eMaintenance Platform for Performing Data Fusion Mutation on Machine Tools

V. Simón[1], **D. Galar**[1] **and D. Baglee**[2]
[1]Division of Operation and Maintenance Engineering, Luleå University of Technology, Luleå, Sweden
[2] The Institute for Automotive & Manufacturing Advanced Practice, University of Sunderland, Sunderland , United Kingdom

Abstract - *Condition monitoring (CM) plays a relevant role in production systems, for example, with machine tools. To obtain an accurate result when analyzing the condition of a machine tool and its components, it is necessary to integrate data from different sources. The types of data include: internal data from the Computer Numerical Control (CNC), external sensors, and value-added information coming from the study of the system's behavior.*

Data from disparate sources can be integrated using several pre- and post-processing methods that provide partial or total results in different formats. The use of an eMaintenance platform seems a reasonable and easy solution when faced with a challenge of such dimensions. This paper proposes an architecture able to cope with the challenge.

Keywords: eMaintenance platform, Maintenance 4.0, data taxonomy, SOA, Web Services

1 Introduction

The application of preventative maintenance techniques is an appropriate strategy to reduce the impact of malfunctions or machine breakdowns on the productivity, cost and quality of production systems. More specifically, the deployment of intelligent predictive tools and technologies can help detect potential failures and provide a solution.

Condition Based Maintenance (CBM) activities can be based on data obtained from sensors on a machine. The subsequent analysis of these data helps to measure and understand the machine's performance. This approach facilitates the computation of indicators at the local level to monitor the machine's local health; in addition, the information can be sent to an eMaintenance platform for more detailed analysis.

It should be noted that there is no single definition of eMaintenance. The term eMaintenance emerged in the early 2000s and is now a common term in maintenance related literature. eMaintenance is sometimes [1] considered a maintenance strategy, a maintenance plan, or a maintenance support: "e-Maintenance is a multidisciplinary domain based on maintenance and information and communication technologies (ICT) ensuring that the e-Maintenance services are aligned with the needs and business objectives of both customers and suppliers during the whole product lifecycle" [2].

eMaintenance can also be considered a philosophy supporting the move from ''fail and fix'' maintenance practices, to ''predict and prevent'' strategies (proactive approach), maintenance as a process (holistic approach), and an integrated concept to optimize performance [3]. Some well-known eMaintenance platforms are ICAS-AME [4], PROTEUS [5], TELMA [6], CASIP and its up- graded version KASEM [7] or DYNAMITE [8]; a more thorough classification appears in [9].

The current analysis assesses the nowcasting of a machine in a preliminary attempt to achieve proactive condition monitoring using non-intrusive monitoring techniques, affordable in terms of cost and effectiveness. In the proposed approach, the health index of the machine can be computed from the results of the signature analysis and associated with the degradation modes of the various components (e.g. gears, missing teeth, etc.).

An original feature of the proposed approach is the use of a remote level, whereby data from several machines are sent to an eMaintenance platform able to store data from different machines. This enables fleet-level performance management and monitoring, across the fleet and over time.

The paper breaks down the proposed process by explaining the data transformation from the initial data collection and warehousing, to the final data management procedures.

2 Data collection

Condition monitoring methods such as vibration or acoustic monitoring usually require expensive sensors. Electrical Signature Analysis primary application includes the diagnostics of electrical machines. Several authors have applied this technique to detect induction motor failures [10]. Others [11] have detected other failures using the induction motor current signature analysis. The controlled values, for example, of a gearbox failure, can be compared in the stator current spectrum, because diverse picks are related to shaft and gear speed. Characteristic gearbox frequencies can be detected in the stator current spectrum. Current-based diagnosis of mechanical faults such as unbalance and misalignment can be performed in the same way.

2.1 From testing to data collection

Good maintenance policies lead to less energy consumption by assets, as stated by [12]. However, the relationship between an electric signal and wear for any complex electro-mechanical system, for instance, a machine-tool spindle, is less evident. The potential correlation has to be learned based on experimental research. The use of test benches allows us to identify a machine´s operating condition, to analyze and describe its various failure modes, to pinpoint the most significant signal to be used in tests for failure, and to design and execute a test plan for fault detection and prognosis.

Laboratory research gives us the ability to run components to failure, working in a controlled failure environment. This helps us relate current and power signal analysis to the selection of features for failure diagnosis.

