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HEALTH MONITORING OF MINING CONVEYOR BELTS

Shuvashis Dey[1], Omar Salim[2], Hossein Masoumi[3], and Nemai Karmakar[4]

ABSTRACT: The paper presents a new methodology for monitoring health conditions of mining conveyor belts using Radio Frequency Identification (RFID) based sensors. The existing monitoring technique is based on simple visual inspections which is quite labor intensive and do not provide accurate health condition of the conveyor belt. The new methodology based on UHF chipped and chipless RFID sensors provides highly sophisticated real-time monitoring schemes for different conveyor belt health parameters such as cracks. When combined with machine learning algorithm-based approach, the proposed technique can detect and predict wear and tear over the entire belt. Simulation results show that the proposed methodology offers high accuracy in detecting cracks with width of 0.5 mm and demonstrates the efficiency of RFID sensors to track the crack orientation in the belt.

INTRODUCTION

Zipper failure and conveyor belt rips induce a great safety, maintenance and financial concern for the coal mining industry. Many injuries and fatalities in coal mines have been caused by such failures. The conveyor belts carry thousands of tonnes of materials per hour and a stoppage in their operation for a mere minute causes the industry to lose a significant amount of revenue between $600 and $1800 Australian dollars per minute (Owen, 1997). To address such issues, many systems for monitoring health of the conveyor belt have been designed in the past to prevent or even reduce the damage of longitudinal belt rips. The first system mentioned in Davis (1987) depends on the mechanically operated devices that use two cables installed under the belt with alarm buttons on each of its sides. Ultrasonic operated devices are also used, which show the differences in the power of received signal if the belt undergoes longitudinal rips. The main problem of using ultrasonic devices is the coupling of the high-frequency waves to the belt materials as well as the impact of air and dust on them. Moreover, the ultrasonic system requires high maintenance and it only works in some special scenarios of the belt. Other systems use electrically operated devices that consist of a stationary transmitter and receiver as well as conductive loops across the width of the belt from edge to edge. The conductive loops must be very large to achieve good coupling between the transmitter and receiver leading to high maintenance cost. Current belt temperature measurement techniques include thermal imaging cameras and non- contact thermal measurement systems. The most recent studies by Yang, et al., (2014) and Li, et al., (2018) investigated the use of machine vision detection for longitudinal rip of conveyor belt. The system based on machine vision is quite expensive and requires high installation and maintenance cost. Moreover, the rip detection based on machine vision is usually influenced by external light sources and electromagnetic noise. In this regard, the passive Radio Frequency Identification

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(RFID) technology could offer a simple solution for monitoring the health of conveyor belts and it provides absolute robustness in harsh environments.

RFID BASED SENSORS

Recent advances in combining sensor and sensing technologies with RFID systems can monitor and share information about the surrounding environment by using sensor-enabled tags. An object that simultaneously provides its own condition and identification simplifies the total infrastructure and enhances the quality of information. Designing appropriate sensors and their associated measurement circuits currently pose a challenge towards developing a low-cost intelligent sensing system; passive RFID sensors shown in Figure 1 can be an excellent solution for this challenge (Subhas, 2013). Passive electromagnetic (EM) transduction based RFID sensors are employed to detect a range of physical parameters to address different sensing parameters relevant to the belt. The sensors are proposed to be integrated into the belts and they are interrogated by RFID reader to obtain their electromagnetic signature which is displayed at operator's dashboard in central database management center.

