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A PROPOSED FRAMEWORK ARCHITECTURE COMBINING IIOT AND ERP IN INTELLIGENT INDUSTRIAL PREDICTIVE MAINTENANCE

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Abstract: - Internet of Things (IoT) technology and Enterprise Resource Planning (ERP) applications have recently gained much attention predictive maintenance. With the emergence of such technologies, it has become essential to redesign the business for innovations based on ERP, and Industrial IoT (IIoT) integrated architecture that helps organizations to improve agility in their operations. This paper aims to discuss this issue and use the integration between business applications and the new technologies to propose a framework architecture for an intelligent predictive maintenance within the industrial enterprises. Machines and Equipment were attached with sensors to monitor its operations on real time to take predictive measures and integrate it with business data captured from ERP systems for further analytics that helps in managing these assets with more agility. The developed architecture was further extended for proposing the use of ERP data and how it can benefit the organization. The known features of ERP applications that allowing autonomous coordination of the devices, along with the boons of IIoT, will help achieve the motto of improving agility in industrial predictive maintenance. This paper gives a new utilization dimension of the IoT technology. IIoT along with ERP systems can give a way forward for enterprises in redesigning the maintenance operations in a more agile way.

Keywords*:* ERP, IIoT, Predictive Maintenance

1. Introduction

Asset-intensive industries could not be surviving without enterprise software tying their processes and data together. The most important solutions - enterprise resource planning (ERP) systems are inexorably linked, and thus the bond is tightening with application and repair service innovations spawned by digitalization and the industrial internet of things (IIoT). The heavy industries are a risk-filled arena. Today, the integration of information systems has become a necessity because the big organizations have developed separate information systems over time, mostly for the automation of various activities. Enterprise Resource Planning (ERP) systems are collective techniques for integrated management of business as an entire from the point of view of the effective use of management resources to enhance the efficiency of enterprise management. ERP systems have, from their very start, aimed at being the IT backbone for business processes in enterprises. To achieve that, they had to employ state of the art information technology and keep an eye on the future trends and developments in industry.

Asset management modules of ERP systems is needed to optimize the equipment, fleets, facilities, and other physical assets crucial to successful business operation. Enterprise asset management (EAM) module addresses the entire lifecycle management of an organization's physical assets to help maximize value. EAM covers the design, construction, commissioning, operation, maintenance, and decommissioning or replacement of plants, equipment, facilities, and other high-value assets. A company's business and profitability are strongly affected by the significant operational and financial impact of any high-value asset. What called it "enterprise" is the fact it extends to departments, locations, facilities, business units, and regions. The goals of managing assets this way include: –Improving utilization and performance –Reducing capital costs –Reducing operating costs –Extending an asset's life –Improving ROA (return on assets) (IBM, 2017).

Another recent trend that is currently being in focus of both industry and academy is *Industrial Internet of Things* (IoT). The term IoT was first coined in the year 1999 by British technology pioneer Kevin Ashton from proposal of uniquely identifiable interoperable connected objects with radio frequency (RFID) technology (Ashton, 2009); (Madakam, Ramaswamy, & Tripathi, 2015). Of course, over time, the concept included more and more evolving technologies. Today, when we speak about IoT, we speak about billions of "*things*" connected to a vast network, which collect data by sensing their physical environment, share this data with interested parties, and intervene into concrete situations.

The Internet of Things (IoT) plays a key role in predictive maintenance. Using this new concept in conjunction with the right sensors, actuators, devices, and cloud services, engineers and technicians can determine the condition of in-service equipment and predict when exactly maintenance and repairs should be performed (Smallwood, 2015). The emergence of the IIoT and related technologies makes a stronger relationship between EAM and other ERP modules more important. Networked sensors and intelligent devices are collecting exponentially more data, and decisions are being facilitated by modeling, machine learning, and advanced analytics (Kennedy, 2018). This capability, supported through IIoT's integration with ERP applications, AI analytics, and cloud-based technologies, gives groups exceptional visibility into the health of their assets. Many technological advances in both ERP and IIoT have been observed but no direct integration is observed due to the complexity involved in the handling of each system. Many studies have been described the functionality and use of computerized maintenance management systems. One major drawback of these studies is that they don't disclose the actual support for maintenance management. To describe the full situation, it is necessary to determine the differences between the required support and the actual support. There are two types of gaps: 1) between the features included in the IT system and the required features, and 2) between the features included in the IT system and the features currently used.