To achieve statistical consistency, during the first phase of testing, failure diagnosis, various faults should be tested along with the nominal one [13].

A local CBM module may consist of two main components based on Condition Monitoring (CM) techniques: first, the fingerprint to be used for the health assessment of the critical elements of the machine and second, operational data to infer the use of the machine.

A health monitoring system helps avoid component defects; consequently, it can prevent poor performance or even breakdowns. As an example of component defects, spindle defects include bearing damage, defects in rotary transmission, clamping malfunction, imbalance, stator error or alignment error. Operational data (i.e. feed, speed) can be used for energy and reliability management. An example is the different usage ratios of the machine: loads, speeds, etc. Note that the collection of operational data (real- and non-real-time) and fingerprint collection do not need to be performed simultaneously.

A fingerprint executed on a periodic basis (weekly, monthly etc...) generates raw data. These data are integrated with available inputs from the operational data to give information on the usage of the machine. These mixed data are pre-processed to obtain a set of relevant features that will be further analyzed for the nowcasting process. In parallel, data obtained from the machine are pre-processed to register the usage of the machine. The three main components of this process are operational data, fingerprints, and health assessments (the latter belongs to data management).

2.1.1 Monitoring working conditions (operational data)

Determining the usage of the machine by the end user yields a more holistic understanding of the real status of a machine's critical components. The historical use of the machine is found in the operational data. The main reason to collect operational data is to determine the operating environment of the machine with the purpose of finding possible reasons for malfunction or failure and optimizing reliability through the proper selection of component or machining parameters. Depending on the already installed or optional sensors, the solution may vary, but in any case, the required data rate should not be high (tens of Hertz). In modern Computer Numerical Control (CNC) systems, several configurations are available: sensors can be connected to the CNC or digital drive system or to a specialized hardware (for accelerometers or main power monitoring). In any case, there are two options to obtain operational data from the machine. The first is dialoguing with the CNC using specific hardware; this facilitates higher acquisition speed and detailed data, enabling some pre-processing. The second procedure implies the use of CNC internal data accessible through different links, like OPC servers, libraries, etc.; this limits the information available on how the machine is being used to showing only its acquisition rate.

Some processing is done to extract all the information from the data, using it to build a historical register of the use of the machine and obtain the data required for further service implementation.

Co-relating operational data and machine condition data using the correct algorithms can guide component maintenance, help to change working conditions to extend component life or even to select a different component, more appropriate for the real machine use.

2.1.2 Machine fingerprint

The term fingerprint has been coined to denote the electrical signature of a machine in a specific time domain.

To obtain the main fingerprint features, machines are run in a pre-defined test cycle in no-load condition to achieve better failure detection and to remove any noise that could affect the normal machine process load. Condition monitoring data are based on the fingerprints obtained from the machine. In the first stage, data analyzed during the experimentation phase may help in the selection of the type of sensors, acquisition rates and tests to be performed on the machine in the production plant. The idea behind the fingerprint is that any load and speed variation within an electro-mechanical system produces correlated variations in current and voltage. The resulting time and frequency signatures reflect loads, stresses, and wear throughout the system, but identifying them requires a mapping process or pattern recognition. Comparing the electric signature of equipment in good condition and equipment under monitoring supports fault identification. Note that Signature Analysis is only applicable to cases where the principal cause-effect is verified and modeled.

3 Data taxonomy

3.1 Asset technical information

Asset data should be collected in an organized and structured way. The two major data categories for equipment are: classification data, including system, location, plant and industry; and equipment attributes as technical features or design characteristics. These data categories are common to all equipment classes, although some specific data for a specific equipment class (e.g. number of stages for a compressor) could be needed.

Finally, the classification of equipment into technical, operational, safety related and environmental parameters is the basis for the collection of asset data, given the different nature of different devices. This information is also necessary to determine if the data are suitable or valid for various applications. Some data are common to all equipment classes, and some data are specific to a particular equipment class.

3.2 Events

Fingerprint trajectory tracking provides a solid study of the evolution of machine components [14]. This evolution, along with context mapping and past situation-based feedback, causes various triggers that define different events. The appropriate maintenance policy is selected based on the appearance of certain events.

3.3 Maintenance policies

Maintenance information includes unit life plans, job cataloguing, etc. for each unit in two different categories: preventive and corrective maintenance. These data are characterized by their identification (record numbers), by the parameters characterizing them (category, activities involved, impact, date), by the resources that imply their deployment (man/hours, equipment), and by outputs in terms of active maintenance time and downtime.