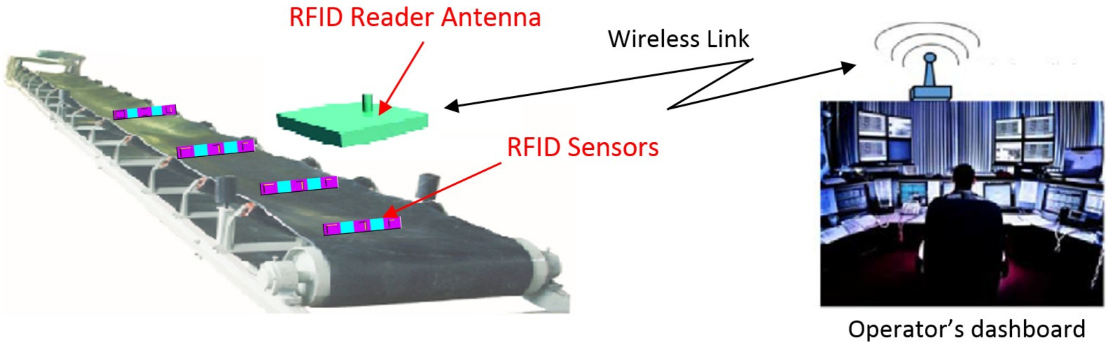


Figure 1: Generic diagram of a conveyor belt with integrated RFI sensors.

Such signatures contain information about the belt health and thus enable the detection of any inconsistencies such as a rip in the belt. Here, the detection of cracks using chipless RFID sensors is achieved by observing the resonance frequency shift compared to that of the one in the intact state, while the change of the received signal strength indicator (RSSI) from the UHF RFID sensor is used to detect the cracks in the belt (Dey, et al., 2015). The machine learning technique is also proposed to analyse the RFID sensor extracted data and enable the prediction of any disruptions on the entire conveyor belt such as applied pressure, local temperature, humidity, and gas concentration. Identifying these physical parameters is important in manufacturing, biotechnology, pharmaceuticals, precision agriculture and consumer goods applications (Das, 2015, Dey, et al., 2015). These sensors can also be used in structural-health monitoring systems to detect strains and cracks in aerospace, military, civil or architectural structures as well as mining industry. The tremendous robustness of RFID sensors in harsh environments has been proved recently (Popperl, 2016).

Monash Microwave, Antenna, RFID and Sensor (MMARS) Laboratory within the Monash University has successfully developed RFID sensors for different practical applications such as crack detection and monitoring (e.g. Kalansuriya et al. 2012, Dey, et al., 2014, Dey, et al., 2015), humidity sensing (e.g. Amin et al. 2013, Amin, et al., 2013, Amin, et al., 2014), precision agriculture (Dey, et al., 2016) and multi-parameter sensing (Amin, 2016).

MACHINE LEARNING

Machine learning is a data analysis technique which can automate analytical model building. In other words, it is the science of enabling computers to perform without being explicitly programmed. It can be used to augment human ability to come up with solutions for different types of problems and make informed decisions on them. Machine learning can be applied to solve a variety of issues starting from diseases diagnosing to even global climate change. This is a specialized branch of artificial intelligence (AI) which lets a system to learn from data, identify patterns and make inferences with least human involvement. Machine learning has iterative characteristics, which allows the system models to independently adapt when they are exposed to new data. It lets the models to learn from preceding computations to generate consistent and repeatable results. As for example, the RFID sensor generated temperature and strain data can be used with the machine learning algorithm t*o develop* a failure prediction tool.

NEW METHODOLOGY USING RFID SENSORS

Figure 1 shows a new methodology for monitoring health conditions of mining conveyor belts using RFID based sensors. As shown in Figure 1, the proposed RFID based wireless sensing system deploys UHF chip based as well as chipless RFID sensors

SIMULATION RESULTS AND DISCUSSIONS

In this section, a conveyor belt made of a combination of four aramid fiber and three reinforced fabric layers is designed using Computer Simulation Technology (CST) Microwave Studio software, as shown in Figure 2. The RFID sensor based on chipless tag is also designed here using Taconic TLX-8 substrate material. The dielectric constant of this material is 2.55 and the loss tangent is 0.0019. The simulated operating frequency range of the designed tag is 2-3 GHz. The CST simulation is conducted to perform the following analyses as well.