2. Technological Review of ERP and IIoT

This section briefly reviews the technology underlying enterprise resource planning (ERP) system's current solutions, and IIoT technological approach as a subset of the IoT.

2.1 ERP Solutions:

ERP systems were first developed to extend the functionality of MRP to the entire enterprise rather than only the material department and operations department.
According to (Jacobs & Weston, 2007), ERP was introduced by the Gartner Group in the early-1990s. The significant contribution of the ERP system they introduced was that it included more interfaces between different departments within a given enterprise, particularly between operational activities and the corresponding accounting transactions. Following the introduction of ERP, a number of specialized ERP vendors such as Microsoft Dynamics, Infor, SAP, SQL, Epicor, and Eclipse have been leading the market (Muscatello, Small, & Chen, 2003).

ERP systems is the high costly (both initial cost and the cost of implementation and maintenance), which prevents small and medium size businesses from purchasing ERP systems. Furthermore, technical personnel need to be hired for maintaining the system, and implementation is a time-consuming process. Initial implementation of ERP may complicate the existing process and thereby negatively affect the productivity of the company. Some companies may require customization of the ERP system to match their unique operations. However, customization of an ERP system can be even more costly and time-consuming (Yen, Chou, & Chang, 2002). Therefore, having a better plan and preparation for implementing the system, such as providing proper training before actual implementation, could potentially smooth the process. Failure of the system implementation in a given company could result from the lack of proper training and unrealistic expectations, lack of IT support, lack of management support, and lack of historical data from previous projects.

Enterprise asset management (EAM) involves managing an organization's physical asset maintenance throughout the lifecycle of each asset. EAM is used in the functions: plan, optimize, execute, and follow up the required maintenance activities according to its priorities, skills, materials, tools, and information (RIO, 2017). This covers the functions of design, construction, commissioning, operations, maintenance and decommissioning or replacement of plant, equipment and facilities. The ERP system tends to be more designed to store data than engaging with it. This means that while it might be the ability to track data related to equipment, the software won't give many maintenance managements tools that are readily accessible without the EAM module. For example, scheduling work orders based on asset health, most ERPs wouldn't make that easy. But using EAM module facilitates work with: Work requests and work order management; Asset tracking, including warranties, downtime, and depreciation; Maintenance scheduling; Inventory management; Mobile apps. EAM packages will come with many of these features, and it is simpler to implement than ERP software. By integrating it into the ERP suite. In this way, to preserve the maintenance management capabilities while also achieving the reliability of data provided by the enterprise resource planning (ERP) application.

2.2 Industrial IoT (IIoT)-Technologies:

(Fleisch, 2010) describes IoT as an extension of the internet to capture the physical world of things from an economic perspective. The first word in the term focuses on network-oriented tools, whereas the second term emphasizes generic "objects" to be integrated into a system framework (Atzori, Iera, & Morabito, 2010). In IoT-based technology, a network of physical devices embedded with software, sensors, and actuators enables objects to connect and transmit real-time data (Giusto, Lera,, Morabito, & Atzori, 2010). Liu et. Al. (2014) introduces the concept of an IoT-enabled intelligent mechanical product assembly system and finds that the performance is greatly improved on the basis of the developed system. IoT also provides a solution for the management of additive manufacturing processes, where the existing technology in the manufacturing environment can communicate and extract data from machines through mobile device in real-time (Gf, Barbosa, & Aroca Rv, 2017).

Qu et. Al. (2016) proposes an IoT-enabled wireless manufacturing execution system that can be automatically controlled and managed. RFID is used in their proposed system to automatically collect the location information associated with other required data. In contrast to traditional manufacturing, this system simplifies the human component in inspection and data recording and improves the accuracy of work-in-process inventory. The information collected is real-time-based and can provide effective feedback between production plan and in-flow. Altaf has developed an automated data collection system for panelized building, using RFID as the implementation technology based on IoT (Altaf, Bouferguene, Liu, Al-Hussein, & Yu, 2018). Pasquier and. Al. (2015) provides a case study on a truck equipped with IoT-based technology that can communicate with the operations manager when a delivery has been made, thus reducing time and resources spent monitoring orders.