Recording maintenance actions is crucial for successful knowledge extraction at some later date. Preventive maintenance (PM) records are mainly useful for the maintenance engineer to estimate equipment availability; lifetime analysis is not only based on failures, but also on maintenance actions intended to restore the failed item to "as-good-as-new" condition. During the execution of preventive actions, impending failures may be discovered and corrected as part of the preventive activities.

A final option is to record the planned PM program as well. In this case, it is possible to record the differences between the planned and the actual performed preventive maintenance (i.e., the backlog). An increasing backlog will be an indication that the control of the conditions of the plant is jeopardized, possibly leading to equipment damage, pollution or personnel injury.

For corrective maintenance, failure records are especially relevant to knowledge extraction; therefore, failure data should be recorded in such a way as to allow further computation. A uniform definition of failure and a method of classifying failures are both essential when data from different sources (plants and operators) need to be fused in a common maintenance database.

Finally the combination of plant inventory and maintenance based information produces a maintenance schedule which is a mixture of available techniques to meet constraints and achieve company goals. This mixture is usually composed of scheduled maintenance and CM to perform CBM.

The maintenance schedule includes preventive maintenance jobs (over a year and longer) listed against each of the units in the life plans. The CM schedule is a schedule of the condition monitoring tasks listed against each of the units in the life plans.

The system must plan and schedule preventive jobs (arising from the maintenance schedule), corrective jobs (of all priorities) and, where necessary, modification jobs. Information coming back from the work orders (and other documents) is used to update the planning system; this provides information useful for maintenance control [15].

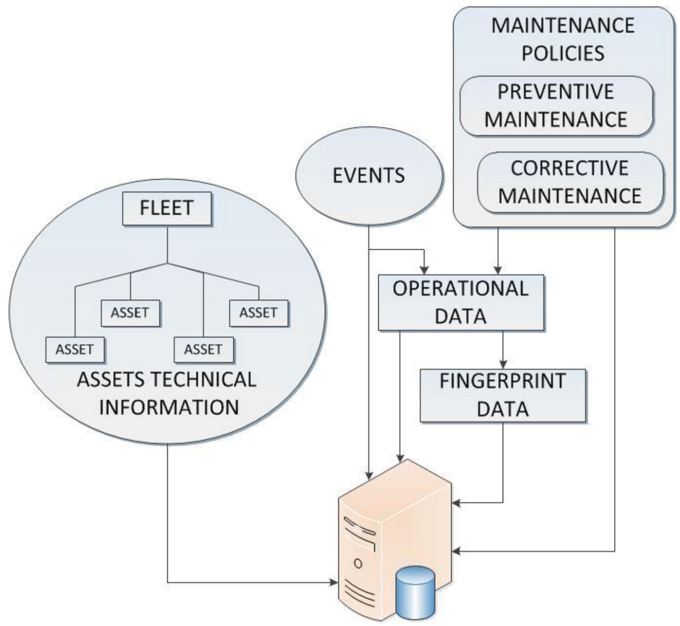

Figure 1 Inputs for the database

4 Data warehousing

4.1 Local module

As mentioned, data must be stored, because continuous connectivity is not assured. It is crucial to find a structured way to save the data; having the data in an organized state facilitates better treatment and sharing. An important issue is the limited storing capacities of some devices, as this could potentially lead to a conflict.

Various general-purpose database management systems (DBMSs) allow the definition, creation, querying, updating and administration of databases. Databases can be divided into two groups: embedded or client/server databases. Those belonging to the first group have an easy installation procedure. Few resources are needed, normally access for a single user, and they are tightly integrated with the application software requiring access to stored data; the database engine runs in the same process as the application. In the second group, the client/server database architecture is oriented to run in a server, running the database in a differentiated process from the software application and supporting multiuser access. It needs administrative privileges for installation.

Two mechanisms are used in the local level data model to support interoperability between local and remote servers: the

Machinery Information Management Open Systems Alliance (MIMOSA) and Open System Architecture for Condition-Based Maintenance (OSA-CBM).

MIMOSA focuses on the standardization of data models in the maintenance and condition monitoring domains. The Common Conceptual Object Model (CCOM) builds a foundation for all MIMOSA standards, while the Common Relational Information Schema (CRIS) provides a means to store enterprise Operation and Maintenance (O&M) information. The standard defines the various types of information that should be gathered to share information among different processes, systems and people.

