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FAILURE FORECASTING - INTELLIGENT SOFTWARE AGENTS IN THE CONTEXT OF INDUSTRY 4.0

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Abstract: The forecasts of the maintenance tasks allow the evaluation in case of troubleshooting and the volume of spare parts that must be provided in case of random failures. Artificial Intelligence and Machine Learning enable manufacturing companies to take full advantage of the volume of information generated not only within the company, but also across their business units and even from partners and third-party sources. Real-time prediction prioritizes the requests necessary to predict possible errors, but this method is a substantial consumer of resources, requiring high-performance technological equipment. Software agents represent a new paradigm in Artificial Intelligence and Industry 4.0. Prediction involves finding appropriate means and methods to contribute to the anticipation of possible defects, taking into account the existing vulnerabilities, as well as the periods in which the system will be prone to malfunctions. This study aims to develop an applied methodology on predictive algorithms related to possible technical problems. Also, a prescriptive maintenance plan must be established in order to define and determine the technical control processes.

Keywords: artificial intelligence, automatic comprehension, Industry 4.0, prescriptive maintenance, knowledge processing.

1 INTRODUCTION

Maintenance is not a discovery of the modern world. The antiquity of this activity is lost in time, it being present throughout the entire history of mankind, whether it was conceptualized or not (Kobbacy, Nathan, Harper, 1995).

The indication of the components that register progressive degradation and require a systematic replacement allows specifying the scheduled maintenance plan. The organization of maintenance and repair services can be considered as a criterion for assessing the competitiveness of a company (Ansari, Robert, Wilfried, 2020).

As a result, the degree of maintenance development is described by a certain level, determined by: the maintenance systems used, the strategy adopted in carrying out the activity, the organization of the service, the techniques, tools and methods used. This article represents an academic research in the field of engineering and prescriptive maintenance, related to university doctoral studies.

The field of interest acquires in the proposed approaches implications related to the mission, objectives and strategies. Thus, the strategies specific to this field were defined, leading to the idea that the efficiency of maintenance manifests itself over time. It is known that, as a rule, companies make great efforts to support re-technological strategies and to increase the technical level of productive activities. Their support can only be done by promoting a modern maintenance activity and a coherent strategy in this area as well (Starr et al., 2010).

To fully define the characteristics of a system, it is important to know the quality and reliability characteristics. The analyzed system is all the more efficient the less the number of identified malfunctions is. Such a process involves additional sacrifices and efforts on the part of resources, regardless of their nature, meaning that the process of installation, motivation, equipment and maintenance must be actively supported (Kobbacy, 1992).

2 IDENTIFYING TECHNICAL SPECIFICATIONS

Technical specifications play a crucial role in influencing the maintenance plan for any system, equipment, or machinery. In the same vein, it is imperative to identify the challenges identified in the assessment of current maintenance processes, establish assessment methods related to prediction results, implement applicable solutions to improve maintenance processes, design a software program specialized in prescriptive maintenance, obtain validation models or of failure models in system analysis and conceptual extension for industrial systems (Canito, Corchado, Marreiros, 2021).

Artificial Intelligence and machine learning can create insights that provide visibility, predictability and automation of business operations and processes. For example: industrial machinery is prone to breakdown during the production process. Using data collected from these assets can help companies perform prescriptive maintenance based on machine learning algorithms, leading to higher uptime and increased efficiency (Adamides, Karacapilidis, 2020).

Predicting failures in technical systems involves analyzing various technical specifications to identify potential issues before they occur. Among the main specific techniques for the detection of possible defects, for prevention, can be listed: monitoring operational parameters, inspection of error logs and event data, maintenance and repair history, failure modes and effects analysis and machine learning.

Technical specifications define the performance standards and expected operational parameters of the system or equipment (Ungureanu, Ungureanu, 2015).The maintenance plan aligns with these standards by including activities that help maintain and restore the system to its intended performance levels. Regular inspections, audit of the performed operations, validation of the results obtained, as well as calibration of the equipment used according to known standards are scheduled based on the performance standards (Horner, El-Haram, Munns, 1997).

Also, the materials used when performing preventive maintenance tasks must be of high quality. Both consumables and compliance with a well-established procedure for carrying out specific maintenance operations are fundamental elements of the technical implementation criteria.

Therefore, the efficiency indicators of the enterprise's activity are interrelated with those of the maintenance, for this reason, due to the previously mentioned implications, the maintenance will have to find its place among the top priorities of any economic activity (Mancini et al., 2018).

3 CONCEPTUAL IMPLEMENTATION

The evolution of IT systems in the context of Industry 4.0 highlights a new approach to the introduction of intelligent software agents (Khoshafian, Rostetter, 2015). This was not limited to theoretical notions but allowed the implementation of techniques related to Artificial Intelligence, including in industrial environments. In this way, intelligent systems manage to highlight aspects of detail that can represent critical elements in the whole set of events. Most of the time, the implementation of a prescriptive maintenance plan consists of two major stages: one of automatic learning and one of structural evaluation.