Industrial IoT (IIoT) as an IoT branch includes the areas of machine-to-machine (M2M) and automation systems of industrial communication technologies. IIoT paves the way for a better understanding of the production process, thereby allowing for effective and sustainable growth (Sisinni, Saifullah, Han, Jennehag, & Gidlund, 2018). The Industrial Internet is a combination of several main technologies to produce a system which exceeds the amount of its parts. By combining computer sensors, middleware, applications, and backend cloud computing and storage systems, the Industrial Internet provides a way to get better visibility and insight into the company's operations and properties (Gilchrist, 2016).

Industrial Internet of Things (IIoT) systems can be used effectively to build efficient smart factories where higher efficiency levels can be achieved. IoT smart objects can be used omni presently to collect field data in order to improve productivity through advanced automated processes (Breivold & Sandström, 2015), protection through deeper knowledge of the role of workers (Petracca, et al., 2013), and by reducing equipment faults through the capabilities of fast event detection (Wang, Zhang, Duan, & Gao, 2015). Industrial IoT, also known as IIoT, is the use of IoT technology in industrial applications where the highly desired performance criteria for IIoT are robustness, reliability, and safety. For aviation the primary economic effect of IIoT is predictive maintenance implementation, which will turn aggregated data and information into actionable aircraft maintenance decisions. Based on the actual conditions of aircraft structures, parts, and sub-systems, predictive maintenance has the ability to determine when maintenance should be performed. Once in operation, predictive maintenance capabilities may remove additional costs such as expedited parts or materials shipping costs, minimize overtime expenses for crews and, most significantly, result in fewer unplanned maintenance downtime events (Liu, Meyendorf, & Mrad, 2018).

3. Framework for ERP, and the IIoT Integration within the Predictive Maintenance

Predictive maintenance is a collection of activities that detect changes in equipment's physical condition (signs of failure) in order to carry out the necessary maintenance work to optimize equipment's service life without increasing the risk of failures. This section introduces IIoT-ERP based predictive maintenance framework that can effectively assist service management staff to obtain real-time information in both internal and external machines and equipment. This IIoT-based approach can potentially improve the asset performance and spare parts inventory management. Figure 1 provides an overview of the proposed integrated IIoT-based real-time predictive maintenance system framework, and figure 2 represents the integration points between the framework main parts.

3.1 Development of the predictive maintenance architecture

To improve asset performance there is a need to develop a framework that will capture data at real time, keep it in a common central location from where all integrated applications can exchange data, provide real-time decisions and can also provide predictive analytical insights for asset management. Architecture has been developed to deliver integrated business benefits by connecting infield sensors installed on the equipment to the cloud/private cloud and then integrating it with various application to extract maximum benefits smartly out of the data. Figure 1 shows the proposed architecture of solution that can be implemented. The architecture can be divided into three different sections; details of each section are as follows:

Part 1,2: the first and second parts of the architecture depicts any rotary equipment; the production parameters taken from existing process control system such as (SCADA, Maximo), in addition to parameters captured by installing sensors, and any manually entered parameters. The performance swings can hamper the foundation of any industry. It is very important to monitor, effectively maintain and take proactive decisions for such assets to preventing accidents due to failures, prevent major asset damage due to breakdown and maximize the return on asset. This section contains the equipment to perform the desired operation and sensors to capture the operating parameters such as temperature, pressure, vibration, flow, rpm, current and voltage of assets in real time to get a captured data from the equipment that will help monitoring the performance of operating asset closely; hence, taking the right action at the right time.

Part 3: this part depicts intermediate media between operation technology (OT) and information technology (IT) to make the sensors communicate using an IoT gateway. Each equipment has sensor node(s), where the data from all the sensors were collected. Many such sensor nodes of each respective equipment and parameters from the process control system communicate with the IoT gateway using various communication protocols as Bluetooth and wired protocols, the IoT gateway then communicates with an IoT client software (CS) using the internet.

