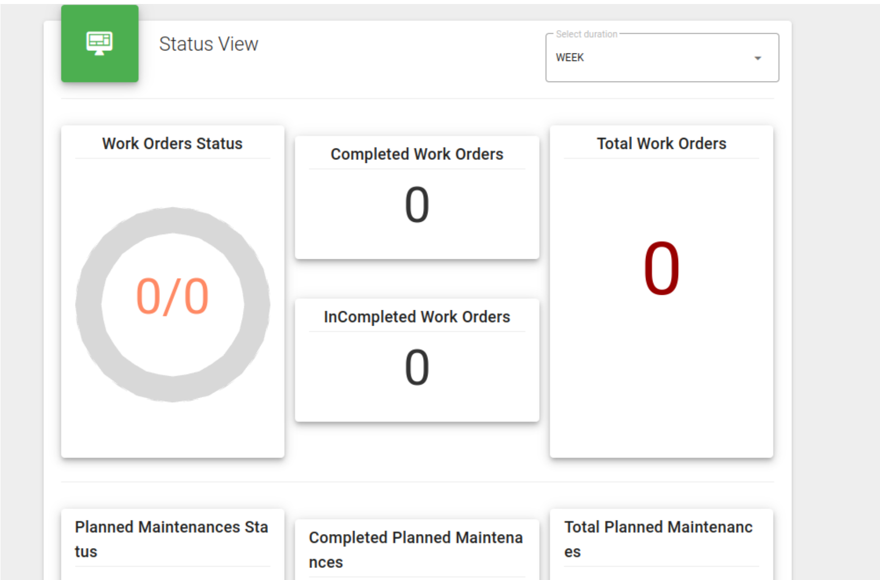

Figure 4. Management dashboard

4. Conclusion

Whilst such dashboards are not uncommon, they normally concentrate upon a single indicator or output from a single sensor to allow skilled operators to make inferences regarding the machine condition. This system and dashboard combine the outputs of multiple sensors to assist maintenance and production personnel to diagnose potential problems. It offers the potential of linking to AI learning algorithms to automate potential failure diagnosis before the failure occurs.

5. Reference list

1. Cakir, M., Guvenc, M.A. and Mistikoglu, S., 2021. The experimental application of popular machine learning algorithms on predictive maintenance and the design of IIoT based condition monitoring system. Computers & Industrial Engineering, 151, p.106948.

2. Bennane, A. and Yacout, S., 2012. LAD-CBM; new data processing tool for diagnosis and prognosis in condition-based maintenance. Journal of Intelligent Manufacturing, 23(2), pp.265-275.

3. Er P V, Teo C S, Tan K K (2016), Approach towards sensor placement, selection and fusion for real-time condition monitoring of precision machines, Mechanical Systems and Signal Processing 68 -69 (2016) 105 – 124.

4. Ghaleb, M., Taghipour, S. and Zolfagharinia, H., 2021. Real-time integrated production-scheduling and maintenance-planning in a flexible job shop with machine deterioration and condition-based maintenance. Journal of Manufacturing Systems, 61, pp.423-449.

5. Goyal D, Pabla B.S.,(2015), Condition based maintenance of machine tools – a review, CIRP Journal of Manufacturing Science and Technology 10 (2015) 24-35.

6. Knowles M, Baglee D (2012), The role of maintenance in energy saving in commercial refrigeration, Journal of quality in maintenance Vol 18, No 3.

7. Kan, C., Yang, H. and Kumara, S., 2018. Parallel computing and network analytics for fast Industrial Internet-of-Things (IIoT) machine information processing and condition monitoring. Journal of manufacturing systems, 46, pp.282-293.

8. Kenda, M., Klobcar, D. and Bracun, D., 2021. Condition based maintenance of the two-beam laser welding in high volume manufacturing of piezoelectric pressure sensor. Journal of Manufacturing Systems, 59, pp.117-126.

9. Manufacturing Ambitions: An industrial strategy for a stronger economy, EEF 2016.

10. Morris A, Baglee D, Knowles M (2020), Using energy consumption profiles as an indicator of equipment condition, International Journal of COMADEM, April 2020, Vol 23, No 2, pp 15 – 21.

11. Sharma, R., Sharma, R., Prabha, Y.B., Devi, S.R. and Saxena, P., 2021. Iot monitoring lathe machine performance. Materials Today: Proceedings.

12. Sharma, S.B. and Tewari, P.C., 2019. A general framework of computerized maintenance management system for an automobile industry. Int. Res. J. Eng. Technol, 6, pp.2087-2092.

13. Wang, Y., Li, X., Chen, J. and Liu, Y., 2022. A condition-based maintenance policy for multi-component systems subject to stochastic and economic dependencies. Reliability Engineering & System Safety, 219, p.108174.

14. Wan, S., Gao, J., Li, D., Tong, Y. and He, F., 2015. Web-based process planning for machine tool maintenance and services. Procedia CIRP, 38, pp.165-170.

15. Lu Y, (2017), Industry 4.0: A survey on technologies, applications and open research issues, Journal of Industrial Information Integration 6 (2017) 1-10.