OSA-CBM is an industry led team for standardizing the interoperability of systems participating in machine health assessment; as such, it is an implementation of the ISO-13374 functional specification. OSA-CBM adds data structures and defines interface methods for the functionality blocks defined by the ISO standard. Whereas the ISO-13374 standard provides guidelines on how to develop a condition monitoring system, OSA-CBM provides additional tools for implementation. Its goal is to promote the adoption of the CBM paradigm.

4.2 eMaintenance Cloud (eMC)

Scattered and fragmented databases cannot be replicated; this encourages the use of cloud computing in asset management. In such cases, a remote server enables us to receive data coming from different machines located in several places (the fleet), aggregate these data and make them semantically comparable, while considering their different contexts: i.e., technical differences (the machines may not be exactly the same), operational conditions, historical failures, etc. The goal of fleet management is to balance acquisition, recapitalization, reset, sustainment, and divestiture decisions across systems' life cycles in order to meet equipping and operating requirements, achieve optimized budgets, and communicate critical knowledge to stakeholders.

eMaintenance solutions offer a mechanism that supports organizations in their transfer of data to handle risk-based decisions through system overview. Decisions should be based on the understanding of data patterns and relationships. Materialized as a set of inter-operable, independent and loosely coupled information services, a framework with its own inherent infrastructure (i.e. eMaintenance Cloud, eMC) can provide fleet-wide, continuous, coordinated service support and service delivery functions for operation and maintenance.

In order to baseline the fleet and assess technical feasibility, fleet managers must have visibility into global equipment inventory and readiness status. This includes having knowledge of current configurations, systems, and block upgrade information, along with access to real-time asset information by system, component, and other customer distribution requirements. It also requires the ability to cross-check the accuracy of the data retrieved from data sources or other data management systems accessible to fleet managers. Other data needed to baseline fleets and determine technical feasibility include planned acquisition fielding, past fielding, system losses, system asset position, new or replacement systems, joint service requirements, divestiture requirements, data interchange requirements, system modifications, and funding requirements. By establishing a baseline, fleet managers will gain an accurate, common operational picture of the fleet, define areas of risk, and develop appropriate risk mitigation by recommending courses of action while achieving an optimized budget. Each is an integral and significant outcome of the fleet management process [16].

Beyond implementing a data warehouse and an application server, the eMaintenance platform should also support infrastructure grounded on Service Oriented Architecture (SOA) and Enterprise Service Bus (ESB) architecture based on Web Services, to bring together a set of company applications in an XML-based engine. The flexible infrastructure makes it possible for different parties to develop different modules in different development environments.

4.3 Module interoperability

As stated above, local and remote levels should exchange information for users to be adequately served. The remote service and the eMaintenance platform need data from different machines to provide added value services. Therefore, service must be defined in the context of end-users' needs; following this, the data that machines should exchange with the platform must be defined.

In terms of connectivity between local machines and remote servers, the availability of full permanent remote connection cannot be assumed.

4.3.1 Local-Remote module connectivity

Communication between machine tools and a remote data warehouse server can be handled in several ways:

- Machine directly connected to the Internet: VPN connection; direct transmission via Internet (HTTPS, FTPS); mail server; GSM card connection…
- Machine not directly connected: the user must periodically retrieve the data exports, and transmit them by creating an email attachment or using FTP. Another option is to upload the files to the server manually.

Various standards of reference guide the information exchange between different systems. Standardization is crucial, as it facilitates data interchange between different applications. A common language is a key component of standardization, as it facilitates the collaboration of various agents and the integration of information systems.

O&M activities are standardized by different organizations on different levels of abstraction. Although there is no single standard, the activity models, information exchange patterns and data models can be standardized. Formal data descriptions, such as XML schemas, can be extracted from the data models and used in content based information system integration, while activity models help in the analysis of business processes.

Operators, maintenance personnel, original equipment manufacturers, part suppliers and engineers have always wanted to have information about the condition of equipment assets at their fingertips when they need it. However, this information is not shared because it is split on different information systems which are not interconnected; these systems include manufacturer's data, operational data, condition monitoring data, diagnostic, reliability data, etc.
Interconnectivity of the islands of engineering, i.e., maintenance, operations, and reliability information, is embodied in MIMOSA's Open Systems Architecture for Enterprise Application Integration (OSA-EAI) specifications. Adopting these specifications offers advantages to maintenance and reliability users; it facilitates the integration of the asset management information and saves money by reducing integration and software maintenance costs. It is equally advantageous for technology developers and suppliers, because it stimulates and broadens the market, allows concentration of resources on core high-value activities rather than low-value platform and custom interface requirements, and provides an overall reduction in development costs.