3.1 Automatic comprehension

The conceptual system proposes the performance of some critical functions in order to ensure the implementation of effective maintenance in the context of the applied environment (Ungureanu, 2001). Functions such as the perception of elements specific to the technical field, the undertaking of tasks necessary for beneficial change, and the presence of decision-making elements for solving problems are integrated both within the reasoning modules and in the transmission-reception process shown in Figure 1.

The system based on subsuming all learning and reasoning components constantly receives input signals from all available sensors. Capabilities such as planning, learning and creating analogies are supported by the proposed architecture. Considering the connector modules to the observed functional components, it appears that the identification of possible faults will actually work in real environments. That is why a simplification of the initial assumptions such as that of perfect perception cannot be applied in the actual context. The prediction activity is focused on the execution of recorded actions.

Continuous monitoring and analysis of sensor data over time provide insights into the performance of the machinery or equipment. The reception transmission process ensures a continuous flow of information between the rationing modules and the particular work environment. This relationship is facilitated by the presence of sensors, being thus integrated including the Internet of Things component. Obtaining an intelligent system requires the correlation of several factors subsumed by the criteria of time, performance and constant operation (Xu, Eric, Ling, 2018).

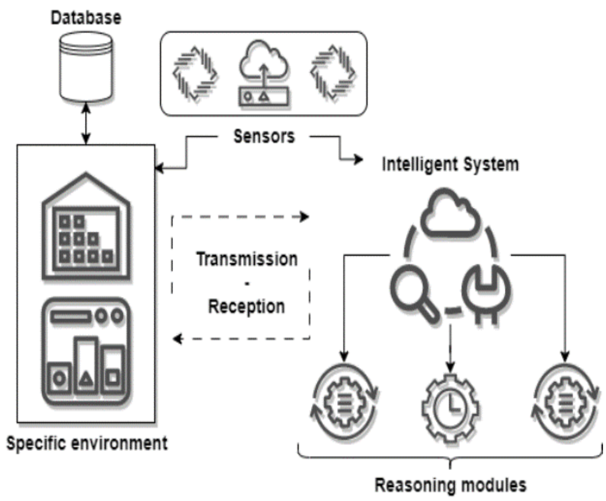

Figure 1. Representation of the interconnectivity method of the prediction model corresponding to Industry 4.0

3.2 Structural assessment

Once the model has been obtained, the usefulness and correlation with the current systems can be determined. Also, there are multiple evaluation options in order to distinguish an optimal structure from an already implemented one. The difference between the identification of defects and their prevention consists in the fact that in order to identify a defect, it must already exist within the analyzed system.

In other words, at the moment of identification, the presence of the defect is established at the moment of evaluation. At the same time, the prediction includes the identification of methods to minimize the impact of dysfunctions and, if possible, the complete elimination of the negative effects experienced. In order to achieve a further classification, Table 1 lists some specific properties of the proposed intelligent software system for fault identification and prediction.

In order to carry out the tasks of prediction and identification of possible failures, the system must exercise control in a non-trivial way over the foreseen operations, thus demonstrating its autonomy. The high-level requirements given by the users must be precisely met, the purpose of the system being a precise one, to ensure the implementation of a correct maintenance plan. Both the prescriptive character and the context of Industry 4.0 lead to the need to develop a flexible system through which the actions performed are dynamically allocated according to the situation and the internal environment.

Of course, the processes must not be stopped because the analysis applied in real time is defining within the continuous patterns in time. Another characteristic aspect of the model is adaptability, the system automatically learning certain knowledge, based on previous experience. Among the best methods of automatic learning we find machine learning which is necessary for the system adapted to changes in the environment. The learning activity is done as the model acts or reacts with the environment. Learning can take the form of an increase in performance.

4 DEVELOPMENT OF THE DETECTION METHODOLOGY

As complex systems they are capable of flexible autonomous behavior in dynamic and unpredictable environments such as industrial ones (Lasi et al., 2014). Artificial Intelligence processing systems are based on software architectures and techniques and by building and evaluating prototypes based on the latest technologies available.

Table 1. Properties and applied utility of system features

Application area	***Specific property***	***Utility***
Predicting	Autonomous	Exercise complete control.
	Continuous learning	Adaptive systems depending on the accumulated knowledge.
	Flexible	Takes into account multiple prediction options.
Identifying	Goal oriented	Not limited to a group of solutions.
	Reactive	Responds to changes related to the production environment.
	Continuous operation	The process takes place continuously, without deliberated interruptions.

