An IoT Solution to Detect Overheated Idler Rollers in Belt Conveyors

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***Abstract*—It is common knowledge that mechanical systems need oversight and maintenance procedures. There are numerous prevalent operation monitoring techniques, and in the era of IoT and predictive maintenance, it is possible to find multiple solutions to supervise these systems. This article describes the design and implementation of a low-cost system, which use an IoT approach to detect overheated idlers in conveyors belt in mining facilities. The system involves the use of temperature sensors, coordinately with heat map image sensors. The users (i.e., mining operators) can monitor overheated idlers in the whole conveyor belt, making on-demand queries using Telegram or a website, and also receiving autonomous warnings. Prototypes of this system were installed on a conveyor belt at a construction materials manufacturing company, and also in a copper mining company, both located in Apurimac, Peru. The usability and usefulness of the system were evaluated by 20 experts in maintenance and operation of conveyor belts, who filled the questionnaire proposed by TAM (Technology Acceptance Model). The results show that 91% of them consider the system useful for detecting the overheating of idlers in a conveyor belt, and 93% of them considers the solution as easy to use.**

***Keywords*—IoT system; overheated idler detection; conveyor belts; mining companies; autonomous and on-demand monitoring**

I. Introduction

Conveyor belts have a wide range of uses across various industries due to their versatility, efficiency, and ability to transport materials smoothly and continuously. Some common uses include, e.g., a) mining industry, where they are used to transport bulk materials such as coal, ore, minerals, and aggregates from the mine site to processing plants or loading docks; b) manufacturing and assembly lines, where they facilitate the movement of components or products along production lines; c) agriculture, where they are utilized for handling bulk materials like grains, seeds, fertilizers, and harvested crops; d) baggage handling, since they ease the transportation of luggage.

In mining industry, conveyor belts are indispensable, providing a reliable, efficient, and safe means to transport bulk materials. Their versatility, adaptability, and automation capabilities contribute to improved productivity, safety, and profitability in mining operations worldwide. Overland conveyor systems are frequently used for long-distance material transport in mining operations. These systems typically consist of a series of conveyor belts, supported by idlers or rollers mounted on a frame structure. Overland conveyors can span several kilometers and are used to move bulk materials between the mining site and processing facilities, stockpiles, and transportation hubs.

In this scenario, the random failure idler rollers is the main concern for conveyor operators [1]–[3]. Every belt, depending on its features, can involve hundreds or thousands of idler rollers. Under normal conditions, the life expectancy of an idler roller on a conveyor belt ranges between 6 and 24 months. The failure of a single idler roller can jeopardize the operation of the whole belt, producing a major incident or a stop to perform unscheduled maintenance activities.

Failed idler rollers significantly increase energy consumption during its operation and may seriously damage conveyor belts. It also increases the maintenance costs, but particularly the economic lost produced by the downtime of belt conveyor systems [4]-[5], which depending on the length of such a time window and the mining activity, the downtime period can cost some millions of dollars. For these reasons, the early detection of overheated idlers in belt conveyors is mandatory in the mining industry.

The failures of idler rollers can be divided into three types: *incipient failure* (failure due to bearing fatigue), *final failure* (the roll must be replaced immediately), and *catastrophic failure* (in which the roll would severely damage the conveyor belt) [6]. The malfunction of inner bearings is the most prevalent cause of failure for idler rollers [6]-[7]. In order to address the maintenance, there are some well-known strategies: online maintenance, portable maintenance, and onsite maintenance [7].

Monitoring the deterioration of idlers deployed to support the belt conveyor is one of the primary challenges. Dusty conditions, excessive humidity, impulsive load, and temporary overloading can accelerate the deterioration of the idler's coating and rolling element bearings mounted inside the idler to provide rolling ability [8].