5 Data management

The evolution of the data throughout the eMaintenance process is governed by the platform. Here, two crucial aspects must be contemplated: the representation of the data in a formalized and standardized way that allows sharing the data easily, and the sharing process itself.

5.1 Data mutation

As explained previously, for a local CBM module, one of the most important issues is defining the component fingerprint and, thus, the component health.
To obtain the component fingerprint, data must pass through several stages to find the most important features of the collected signal, i.e. Knowledge Discovery in Databases (also known as Data Mining). The first step requires processing the data to obtain a prepared and reduced dataset using various techniques: time synchronous averaging or windowing, for instance.

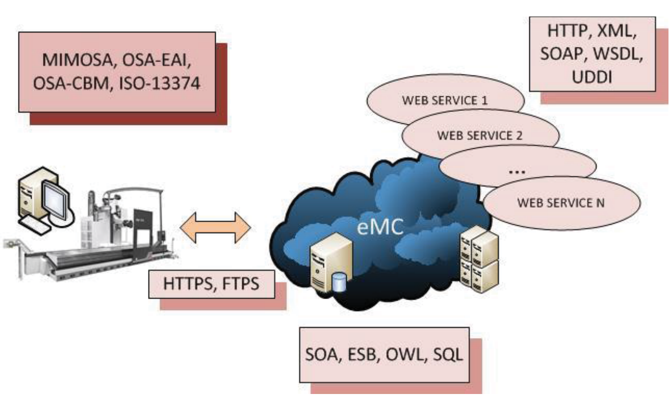

Figure 2 Overall Architecture

At a second stage, features are selected and extracted from the prepared data. This selection it is not yet a minimum feature set, however. Feature extraction is a common term used in pattern recognition and image processing. To classify a fingerprint, some characteristics are extracted for future identification and comparison. Features extracted are used to characterize properties of a component's condition. Implementation techniques are commonly used for vibration analysis [17] and motor current signal analysis [18]. Most methodologies are applied to the signal in the time and frequency domains.
In the time domain, a number of statistical parameters are used: root-mean-squared (RMS), peak value, crest factor, kurtosis, skewness, clearance, impulse and shape factor, average, median, minimum, maximum, variance and deviation. These parameters attempt to capture unusual behavior and/or impacts associated with early degradation stages and faults [14].
Frequency domain analysis refers to the mathematical functions or signals related to frequency, rather than time. Fast Fourier Transform (FFT) or wavelet transform (see for example [19]) are techniques to consider. In the frequency domain, frequency bands may differ based on the design of the machine.
At this stage, condition assessment and forecasting are done with the selected features, using such techniques as support vector machine, self-organizing map, artificial neural network, or regression methods.
A reduced set of relevant features is derived and compared to the fingerprints' time values. This provides the health assessment of the machine.

5.2 Data depiction

Ontology involves formal specification of knowledge in a domain by defining the terms (vocabulary) and relations among them [20]. Ontologies are composed of classes, descriptive concepts, class properties, and classes' relationships and instances.
Ontologies represent a suitable modeling method to provide common semantics and to query heterogeneous databases. Reference [21] states an ontology process enables: sharing common understandings of the structure of information among people or software agents, making domain assumptions explicit, defining concepts and knowledge and making domain inferences to obtain non-explicit knowledge.
Web Ontology Language (OWL) facilitates the definition of generic conceptualizations that can be used in multiple domains; it enables the creation of Web-based applications, such as a module of an eMaintenance platform [22].
OWL provides inference capabilities with plugged reasoners which perform consistency checking. Hence, there is the need to ensure that ontology is built correctly, in the sense that no syntactic error or inconsistency remains in it. In addition, explicit and manually constructed classes that belong to taxonomy constitute an asserted hierarchy, but thanks to OWL reasoners, an inferred hierarchy is automatically computed, allowing us to infer new knowledge.