Planning is one of the most important capabilities possessed by the proposed conceptual model. In the vast majority of cases, the tasks to be performed are expressed as goals, objectives to be achieved, thus having to develop a series of actions to reach the expected result. Planning itself is a mandatory prerequisite for some necessary capabilities.

Learning and planning have a reciprocal relationship where planning creates a new method of performing tasks that can be learned by the planner for later use. Problem solving includes the ability to acquire and reason about knowledge, although the degree to which this ability is operable differs between architectures.

Problem solving consists in defining the possible states for the particular problem and the presence of specific operators available to change one particular state into another. In this formulation it can be said that the system searches through a finite space of states applying operators until it reaches a level that can be defining the proposed objective.

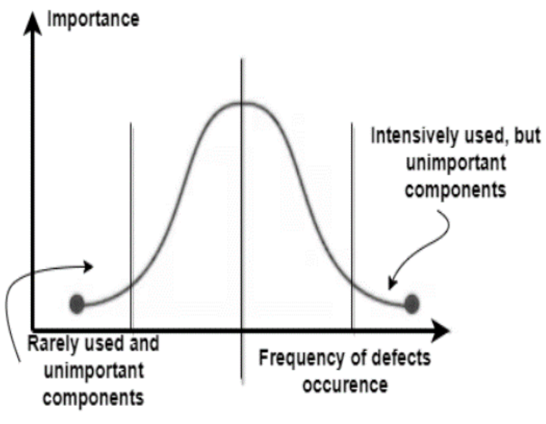

Figure 2. Filtering for identification based on the usage degree of the components

Figure 2 illustrates the normal distribution of defect occurrences depending on the importance of the affected subassemblies. It can be observed that the importance of a subassembly decreases as its degree of use departs from the average value of all the degrees of use of the other components in the analyzed assembly. The frequency of the appearance of defects is directly proportional to the frequency of use of the components. The components with a moderate degree of use have a higher importance than the intensively used or rarely used ones. The average frequency of defects is closely related to the importance of the affected components, they being used in a moderate way.

5 OPERATIONAL PATTERNS

Most of the time, it can be easily observed that a change can occur within routine tasks, if certain conditions are met such as: the existence of a malfunction within certain equipment, the temporary removal from production of a system or a faulty operation. A maintenance operation of equipment can be carried out in several ways, depending on the moment of the maintenance, the operating conditions, the state of the equipment or the way it was used. The application of a certain maintenance plan must take into account the operation specifics for each individual system. In this case, it is recommended to combine multiple maintenance techniques to obtain the optimal plan.

5.1 Knowledge processing

Simultaneously with obtaining the expected non-functional characteristics, the system design must offer architectural and functional solutions conducive to obtaining maintenance plans specific to organizational requirements. Based on the implementation of these maintenance actions, the designated engineers and control staff will issue and apply the corresponding decisions so as to minimize the occurrence of errors and failures. Figure 3 presents the main premises of the automatic processing of failure occurrences in the production environment.

Information filtering has the role of solving the problem of overloading the systems, due to the impressive volume of data coming to the developed prediction modules. Monitoring system behavior against specific performance is necessary to determine preferences for a particular type of maintenance plan application. These affinities can be both generic and utility-specific at the level of integrated and used equipment.

As a rule, in the stage of processing the acquired knowledge and data, multiple patterns can be applied that correspond to the implementation needs. In this case, there are three models, namely: real-time prediction, prescriptive approach and key-chain analysis. Of course, any of these can be properly applied to data processing. In the same vein, real-time prediction makes an estimate of the most likely time when a malfunction could occur. The generic model generates decisions constantly, based on the de facto situation in the production environment. The decision-making relationship is mutual, meaning that decisions are made based on the previous rules. Another processing method is key-chain analysis, which provides recommendations regarding the analysis of dysfunctions.

The second model involves the chaining of the constituent elements of storage, processing and decision-making. In the first phase, the data stored in the database will represent entry points of the conceptual model. After the pre-processing of the knowledge, there will be stages such as the identification of weak points and the finding of technical shortcomings. The prediction stage is the most complex, involving specific automatic learning techniques through which the data is divided into two important sets: a training data set and a test data set. Thus, based on the necessary classification, regression or clustering, relevant decisions will be issued regarding obtaining the maintenance plans. From the performance point of view, one of the most effective techniques is represented by the prescriptive approach. This takes into account all the sensors and equipment integrated in the analyzed system.