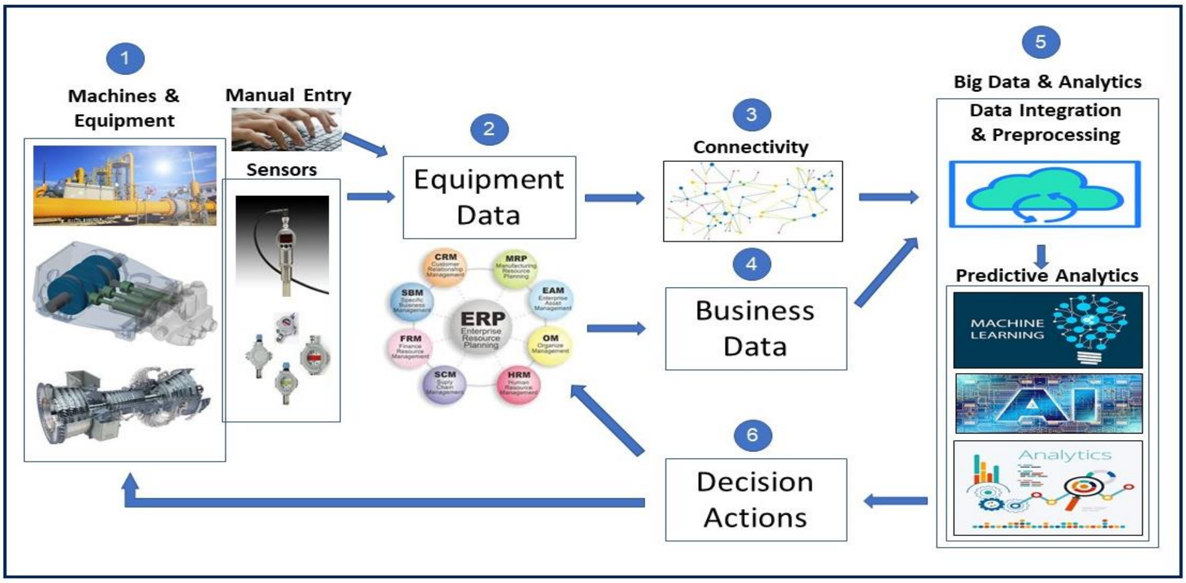

Figure 1: Architecture of The Proposed Predictive Maintenance Conceptual Framework

Part 4, 5 and 6: In these parts, data from IoT gateway is transmitted to IoT CS on real time with an adjustable frequency of sending data as per the business requirement. Using an integration layer, data from the IoT CS are inserted in database. Using various web services created using the integration layer data is utilized by various applications like ERP, business intelligence, big data, and other tools that can help extract maximum inference off the data. Predictive maintenance model can be built up by algorithms using machine learning and AI techniques such as classification, clustering and time series. This produces integrated data with the enterprise applications at the operational level, giving real-time visibility of all the process, and triggering appropriate decisions.

3.2 Data Integration within the Proposed Framework Architecture:

As shown in figure 1 that presents a framework integrates predictive capabilities with ERP solutions, it combines sensor data with business information in ERP system specially with enterprise asset management (EAM) module, and apply sophisticated machine learning algorithms to process the data generated by information and operational technologies to automatically generate recommendations on optimal maintenance schedules that maximize machine uptime using artificial intelligence and machine learning.

A detailed integration is shown in figure 2 that represents the ERP system integration within the proposed architecture of predictive maintenance, the integration can be presented between three main different parts: IoT, Prediction model, and ERP system as described in the following points:

- Operational data (equipment data) includes input on a range of equipment factors from temperature to pressure and engine speed that captured from IoT sensors attached to the equipment are passed to the prediction model.

- Operational data (equipment data) includes input on a range of equipment factors from temperature to pressure and engine speed that captured from IoT sensors attached to the equipment are passed to the prediction model.
- Business includes maintenance master data such as Equipment, Functional Locations, Catalogues, Failure Codes, and Task lists, maintenance history records that captured from Maintenance module of the ERP system are passed to the prediction model in addition to another important type of data which is the historical information of maintenance records.
- Then, the input data from previous two parts be analysed by different machine learning algorithms to predict the prognostic failure and the remaining time to failure. The output from the predictive model algorithms is a warning of a future system or part failure. Then, the system can determine when a failure is likely to occur.