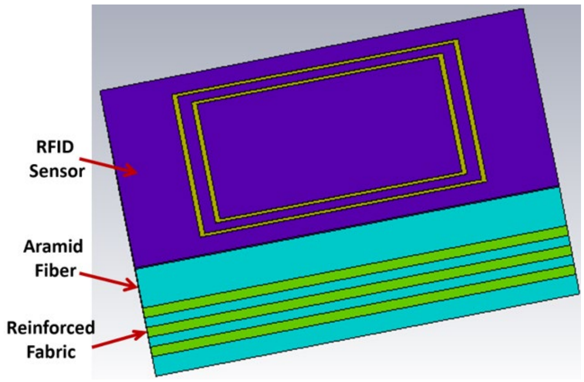


Figure 2: CST Design of conveyor belt along with the RFID sensor

RCS response

The backscattered radar cross section (RCS) response of the sensor is extracted and analyzed by interrogating it using a vertically polarized plane wave as shown in Figure 3.

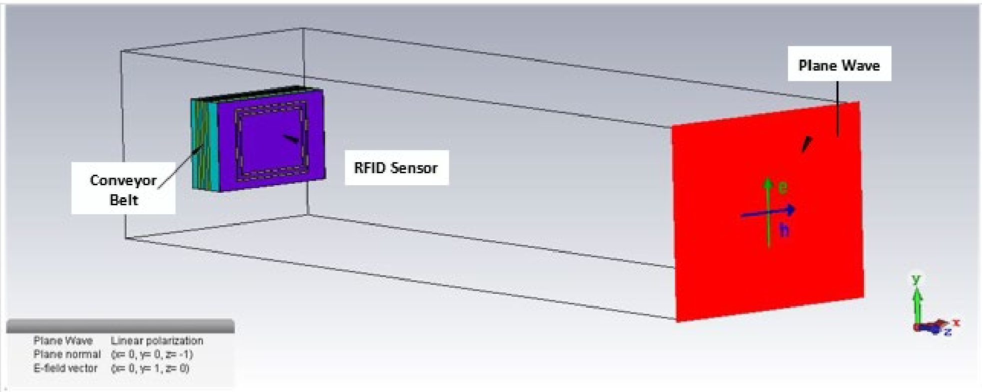


Figure 3: Sensor interrogation using plane wave

A comparative RCS response of the conveyor belt at the presence and absence of sensing tag is shown in Figure 4. As depicted, the belt alone provides a flat RCS response whereas the sensing tag has a resonating notch of about 20 dB with a resonance frequency at 2.74 GHz. This frequency is used as the reference frequency of the intact (healthy non-cracked) state of the belt to detect and measure the crack variation in the next analytical sections.

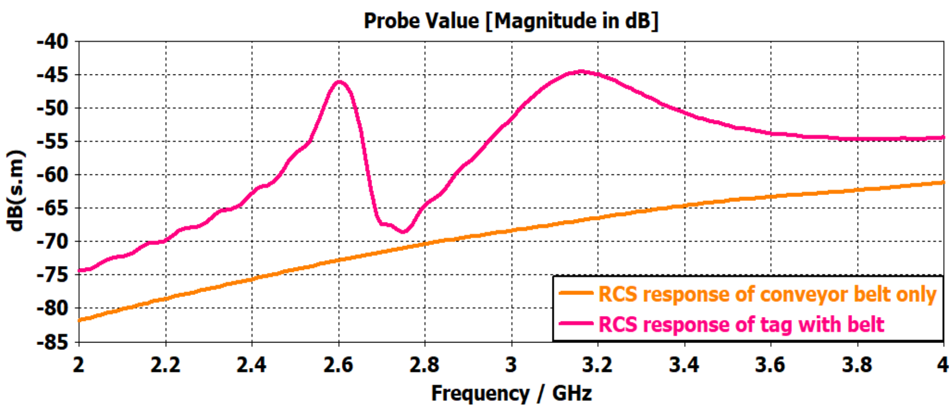


Figure 4: RCS response of the sensing tag compared to the belt response

Crack detection and analysis of its width variation

In this section, the sensor is used to detect cracks on the belt. Figure 5 shows the sensor with belt having a crack of 0.5 mm width. The comparative RCS response of the sensor for the healthy and cracked condition is shown in Figure 6. The crack introduces an apparent reduction in the dimension of the resonating arms and this in turn interrupts the electrical current path inside the tag's structure. This results in a resonance frequency shift of the sensor by 47.65 MHz from that of the intact state. Such phenomenon clearly indicates that the RFID based sensors have the ability to detect cracks even if their width is very narrow.