5.3 Data sharing

A remote platform aims to provide openness and connectivity of the components installed in each machine and to guarantee the added value remote services. Modern day information technologies have resulted in a set of principles for designing and developing software as interoperable services, also known as SOA. SOA consists of the implementation of a platform containing several services. These services are business process oriented resources representing the possibility of performing tasks that ensure coherent functionality from both the provider and the consumer points of view. Within the operation and maintenance context, eMaintenance solutions provide a mechanism that supports organizations in transferring data to enable decision-making from a system perspective, and facilitates their understanding of data relationships and patterns.

SOA software architecture aims to implement an information system comprising independent but interconnected services. In that sense, the objective of SOA is to decompose functionalities in a set of services and describe their interactions.

From a technical point of view, SOA defines software in terms of discrete services, implemented using components that can be called upon to perform a specified operation for a specific business task. The SOA concept changes the existing software concept of a function—a specific piece of code that performs one particular task—to include the notion of a contract, a technology-neutral but business-specific representation of the function [17].

In that sense, SOA considers different elements such as the service concept and the service provider, consumer and broker. These elements interact to perform business tasks. The roles of SOA can be described as follows:

- Service: self-contained business function that accepts requests and returns responses through a well-defined standard interface.
- Service Provider: the function which performs a service, i.e., the owner of the web services. It registers the services with a Service Broker (registry), and it publishes information about the service to the service broker in standard format.
- Service Consumer: the function which uses the result of the services supplied by a provider, i.e., the user of the web services. It searches the registry provided by Service Broker and gets the information about the service. It builds the request message and sends to the Service Provider and gets the response back.
- -Service Broker: provides a registry of available services, i.e., the registry of the web services. The requester builds the request message, sends it to the service and gets a response.

Benefits of using this type of architecture are: reusability promotion, modular programming, better flexibility and easy to maintain services. SOA promotes the goal of separating users (consumers) from the service implementations. Services can, therefore, be run on various distributed platforms and accessed across networks.

SOA is implemented using new technologies and is principally based on XML and Web Services. Web services consist of exposing one or more applications (i.e. services) to an Internet network. These services can propose simple functions or a set of tools to compose a complete application. The following open standards are regularly used:

- SOAP (Simple Object Access Protocol): an XML based protocol specifying envelope information, contents and processing information for a message.
- WSDL (Web Services Description Language): an XML-based language used to describe the attributes, interfaces and other properties of a Web service. A WSDL document can be read by a potential client to learn about the service.
- UDDI (Universal Description Discovery and Integration): a specification for creating an XML-based registry that lists information about businesses and the Web services they offer. Though implementations vary, UDDI often describes services using WSDL and communicates via SOAP messaging.

As explained previously, SOA defines a method to design applicative interactions between different distributed components. This method is based on the services which are executed by a supplier component for a consumer. One of the properties of such a method is that it allows a component to be on different systems and distributed over various networks. SOA is based on services invoked through interfaces and vocabulary common to all agents (supplier and consumer). The more advanced these elements are in terms of modeling, the more advanced the services are in terms of different treatments and larger evolutions. SOA allows the architecture to be flexible and adaptable to many situations.

As a result, the eMaintenance platform enables the integration of other applications by acting as a hub of technologies. As it includes a Service Oriented Architecture foundation and web-based technologies, the platform offers openness and integration, with (web) services sharing data and results with other applications to help users cope with various business organizations and models (e.g. fleet monitoring application with expertise center, multi-site applications with expertise center, multi-client and multi-site, etc.) within an integrated enterprise architecture. The openness and flexibility of the SOA platform offers many possibilities, supporting data acquisition, storage, and transportation and contributing to service implementation at the remote level.

Finally, the service-based principle of the SOA design offers the possibility of using a methodology based on service composition and service reuse.

6 Conclusions

As the paper shows, the suggested architecture deals satisfactorily with the integration of different data formats through a combination of local and remote modules, in spite of their disparate nature and granularity. The paper also suggests the possibilities inherent in an architecture that allows the monitoring of machine tool performance to support proactive degradation detection through the analysis of the current signal, enhanced by the application of several data transformations extracting the required information.

The sharing capabilities of the proposed platform provide an excellent opportunity to improve work already done in the area by facilitating communication with the most up-to-date and powerful methods currently used in the maintenance arena.

In summary, eMaintenance, or most recently Maintenance 4.0, provides forecasting capabilities to determine machine health in order to optimize maintenance actions and maximize the productive capacity of assets, expanding their lifespan.

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