An Integrated Inspection System for Belt Conveyor Rollers
Advancing in an Enterprise Architecture

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Abstract: One of the most critical equipment used by mining companies is the belt conveyor. Thousands of kilometers of these elements are used for bulk material transportation. A belt conveyor system is composed of several components, and the maintenance process is not trivial and usually reactive. Thousands of dollars are lost per hour with the failure of a conveyor belt system. This occurs due to the lack of appropriate mechanisms for efficient monitoring and integration of this process to the enterprise systems. This paper presents a novel monitoring and integration architecture for a Brazilian mining company. The challenge is to provide a mobile control system and its integration with the current enterprise solutions. We also describe a set of restrictions for the particular component (rollers) in order to identify methods for the integration. Preliminary results demonstrate our solution is a feasible alternative for the case study.

1 INTRODUCTION

Belt conveyors are the most common means used to transport bulk material in the mineral industry. Despite their importance, there are still significant challenges to guaranteeing their operation under reasonable and safe conditions. Part of the problem refers to the equipment extent that ranges from a few meters to several kilometers. A small number of components is grouped on the head or the tail of the conveyor belt system, but most of them are spread along the belt conveyor extension, posing difficulties to their monitoring and servicing. One of the components that requires particular attention is the roller. A small conveyor belt of 150 meters has nearly 450 carrying rollers and 50 return rollers. Currently, the company has no solution to remotely evaluate the condition of a roller and trigger adequate actions on enterprise systems, such as opening work orders or requesting the purchase of new rollers, so inspectors manually input all the data resulting from inspections on such systems. This lack of integration leads to a wide range of problems, which vary from low-consequence typing errors to serious situations, where a defective roller is not replaced and may result in a belt catching fire. Therefore, the condition monitoring solution needs to be seamlessly integrated with enterprise systems. In this context, this paper reviews some of the available solutions to monitoring the status of rollers in conveyor belt systems and proposes an architecture to address the main requirements related to the integration of such solutions with enterprise systems used in the company. A Data Capturing Layer is proposed with the use of an Unmanned Aerial Vehicle (UAV) carrying different sensors to obtain condition data from the rollers. On-field preliminary tests demonstrate that the utilization of the UAV is feasible, as it can quickly get high-resolution images from several components; thus, reducing inspection time and increasing safety. Therefore, the main contributions of this paper are:

- A review of the main techniques to monitor the status of rollers and a discussion about some of the solutions
- An architecture to integrate the condition monitoring of rollers to enterprise systems

This paper is structured as follows: Section 2 states the main difficulties to monitor the condition of rollers and the consequences of the lack of integra-

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tion with enterprise systems. Section 3 describes key aspects of the rollers status monitoring scheme and discusses some of the solutions and their applicability as the Data Capturing layer of the integrated architecture. Section 4 presents the main requirements of related companies in the area and proposes a system architecture to address them. Section 5 reviews the concept of Enterprise Service Bus (ESB) and its role as a key component to integrate condition monitoring with enterprise systems. Section 6 describes the on-field tests performed with the UAV and related sensors to confirm the feasibility of the Data Capturing layer.

2 PROBLEM STATEMENT

Assets monitoring can follow two different strategies. One of the models currently in use is based on the type of inspection, in which tasks are split into several teams, such as mechanical, electrical, and hydraulic. Each team walks through the entire port and assess equipment conditions without using instruments. After that, they register the data in the Computerized Maintenance Management System (CMMS) requesting to repair or replace the faulty components through a Work Order (WO). This sensory and subjective procedure is known as **sensitive inspection**. This type of inspection uses tacit knowledge of the operators to identify problems on the components. Another approach is the so-called **predictive inspection**, in which teams use instruments to collect data from vibration, noise, and temperature for subsequent analysis in a specialist software. If necessary, a WO is manually created in the CMMS.