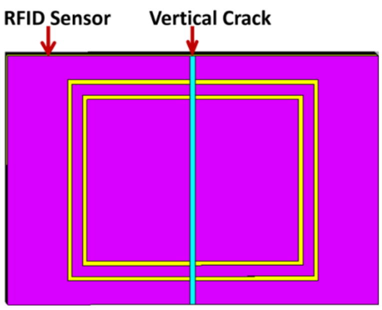


Figure 5: RFID sensor with crack

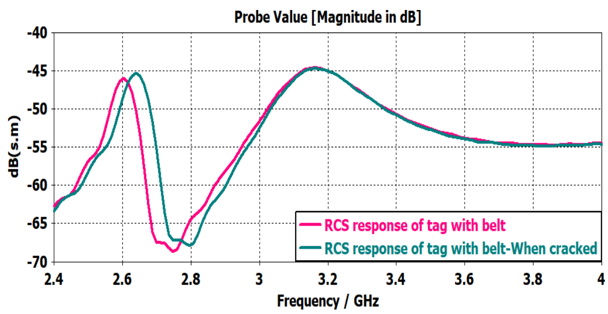


Figure 6: Comparative RCS

Response of sensor

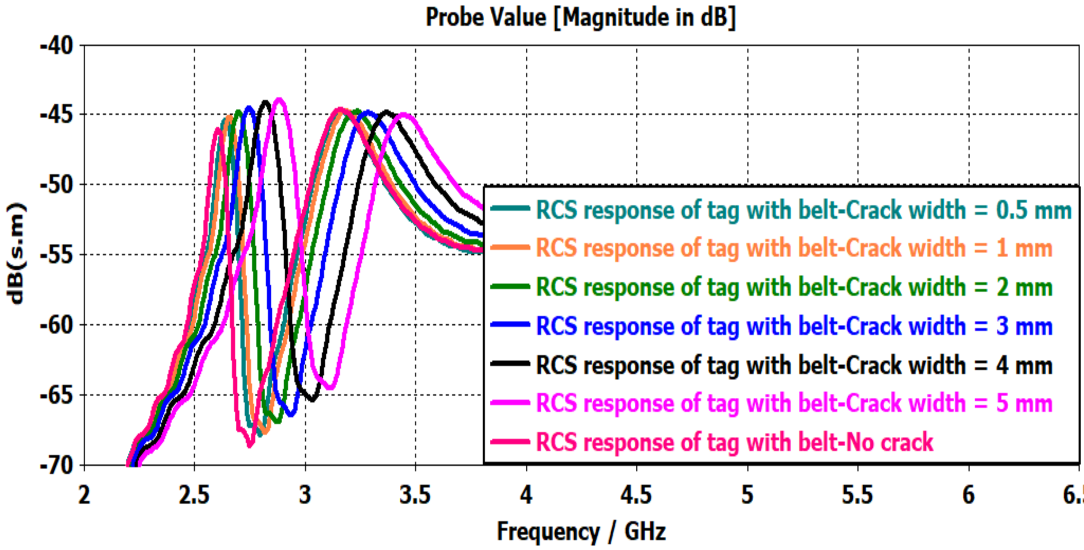


Figure 7: RCS response of sensing tag at different crack width

Figure 7 shows the RCS response variation of the sensing tag for different crack width ranging from 0.5-5 mm which corresponds to the resonance frequency shift between 47.65 - 370 MHz. As observed from the figure, the resonance frequency shift can suggest the presence of a crack in the belt whereas the value of the resonance shift can indicate the crack width.

Figure 8 shows the resonance shift of the sensor for different crack width. As illustrated in the figure, the RFID sensor can track the crack variations since the shift of resonance frequency has a linear relationship with the crack width. The result in Figure 8 also clearly shows the ability of the RFID sensor to monitor the health condition of the belt. Such monitoring can help making a decision to manage maintenance actions such as mechanical services, repairing and replacement.