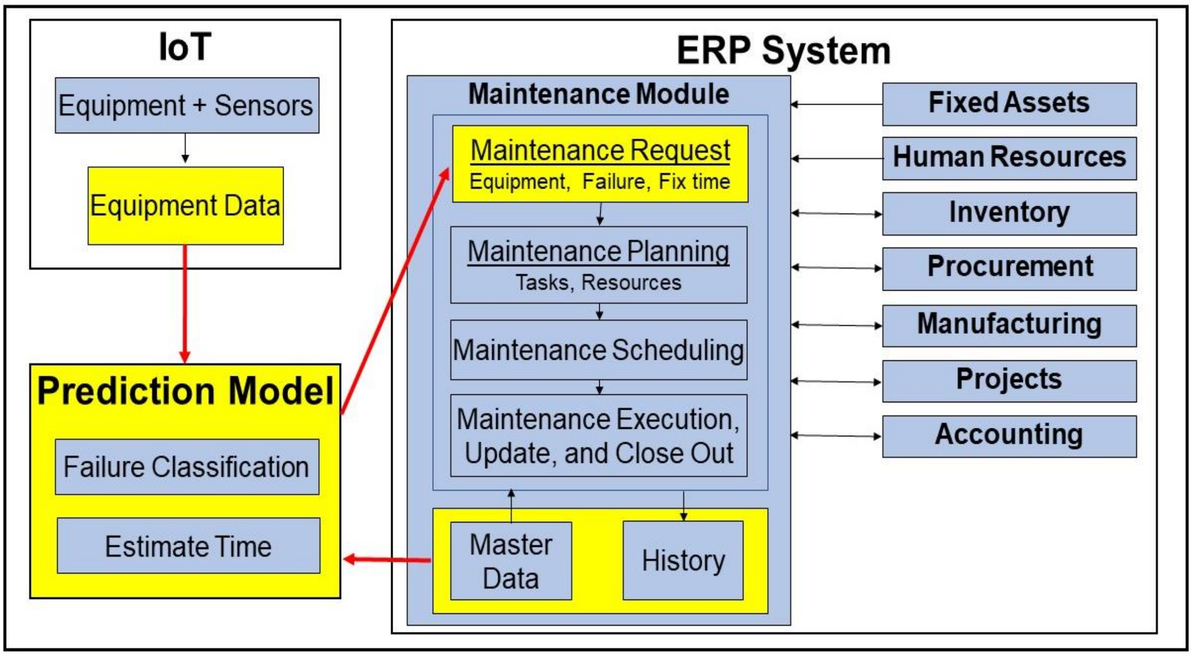

Figure 2: The Data Integration within the Proposed Framework Architecture

- Then these data passed to the ERP system in the form of maintenance request creation. The most important data to be based to the ERP system through the maintenance request creation are the equipment code, the functional location code, the prognostic failure code, the reason code, and the proposed fix time. This data encourages the maintenance team to take action and help significantly decrease unnecessary downtime, increase overall performance and reduce cost of repair. In addition to the ERP already existed internal integrations between the ERP maintenance module and other ERP modules is presented in figure 2. Fixed Assets module defines the equipment used in the work order, and work order charges updates the equipment capital depreciation. Human Resources (HR) module defines employees and jobs to be assigned to a work order and scheduling technicians. Inventory module and purchasing integration to manage and purchase parts required to the work orders. It possible also to associate project to a work order to see and work with project details such as resources, scheduling and costing. Integration with manufacturing to improve the coordination between production scheduling and maintenance scheduling. Work order cost will be calculated and recorded using the integration with accounting module. And many other ERP internal integration points are used and already exists in most of ERP systems.

4. Conclusion

This study proposes a concept of integrate ERP systems with IIoT technology. Based on the IIoT technologies, an overall framework of predictive maintenance is proposed. The real-time machines and equipment's data can be sensed and captured. Then, data will be moved to the cloud through communication methods. And then, the data will be integrated, pre-processed, and analysed using AI machine learning techniques to predict and classify prognostic failures and predict the remaining useful life. A real-time maintenance decision-making method is analysed, and a data flow conceptual model is presented to implement the predictive maintenance decision-making process. The data and knowledge sharing mechanism within the proposed architecture are also discussed. This integration can support for efficiently plan and execute work with an integrated solution that connects the organization's maintenance, supply chain, and financial applications.

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