Regardless of the inspection type, the lack of integration between the collected data, the specialist systems and the CMMS presents several problems for the company. This is particularly critical in heterogeneous environments, such as the Maritime Terminal of Ponta da Madeira (TMPM), located in the São Luís, the capital of Maranhão State. The port is the end point of the logistical system that transports the iron ore extracted in the Carajás mining complex to load ships bound for Asia and Europe. This is the biggest port for the export of Brazilian iron ore and one of the largest in the world (ANTAQ - Agência Nacional de Transporte Aquaviários, 2015). The forecast is to embark 170 million tons (Mt) in 2017, which pushes its extensive and complex infrastructure to the limit. This infrastructure is composed by: 8 ship loaders, 8 car dumpers, 7 reclaimers, 5 stackers, 4 stacker-reclaimers, and 149 belt conveyor lines, totaling 120 kilometers of conveyor belts and around 200,000 rollers, scattered on approximately 500 hectares. Figure 1 shows the entire port area, which is bounded by the red polygon.

Figure 1: Maritime Terminal of Ponta da Madeira (TMPM). Captured from Google Earth.

Although it is not complex equipment, the belt conveyor lines are the primary asset of the port since stopping one of them impacts an entire embark route. The rollers are the most numerous and critical components, whose function is to support the conveyor belt and the material it carries, as well to receive the impact of material that is transferred between belt conveyors and the transfer points (i.e. chutes). Taking into consideration the enormous quantity of rollers in the mining industry, monitoring their condition becomes a significant challenge. Figure 2 shows some of critical points to be monitored, including rollers.

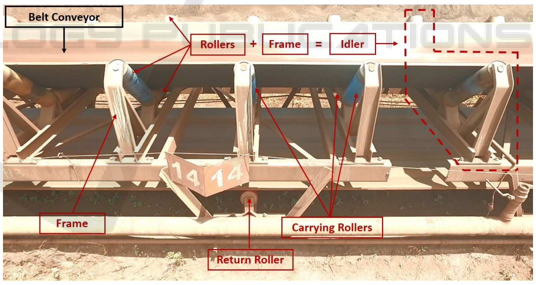

Figure 2: Section of a belt conveyor line.

Rollers suffer from severe wear and demands a higher frequency of inspection. Usually, the TMPM only uses sensitive inspection, where each one of the rollers installed in the conveyor belts is checked visually. Given that it is impossible to view the rollers on the other side of the belt, both conveyor sides should be covered. Given the large number of rollers, the use of a predictive instrument to collect thermal, acoustic, or vibration data becomes prohibitive because of the time it would take to collect such information manually for each roller. Another problem caused by the lack of integration between the specialist systems of instruments and the CMMS is the time required to create a manual WO for each roller. Without external tools to measure data, defect location depends on inspector experience. Furthermore, the uncertainty may lead to the replacement of all three rollers of an idler, resulting in unnecessary costs to the company.

Given that the port's resources and capacity to execute maintenance are limited, prior planning of all requested services must be carried out with mastery. The Maintenance Planning and Control (MPC) is responsible for prioritizing the WO from different inspection groups and regular maintenance plans. Due to a predominance of subjective criteria over several sources of information, it is difficult to define clear policies for resource allocation, including human resources. Therefore, the meetings with all stakeholders to determine the prioritization may not always achieve the best results since prioritization is defined by the persuasive power of the participants and not by technical aspects. The consequence is that if a critical task is not prioritized, the probability of equipment breakdown dramatically increases and may cause undesired operational shutdown resulting in additional costs and production loss.

A remarkable occurrence of a critical case was the fire that occurred in the belt conveyor TR-315K-36. Rollers were damaged and there was the loss of 300 meters of belt, as well as damage to all the electrical and automation systems. The fire was caused by a broken bearing of a roller of the catenary table. Figure 3 shows the damage caused by a maintenance failure. In this case, an inspection was performed a few days earlier, but the problem was not identified or the roller was not damaged at the time of inspection. A higher inspection frequency could have detected the problem, but due the large amount of equipment, and the limited human resources available its **impossible to increase visiting frequency with the current inspection methods**.

Figure 3: Fire on belt conveyor system TR-315K-36.

The fire of the TR-315K-36 was not an unfortunate coincidence, but a recurring problem whose consequence of the damage can be catastrophic. Data extracted from company's internal systems show that between 2014 and 2016, only in the ports of Ponta da Madeira (Northern System) and Tubarão (Southeast System), there was more than R$ 2.7 million in material losses due to fires caused by rollers failures, accounting for 600 hours of operational stops.