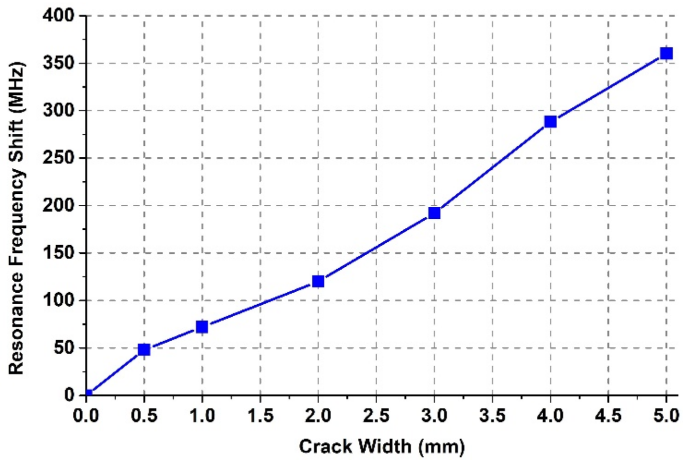
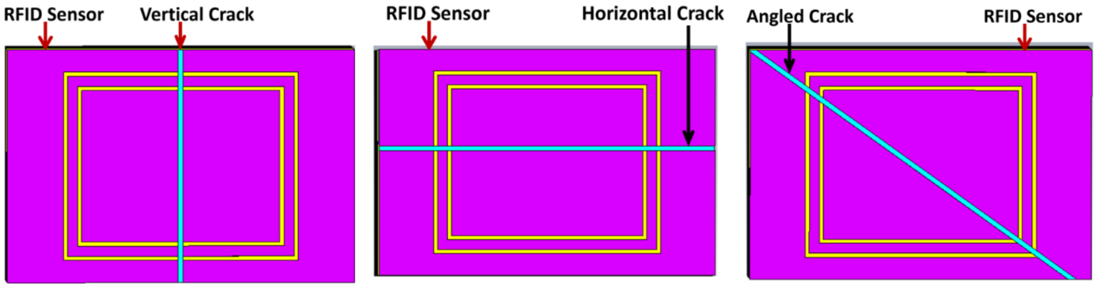


Figure 8: Resonant frequency shift of sensor for different crack width

Crack Orientations

In this section, the RFID sensor is analyzed for different crack orientations such as vertical, horizontal, and angled crack propagation in the belt as shown in Figure 9.



(a) Vertical crack (b) Horizontal crack (c) Angled crack

Figure 9: RFID sensor with different crack orientation

The RCS response of the tag at different crack orientations is illustrated in Figure 10. As shown in the figure, the nature of RCS response is varied based on the orientation of crack. When compared to the response of an intact state, the vertical crack incurs a linear shift of resonance (as observed in figure 6, 7 and 8). However, for a horizontal crack, an abrupt shift of 2.29 GHz is encountered as the resonance frequency changes to 5.03 GHz from the intact state resonance of 2.74 GHz.

For the angled crack, the resonance notch appears to get split into two separate notches with a significantly shorter RCS depth. The results depicted in Figure 10 clearly shows that the orientation of crack propagation on the belt can be identified based on the RCS response of the sensor