Typically, mechanical systems require oversight and routine maintenance. There are several approaches for overseeing belt conveyors, especially combining IoT technologies to perform predictive maintenance. Some of these solutions are limited to belt conveyors used in underground mining or overland mining [9]. Due to their large quantity and spatial distribution, it is still challenging to monitor idler rollers effectively [10]. Traditionally, this industry relies on routine human inspection to detect defective idlers, which is an intensive, inefficient, and expensive labor [11].

If we consider the use of idlers in conveyor belts for long distances, the monitoring activity becomes more challenging. Some of the regular problems in these belts include: a) *wear and tear*, especially in long-distance conveyor applications where they are exposed to continuous friction, impact loading, and abrasive materials; b) *misalignment*, it means idlers may experience misalignment due to uneven loading, structural misalignment, belt mis-tracking, increased friction, and premature wear on the conveyor belt; c) *belt damage*, it means idlers can cause damage to the conveyor belt, including belt edge wear, cover damage, and splice failures; d) *roller seizure*, it means that idler rollers may seize or lock up due to inadequate lubrication, contamination, or bearing failure and e) *environmental factors*, since idlers in long-distance conveyor belts are exposed to harsh environmental conditions, including dust, moisture, temperature fluctuations, and corrosive substances.

In addition, a mining plant is divided into three areas: *crushing*, *grinding* and *flotation*. The *crushing* area usually has a scheduled shutdown frequency of one stop every 10 days regardless of the weather in the operation area and the features of conveyor belts. The length of the maintenance period depends on several criteria (e.g., complexity and length of the belt), and it can go from two to three hours to the whole day in critical situations.

Similarly, the *grinding* area has also a scheduled shutdown frequency of one preventive maintenance stop period every month, regardless of the weather in that area; and the *floating* area considers one stop every three months, also considering several variables including the weather.

As mentioned before, the inspection of idlers on conveyor belts is crucial for ensuring optimal performance, identifying potential issues, and preventing costly downtime. The manual inspection (made by human) involves visual review of idlers by trained personnel, who visually check idlers for signs of wear, misalignment, damage and other issues. Typically, manual inspections are conducted during the shutdown periods. These inspections try to ensure the regular operation of the conveyor belts, and minimize the stop periods required for preventive maintenance.

Next section presents the related work. Section III describes the design and implementation of the system prototype. Section IV presents the system evaluation and Section V shows the obtained results. Section VI presents the main conclusions and the future work.

II. Related Work

Detecting failures in a conveyor belt is challenging, one way to address it is monitoring the noise. In that sense, Fedroko et al. [12] states that a reliable trouble-free operation of continuous transport systems requires regular monitoring and evaluation of each operational indicator. Particularly, advantageous evaluation technologies are those which allow the transport system to be monitored to the widest extent, in the easiest way to identify adverse parameters or locations of occurrence of undesired operational conditions. Such monitoring approach include acoustic visualization techniques.

Despite their undeniable advantages and great potential in the field of belt conveyance, they have been used only minimally. Particularly, the work reported in study [12] examines possibilities of using acoustic visualization techniques in belt conveyance with focus on selected functional parts.

Likewise, Chamorro et al. [13] implement multiple sensors and communication protocols along with computer vision for monitoring the health of a conveyor belt system. The data of the monitored variables is captured using industrial-grade sensors and conditioned in a PLC. This data is sent to a wireless radio frequency module that transmits wirelessly to a remote receiver paired to an IoT gateway. Images taken by a camera are simultaneously processed by a local computer, which runs a computer vision algorithm used to establish if the conveyor belt is operating normally. Both data, i.e., those retrieved from the sensors and the visual information, are sent to the cloud for remote users to monitor the system's operating conditions, and also to detect potential failures prior to their occurrence.