The occurrence of a high number of undesirable breaks can lead to a vicious cycle, since any unexpected breakdown causes the cancellation of a preventive service to attend the emergency service, and failure to perform preventive tasks can generate further breaks. Furthermore, it elevates the maintenance cost and operating losses, as well as the exposure of employees to risk.

Even with an automated and assertive inspection system, but without a robust integration between collected data and enterprise systems leads the company to face the same management and planning problems previously mentioned. On the other hand, an automated inspection process integrated with such systems will contribute to a greater assertiveness in the diagnosis of the failures, allowing greater inspection frequency of the assets, and finally technical prioritization criteria to be used by the PCM. Such improvements can contribute to new levels of equipment reliability, reducing maintenance costs and increasing production.

Considering that the belt conveyor rollers are the most numerous components of the TMPM and they present the biggest challenges in its inspection, this paper proposes an architecture to address the problems related to the rollers' data acquisition and the integration flow to enterprise systems.

3 BACKGROUND

This section presents the techniques to monitor the condition of rollers and some of the available solutions, discussing whether they can be adopted or not regarding the data capturing layer on the study case.

3.1 Techniques for Rollers Condition Monitoring

Before introducing the techniques to monitor the condition of a roller, it is important to present a brief explanation of its parts. A roller is composed of an outer cylindrical surface (cladding) with a pair of bearings (left and right) mounted on a stationary shaft (Reicks, 2008). With such structure, three primary defects can affect a roller: breaking, overheating, and locking. While the latter affects only the bearings and can lead to overheating, remaining failures affect both the bearings and the cladding (Xiao-ping Jiang and Guan-qiang Cao, 2015).

Since most of the failures originate on the bearings, the rollers' condition monitoring techniques must be primarily capable of assessing their state. Literature highlights three main monitoring methods according to the signal used: acoustic (Xiao-ping Jiang and Guan-qiang Cao, 2015), vibration (Tan et al., 2015) and thermal(Yang, 2014). Both acoustic and vibration analysis rely on the principle detailed by (Girdhar and Scheffer, 2004) where frequencies emitted by the bearing depend on its construction characteristics and faulty behaviors can be detected by unexpected frequencies with specific signatures. In brief, such techniques consist of signal capturing, treatment, and the extraction of features that indicate current defects or future failures. On the other hand, thermal monitoring consists of obtaining the temperature of the bearing at a specific instant, given that temperatures above a clear-cut threshold indicate that the idler roll has to be replaced immediately. An important consideration is that vibration and acoustic monitoring can detect failures at an early stage whereas thermal monitoring is reactive, as temperature rises only occur when the defect is already in a critical phase and there is little reaction time (Hawksworth et al., 2003).

This behavior refers to the discussion of online monitoring versus periodic inspections, which are performed in cycles defined by assets criticality and the availability of resources (human, tools, sensors). Sensor position and installation characteristics, such as fixed, semi-fixed/semi-mobile or mobile (Liu et al., 2014) change the monitoring cycle and are decisive in categorizing the system as online or periodic, as demonstrated in Figure 4. Fixed sensors are continuously monitoring the system (online) while mobile sensors (or semi-fixed) can monitor the system only during the periodic inspection. Although online monitoring is preferable in most situations, their adoption for belt conveyor systems poses significant issues that cannot be overlooked, particularly because of the following restrictions: a) the ability to obtain data from multiple components without yielding additional maintenance, and b) the installation and maintenance costs cannot be proportional to the number of monitored components.

This study describes the background technologies for the development of a solution integrated into the architecture proposed in the Section 4. This section represents a guide to define the technologies able to provide the final settlement for the Data Capturing layer.

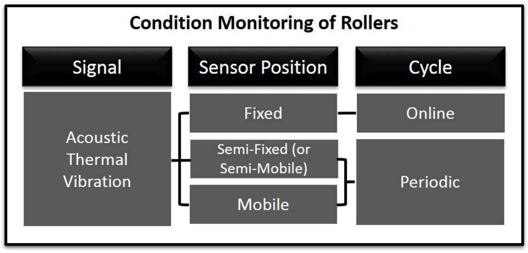

Figure 4: Diagram of the condition monitoring of rollers.