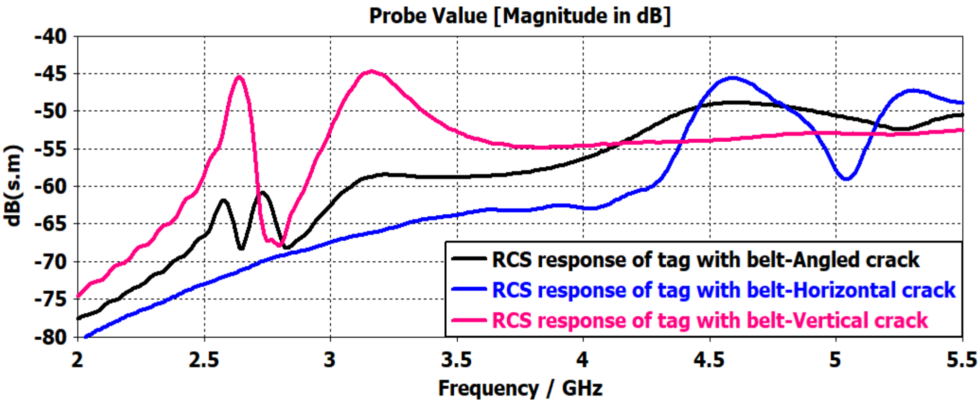
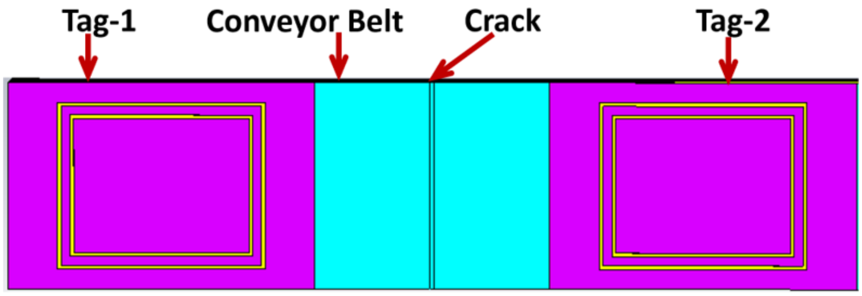


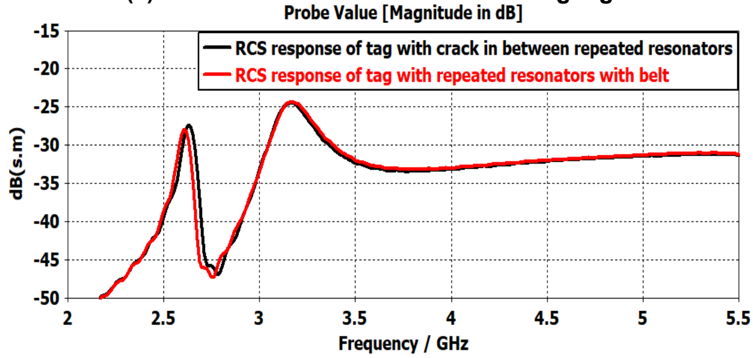
Figure 10: RCS response of tag at different crack orientations

Crack propagation in between sensing tags

This section describes the RCS response of crack in between the tags (severing the belt only). In this analysis, a crack with the width of 0.5 mm is propagated through the conveyor belt without perturbing any of the tags, as shown in Figure 11 (a). Figure 11 (b) shows the comparative response of the scenarios when a crack is present and absent in between the sensing tags. As observed, the resonance frequency of cracked condition is shifted by 54 MHz compared to that of the intact state.



(a) Crack in between two sensing tags.



(b) Comparative RCS response of crack presence and absence between two sensing tags.

Figure 11: Crack propagation in between sensing tags

The result in Figure 11 highlights a significant use of RFID sensors to monitor conveyor belts since the crack is detected even if it is not occurred in the sensor structure itself. Therefore, it can be deduced that the RFID sensors can be used to detect the presence and growth of the crack irrespective of whether it propagates through both the belt and the sensor structure or through the belt only.

CONCLUSIONS

This paper provides a brief overview of the RFID based conveyor belt health monitoring system. A proof of concept of the sensing scheme is provided by using a simple chipless RFID based crack sensor design. The simulated analysis depicted that the sensor is able to detect the presence and growth of a crack on the belt surface. The future analysis of such sensing system would involve the fabrication and field measurement of the sensor. The extracted information from the field test will be used as training data set for machine learning to develop a reference/calibration data set. When the sensors are deployed in a mass scale for sensing operation, such reference data set can be used for analyzing any random sensor response. This will enable an efficient integrity testing of conveyor belts and will eventually reduce the zipper failure by a significant scale and hence make the Australian coal mines a better, secure and safe place for the workers.

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