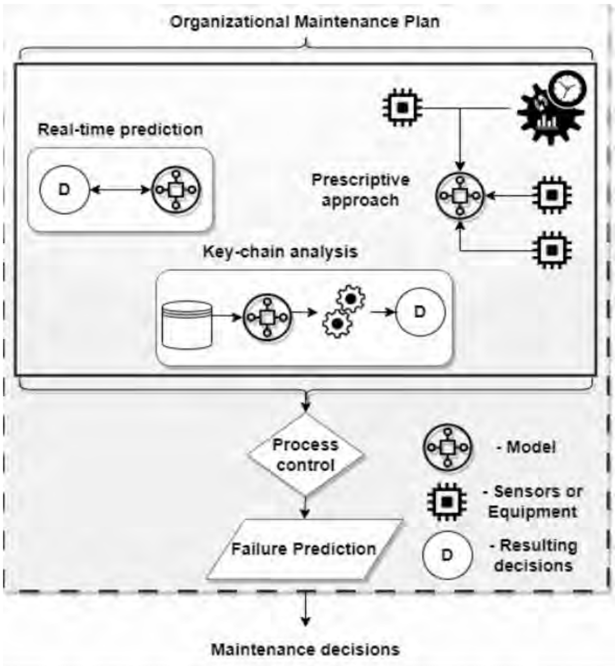

Figure 3. The generic maintenance model of the specific architecture of prediction patterns

Using this method, not only possible problems are identified, leading only to corrective or preventive maintenance, but also to the optimization of the entire applied process. Regardless of the processed usage pattern, there is an advanced process control stage that monitors the activity undertaken, thus facilitating the timely obtaining of predictions related to failures.

5.2 The algorithmic approach of prediction

Like any operation to obtain predictions regarding errors or malfunctions, the procedures are complex, and require an incremental approach to solving the problem. Thus, one can see the importance of defining a generic algorithm as a landmark in specifying the main stages of monitoring, identification, validation and processing of the specifications. Figure 4 presents an algorithm whose purpose is to determine what kind of defects could appear in the future and the possible moment of their appearance.

The content of the database, as well as the information collected by the sensors, will be used as input data based on which, after following several steps, a prediction of potential defects will result. The data stored in the organizational database, respectively those collected by the sensors installed at the reference points, represent input data for the entire processing process. After completing all the specified stages, it is desired to obtain predictions related to potential failures as output data. The monitored systems can be represented by priority or less relevant subassemblies for the maintenance activity. The choice and identification of the fields applicable to the analyzed case are preliminary stages to the validation and structuring the conceptual model. Validating the consistency of the preprocessed data is a necessary step in order to filter and select the next iterations.

Input:	Data internally stored in the database and data collected by sensors.
Output:	Predictions related to possible future failures.
1.	Choosing the monitoring domain area.
2.	Identifying the field of applicability.
3.	Validating the correctness of existing data.
4.	***If*** (*isConsistent* == true) ***then***
4.1.	Structuring the conceptual model.
4.2.	Data sampling.
4.3.	Model training.
4.4.	Specification of additional annotations.
4.5.	Failure prediction.
5.	***Else***
5.1.	***Go to*** *step 2;*

Figure 4. The general flow of failure prediction algorithm

Obviously, if the data set is consistent, the steps of structuring, dividing and training the obtained model can follow. Additional annotations can be added to record additional details corresponding to the preliminary results. The final result consists in the prediction of failures in the context of supporting all the previously mentioned stages.

6 CONCLUSIONS

The described situation leads to the concept of quality based on data processing and obtaining the superior performance of the equipment and technique owned. On the other hand, the objective of adopting a qualitative maintenance plan is to preserve specific technological attributes for as long as possible. The identification and prediction patterns can represent applicable directives in order to obtain the stability, safety and controllability of the monitored systems.

In this new stage of technology development, especially in the case of Industry 4.0, the theories developed up to the present moment can be applied by interconnecting computational capacities of any kind, thus leading to obtaining maintenance systems for the successful completion of complex operations. Of course, the development and application of maintenance techniques would not have been possible without the contribution brought by the improvement of computing techniques, as well as digitization elements, of Artificial Intelligence.

The prediction and identification of defects can be achieved through various techniques and methods, each of which has specific advantages and disadvantages. As a rule, the implementation of prescriptive maintenance plans represents the most effective method from the point of view of the accuracy of the resulting data. As the development goes through the pre-design stages, the detailed implementation is reached. In this way, the risks related to maintenance are controlled through a formal and documented approach to the review and imposition of maintenance rules and procedures. By integrating the application patterns, the maintenance plan is first evaluated in the initial phase of the project, then, as new information is collected, the predictions are refined.

Industry 4.0 is an offering field in terms of functional extension possibilities. As future directions for research and development, it is worth noting the possibility of introducing an automation mechanism that would index the content of each individual defect, subsequently generating inconsistency templates. Along the lines of integrating the mechanisms characteristic of Artificial Intelligence, knowledge-based systems can be integrated, in the form of data connection within the ontologies specific to the analyzed field. Using description logic, there is the possibility of including Probabilistic Description Logic. Thus, by including the rationing technique, the system could establish the probability of being predisposed to a certain defect, depending on the risk factors or predisposing factors.

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