3.2 Available Solutions for Assessing a Rollers' Condition

One of the main discussed restrictions is the sensors installation and maintenance costs that can be prohibitive due to the huge volume present at the port of this study case, which is close to 200,000 rollers. In this scenario, the adoption of fixed sensors must be carefully appraised. Nevertheless, in 2007, (Lodewijks et al., 2007) proposed the concept of a "smart idler", an IoT solution that consists of a roller embedded with an electronic circuit containing a battery power supply, a RFID identification tag, a temperature sensor, and a radio for data transmission. As a prototype on early development stages, the author recognizes that the costs are forbidding (around 40% to 50% of the roller value) and requires battery replacement.

To address some of these issues, (Pang and Lodewijks, 2011) presents an evolution, where each roller (with sensors) has an energy harvesting system and roller-to-roller communication using self-healing networks. This strategy reduces the number of communication gateways and improves system's reliability. The authors do not detail the costs, but the incorporation of an energy harvesting system is prone to increase acquisition price and to reduce sustaining costs since the battery is no longer required. Some manufacturers, such as (Ingenuity, 2016; Vayeron Pty Ltd, 2016) already market similar technologies. The main handicap is the requirement to replace each roller of a conveyor system with a Smart model to obtain online monitoring; if a single roller is not replaced, the whole system is impaired. Conceded that the average lifetime of a roller is around 3 to 4 years, new projects are more likely to adopt such technology since it is hard to support scrapping the existing rollers to install Smart ones.

Another approach using fixed sensors, but which aims to reduce the number of sensing elements, is detailed by (Li et al., 2013). The authors propose to install a limited number of accelerometers on the outer structure of the belt conveyor system to obtain the vibration data of multiple rollers. They used Wavelet

Packet Decomposition (WPD) (Coifman and Wickerhauser, 1992) to decompose the vibration signals and determine the energy of each band as the feature of interest. Finally, they adopted Support Vector Machine (SVM) (Cortes and Vapnik, 1995) to classify faulty signals in different failure modes. The approach is promising, but they had to install one sensor for each three frames, corresponding to a distance of approximately 6 meters; what still means a significant number of sensors since some of the belt conveyor systems can extend themselves for kilometers.

Still discussing fixed sensors, (Hu et al., 2011) performed tests in an underground coal mine of a roller's temperature monitoring system based on optical fiber. The Distributed Optical Fiber Sensor (DOFS) uses optical fiber both as sensing and transmission media for roller temperature; an interesting approach to reducing the total number of sensing elements. The system is capable of self-diagnosis, detecting signal degradation and fiber disruption; another positive characteristic due to the harsh environment where it is used and the possibility of accidental damage during maintenance activities. (Yang, 2014) conducted a series of trials on a similar system and concluded that the technology is indeed suitable to perform condition monitoring on rollers, but requires a detailed analysis to define optical cable positioning in order to enhance temperature detection and insulate environmental influence (humidity, ambient temperature variance, ventilation, dust, etc.) from the results. This can pose a challenge to operations because of the diversity of belt conveyor systems and conditions found on mining operations, even though some commercial solutions with this technology are already available (AP Sensing, 2017; Yokogawa, 2017).

(Yang et al., 2016) describes an intermediate solution between fixed and mobile sensing. The authors developed a mobile robot that uses the existing structure of a belt conveyor system to perform inspections using infrared thermography of different components (rollers, pulleys, and motors). An inspection track is attached to both sides of the belt conveyor frame and vertically positioned between the carrying idlers and lower belt. The robot has an infrared camera and employs the gear-and-rack method to move along the track while continuously capturing images, which are processed with a combination of pattern recognition algorithms to identify components of interest and temperature. The use of the belt conveyor system's own structure can simultaneously be seen as the method's main advantage and disadvantage. While long belt conveyor systems can benefit from having a continuous monitoring system as proposed, it may not be economical to install one on all conveyor systems, particularly the short ones. It is reasonable to employ maintenance efforts to inspect and maintain a robot that can autonomously monitor a 900-meter conveyor system, but it is not feasible to do the same for a 20-meter belt conveyor line. Regardless of the extension, the existing belt conveyor systems can also present challenges regarding the required adaptions to installing the robot as proposed.

An alternative to installing sensors on each belt conveyor system is the use of mobile sensors. In this direction, the periodic inspections that maintenance personnel performs today can illustrate this method as long as they use adequate tools to collect acoustic, thermal, or vibration signals. Due to the risks, inefficiency, and other drawbacks already explained, it is preferable to adopt an inspection method that minimizes the need for humans on the field. Thereby, the patent requested by (Yong et al., 2014) claims the use of a multi-rotor UAV (i.e. drone) to carry out inspection missions. The main innovation is the autonomous navigation system, which uses reflective adhesives installed on the belt conveyor system and other structures to obtain the vertical and horizontal orientation of the route and the actions to be performed at each point. The UAV is equipped with a high-resolution camera for navigation, an infrared camera for inspection, a RFID reader, and gas concentration sensors for the use in coal underground mines, where methane can cause explosions. It also sends captured data to base stations, which can perform signal processing and retransmission. A similar solution is claimed by (ABB Technology AG, 2014), which proposes the employment of ground-engaging vehicles and cable drones for carrying the sensor structure besides UAV's.

The main advantage of these proposals when compared to the work of (Yang et al., 2016) is that the vehicle, aerial or not, can be used to inspect multiple belt conveyor systems in an industrial plant since they are not tied to one of them. On the other hand, an important question that arises is the limited battery autonomy, particularly with the adoption of UAV's. The fact that the vehicles have to carry a sensor structure and transmit data significantly contributes to the problem. Such limitation can be mitigated by the use of battery replacements and recharge stations, as discussed in (Suzuki et al., 2012) and (Michini et al., 2011).

Finally, although online monitoring methods are preferable, employing them on belt conveyor systems is not trivial. Even techniques that do not require installing individual sensors demands adjustments and individual assessment for each system to be monitored. Thus, we understand that mobile sensing using UAV's is the best alternative to carrying out the transition between status quo with a full dependence of humans to perform inspections at a whole new level where routine inspection is automated. Moreover, the proposed architecture plans to deliver seamless communication between the data capturing layer and other systems in the organization, which seeks to address several of the problems caused by the lack of integration. This can compensate some of the benefits of online monitoring, while the company prepares itself to adopt fully monitored systems using fixed sensors. The next section describes in more detail the requirements and the proposed architecture to address them.

4 PROPOSED SOLUTION

This section describes current enterprise requirements for belt conveyor inspection systems and proposes a new integration architecture between the new monitoring and existent enterprise systems.

4.1 System Requirements

System requirements were discussed together with the technical staff of the enterprise, while some of the authors have met the staff on site. Although technicians report several kinds of problems related to the belt conveyor system, roller monitoring was defined as the priority and focus of this paper. Due to this fact, Section 3 presents an evaluation of the kind of problems and the state-of-the-art solutions proposed. This assessment was necessary for the design of the integrated architecture.

A second requirement of the company is to reduce the need for human interference and presence in the belt conveyor system while obtaining technological platforms for remote monitoring. This fact significantly reduces human risks.

Static sensors are not a choice to be considered along with the belt conveyor system. This approach increases the demand for maintenance. For instance, if cameras are placed on the belt conveyor system, they should require periodic maintenance, as do the rollers. In this case, the use of mobile sensors should be the better solution.

Mobile Robots and Unmanned Aerial Vehicles (UAV's, i.e., drones) are alternatives for the monitoring system. On the other hand, these devices bring the challenge to integrate them with the enterprise systems. At the same time, a friendly user interface is necessary for the specialist technicians to evaluate the need of roller maintenance during remote assessments and to give support for them on the inspection. The board requested a software interface that provides the information for the user in real time through an algorithm that is able to make the analysis based on data captured from the sensors. This module was named as **Assistance Module (AM)**.

The next section presents the system architecture as a proposal to solving the problem. The structure is shown in layers and represents the integration of all the monitoring process from the sensor equipment to the strategic analysis. Although this paper focused on the rollers, since they are the main assets of the port, the architecture here proposed is generic and can be adapted to address other industrial problems, such as the inspection of transmission lines, wagons, confined spaces, and others.

4.2 System Architecture

Figure 5 shows the proposed architecture for an integrated monitoring system. All layers have a user interface except the ***Data Capturing*** and ***Legacy System Integration*** layer. The user interface appears after processing the data collected by the sensors on the ***Sensors Data Extraction*** layer. The shaded area in the Figure 5 represents the user interface level. The dashed area represents the IoT components presented on the architecture. Both components are discussed in the Section 4.3. Afterward, each layer and the components are described.

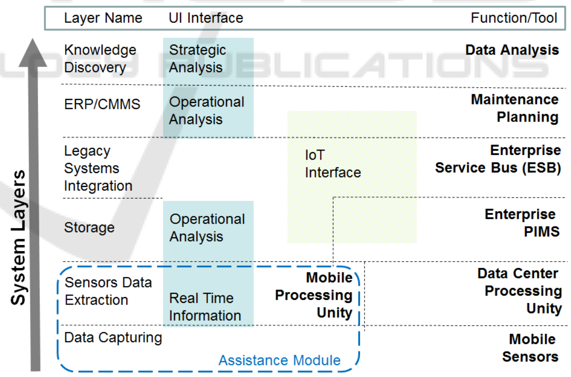

Figure 5: System Architecture.

Data Capturing: This layer represents the sensors used to capture data on the belt conveyor system. A mobile sensor for monitoring should be utilized as described in the system requirements. We should use many kinds of sensors, according to what is shown in the Section 3 when connecting to a robot and a drone. For instance, a drone can use a camera as a sensor providing images or streaming videos for the manual/automatic analysis. Besides, the video stream should be processed in order to identify and notify some anomaly to the operator. This procedure is executed by the next layer and is described below.

Sensors Data Extraction: processes the raw data captured on the previous layer. We define two subclasses of processing unity on this layer: ***Mobile Processing Unit***, and ***Data Center Processing Unit***. The mobile processing unit represents embedded hardware with power computing capability connected to the robots or UAVs. This component is necessary due to the use of mobile platforms, and the raw data collected by sensors should be processed into MPU. For instance, the stream obtained from a microphone can be processed, and an unusual noise that represents a roller's anomaly can be detected; then, an event should be generated. The environment monitored can have no conditions for providing the connection among the sensors and information technology (IT) infrastructure. The absence of this component makes the **assistance module** an unfeasible alternative. Algorithms unable to be executed on embedded platforms have to be performed in data center processing units. In this case, the data collected from the sensors are stored in the secondary memory of the mobile platform and transferred when the mobile platform has a connection available.

Storage: This is the first layer of the architecture that demands integration with third-party systems. The process information management system or plant information management system (PIMS) is a historical database that receives data from several sources. In a second phase, this data is used for the production of statistical information provided by the PIMS functionalities. The current version stores data from many different industrial components and the data collected from the mobile sensors should also be stored into PIMS. This way, the engineers and technicians can make an operational analysis about the status of the belt conveyor system.

Legacy Systems Integration: The current systems available in the company can receive data from legacy systems using the concept of Service-Oriented Architecture (SOA). Several services are already available on the Enterprise Service Bus (ESB) via API's, web services, message queues, etc. They can receive data from bottom layers and provide it to enterprise systems, and can send information from such systems to the layers below. Due to this feature, a ***Sensor Data Extraction*** layer can release sensor data to these systems without creating additional services. This layer is essential for the integration of the new components of the monitoring system and the other systems available in the company. Due to this fact, the Section 5 provides more details of this layer.

ERP/CMMS: Layer of the integrated system used for maintenance planning. The main bottleneck of the current practice in the company is to receive data from the systems contained in the previously mentioned layers. In some cases, there are no sensors to identify maintenance demands and the process is wholly dependent of human verification. Currently, the company uses the SAP Plant Maintenance (SAP-PM) as its CMMS system, which is part of the SAP ERP. No further details can be discussed about the ERP and other systems due to company restrictions.

Knowledge Discovery: This is an additional layer compared with the current version of the company's enterprise system. This new layer uses data mining and machine learning algorithms in order to identify and extract new features and knowledge. Such results can be used in expert systems or modules at the ERP/CMMS layer for operational analysis, making decision-making smarter and more autonomous.

4.3 User Interface and IoT Components

Besides the services that each layer provides, they may interact with User Interface services and IoT Interface services. This section describes these relationships.

User Interface: Users can receive information about the maintenance status in distinct granularity. This means that the architecture provides different levels of analysis. Real Time Information represents the information retrieved for the user while a conveyor belt line is on inspection. Operational Analysis provides information about the status of the components from a short period of observation, and Strategic Analysis is information retrieved for the user related to the long-term maintenance planning as well as new information generated by the use of data-mining algorithms.

All layers, except Data Capturing and Legacy Systems Integration, include a User Interface. Table 1 summarizes the relationship between each layer, the type of human analysis, and a user interface example.

IoT Interface: Some components of the belt conveyor system have machine-to-machine communication and can perform an IoT application, such as the smart-idlers, discussed on Section 3. Although it is not the focus of this paper to incorporate these elements, they are represented in the architecture proposed for further integration. Relevant information should be delivered to the users, considering the aggregation of the data collected from IoT components and the monitored rollers.

5 SYSTEMS INTEGRATION

As discussed on Section 2, a central contributor to the existing problems is the lack of effective integration between inspections and enterprise systems, thus impairing the information flow from different sources and jeopardizing maintenance planning, procurement, and other processes. The company already has in place an Enterprise Service Bus (ESB) with different services that can be used to seamlessly integrate the Sensor Data Extraction layer (at this moment, referred to as SDE) with corporate systems. The reuse of existing services on the ESB brings several benefits to the company: (i) the deployment of new tools is faster and cheaper, considering that most of the integration capabilities can be delivered without creating additional services and (ii) also facilitates communication with the use of adapters for different standards and protocols.

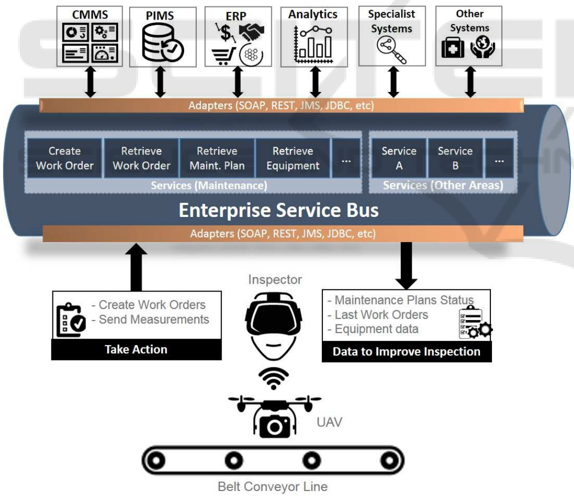

Figure 6: Use of an ESB to integrate inspection to enterprise systems.

Figure 6 presents a practical example of how the proposed architecture takes advantage of the existing ESB. Some of the available services expose the CMMS data, such as work orders, maintenance plans, and master data of equipment. As the UAV inspects the belt conveyor system, the SDE can use a combination of these services to display information to the inspector, such as the status of the latest work order created for the inspected roller combined with manufacturer information and the component's installation date. As the CMMS also exposes services that allow external systems to manipulate its entities securely, the SDE can send the current temperature of a roller and allow the inspector to create work orders right from the user interface as soon as it detects a failure. This set of possibilities reduces rework and give maintenance planners a view of the situation right from the inspection, addressing most of the gaps discussed. Such benefits are not restricted to the CMMS system and maintenance processes. The integration with environmental monitoring systems can display live information of weather forecasts, wind speed and direction, aiding in UAV teleoperation avoiding possibly dangerous situations.

Finally, all the raw data captured during the inspection can be stored on PIMS using its services. Later, specialists, along with analytics systems, can read and analyze inspection results from PIMS. This reduces the effort to deliver the architecture of Section 4, as such systems also use the ESB to communicate among them with several services already available.

6 PRELIMINARY EVALUATION

In order to improve awareness of the difficulties faced by the inspector on the field and to confirm the feasibility of the proposed Data Capturing Layer of the architecture, some preliminary tests were executed. The equipment used to perform the evaluations was composed of DJI 3 Professional UAV, equipped with a full-HD camera mounted on a gimbal stabilizer, an UltraProbe 10000 for audio acquisition, and an FLIR i5 thermographic camera. As a preliminary evaluation, each equipment was tested independently. The integration of all components, data transmission and integration with enterprise systems are not the focus of these specific tests and they are planned as subsequent steps of the project.

A certified and experienced operator piloted the UAV, keeping a constant altitude while positioning the UAV parallel to the belt conveyor line (BCL) and focusing the full-HD camera to obtain lateral images of the BCL that contain central and lateral rollers. Despite the wind, the operator was able to make the UAV follow the desired route, capturing high-quality images of the belt, the rollers (both central and lateral), and the complete lateral structure of the BCL. A second flight obtained images of carrying and return rollers. The simple execution of this test demonstrates an improvement on operator safety as the simulated inspection was performed from a fixed pilot location, eliminating risks related to incidents with venomous animals and drops. Besides, the total time spent to si-

Table 1: User Interaction by layer.

Layer	*Type of Analysis*	*Description*	*Interface Example*
Sensors Data Extraction	Real time/Online data	Provided by embedded algorithms	Head Mounted Displays, tablets, smartphones with virtual reality and augmented reality capabilities.
Storage	Operational Analysis	Statistics information from PIMS	Reports and graphics
ERP/CMMS	Operational Analysis	Statistics information from ERP/CMMS	Reports and graphics
Knowledge Discovery	Strategic Analysis	Resulting information data mining and machine learning algorithms	Reports and graphics
User Application	Strategic Analysis	Use of the new information for creation new expert systems	Experts systems

mulate the inspection was 3min 40s, with 456 rollers filmed. Comparatively, an average walking along the BCL at a walking speed of 1.4m/s plus two seconds to assess each roller would take 17min 54s (Long and Srinivasan, 2013). During the simulated inspection, the pilot was not flying at full speed and made several stops, but the quality of images obtained shows that no stop is required and the UAV could fly at a higher speed, reducing even more the inspection time. Taking into account that the flight was over 228 m and the maximum speed is 16 m/s, the UAV used can cover this distance in only 14.25 s. Figure 7 shows the UAV performing the flight besides a belt conveyor on a real production environment.

Figure 7: Simulated inspection with an UAV over a real production environment.

The second test obtained audio signals from eight lateral rollers. The average setup and recording time using the UltraProbe 10000 for each roller was 20 seconds. During the tests, an early-stage defect on the bearing of one of the rollers was identified - so an additional time of 40 seconds was spent to confirm which roller was originating the signal. The defect identification depends on the experience of the inspector who needs to concentrate on the audio reproduced by the headset. The instrument has an alarm, but this does not reduce the required attention while listening to the audio.

Finally, a thermal shooting was performed. The thermographic camera allows to assess multiple rollers at once, but the inspector needs some time to identify the hottest point of the image and its temperature. Since the tests were performed on a hot day, sometimes the camera identified the soil in the background of the BCL as the hottest point. This is an additional problem because sometimes the soil temperature mixed with the bearing temperature, and the inspector took longer to confirm roller failure. For safety reasons, to avoid stumbles and drops, the inspector needed to stop on each idler to evaluate the image, which increased the total time required for inspection.

According to the results of the individual evaluation of the sensors and the UAV, the Data Capturing layer of the proposed architecture is feasible regarding equipment. The merging of individual sensors with the UAV, the adoption of algorithms to aid the inspection, and the integration with enterprise systems will bring more accurate defects detection, reduce rework, and improve the maintenance planning routine.

7 CONCLUSION

This paper presented several challenges related to the data acquisition of rollers installed on belt conveyors and how the lack of integration of such information with enterprise systems affects the management and maintenance activities. We proposed a mobile data-capturing layer with the use of a UAV with embedded sensors that seeks to bring more accuracy in defects detection and reduce manual steps in the maintenance processes. We also proposed an Enterprise Architecture to integrate the condition monitoring with existing enterprise systems, improving the on-field inspection and providing a holistic view of all belt conveyors present in the port of the study case. A set of preliminary on-field tests to evaluate individual equipment demonstrated that the feasibility of the mobile data capturing unity has promising results regarding inspection time and assertiveness. Although, to embed sensors in the UAV, to develop algorithms to process and present data to inspectors are still challenges to overcome. Therefore, future work will concentrate on the following:

(i) Embed different sensors in the UAV and perform on-field testing to validate data acquisition

(ii) Create and embed algorithms in the UAV to efficiently detect defects on rollers, integrating the outputs with the user interface to improve inspection

(iii) Evaluate power consumption of UAV and sensors, developing solutions to improve battery autonomy

(iv) Develop API's on the ESB to integrate the mobile data capturing unity with enterprise systems

(v) Develop semi-autonomous and fully autonomous navigation algorithms in the UAV

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