Dabek et al. [14] report an automatic procedure to detect overheated idlers in belt conveyors using fusion of infrared and RGB images. It was proposed to conduct routine inspections of machines operating under extremely harsh conditions in deep underground mines. Particularly, this paper proposes a mobile unmanned ground vehicle (UGV) platform, equipped with multiple data acquisition systems, to support inspection procedures. Even though maintenance personnel with the required experience can identify problems almost instantly, their presence in hazardous areas is restricted due to harsh conditions, such as temperature, humidity, and poisonous gas risk. Therefore, it is recommended to employ inspection robots that collect data, and algorithms for their processing. The authors propose combining red-green-blue (RGB) and infrared (IR) images to detect idlers that have become overheated.

The work reported in study [14] also presents a novel method for image processing, which uses conveyor-specific characteristics to pre-process the RGB image, and thus to reduce the number of non-informative components in the images collected by the robot. The authors then apply this result to the processing of IR images to increase SNR and detect hot spots in IR images.

Likewise, Liu et al. [11] conducted an experimental research on condition monitoring of belt conveyor idlers. Depending on the length of a belt conveyor, tens of thousands of idler rollers are susceptible to random failure. However, monitoring solutions for idlers of belt conveyors are underdeveloped, and this is because the selection of monitoring parameters remains arbitrary. This work seeks to determine which parameters can accurately determine the technical condition of idler rollers for monitoring purposes. According to the authors, measuring the temperature at the roll shafts is a simple and effective method for condition monitoring of belt conveyor idlers.

In Marasova et al. [15] the researchers examine the incorporation of RFID tags as information carriers to monitor conveyor belts (ozone-induced aging or accelerated thermal aging, damage to cover layers and the carcass, and ignition). During the monitoring, it is essential to document conveyor belt failures and the causes of damage, as well as any other issues that arise from using belt conveyors. The research results on RFID tags and an analysis of their thermal aging behavior show that it is easy to simulate the conditions of hot vulcanization of conveyor belts, particularly during splicing (as well as production) and ozone-induced aging of conveyor belts. The outcome of this article is a determination of the feasibility of implementing RFID technology in transporting mineral materials via belt conveyor systems in actual operations.

In the research papers mentioned above, the authors agree that idlers on the conveyor belt require scheduled supervision to verify the current status of each idler; however, sometimes idler overheating occurs suddenly. In this paper, we propose an IoT system that uses a temperature sensor and thermal camera to detect overheated idlers in belt conveyors. It allows inspectors to perform preventive inspections during operation and shutdown periods, by making queries to the sensors and receiving warnings through the Telegram Social Network. This online monitoring does not avoid the stops for scheduled visual inspections, but it reduces the length of these time windows and the unexpected stops. Both aspects positively impact on the operation costs of the conveyor belts.

III. Design and Implementation of the Prototype

In this section we describe the operational environment for which the proposed system was designed and built. We also describe the system architecture, and its main components and behavior. This section also presents the functionality to monitor the operation conditions of the idler rollers in conveyor belts.

A. Operational Environment

The prototype of the system is inside the green casing shown in Fig. 1; it is located near the idler of the conveyor belt. The system includes three main components: a) a temperature sensor that measures the temperature of the idler; b) a thermographic image sensor that obtains a heat map of the idler; and c) a video camera that takes snapshots of the current state of the idler rollers to see if there is dust or sand around it. This latter component also records video to see the movement and hear the noise that the idler could generate.

Fig. 1. The prototype installed in "MMG Las Bambas" mining company (Peru).

The prototype is placed near the idler on a conveyor belt, then the person responsible for monitoring can make queries using their mobile device through the Telegram social network, and the system responds with the temperature, photo, heat map or video depending on the request. This allows monitoring the heating of the idler on a conveyor belt over time.

B. System Architecture

The system architecture shows its main components, their externally visible properties, and their relationships (see Fig. 2). Particularly, the temperature sensor reads the data from the environment; such data is sent to the Raspberry Pi (local mini-server) and then sent through the Wi-Fi or Modem connection to the database server. If the internet connection is not available, the data will be stored temporally in the Raspberry Pi in "CSV" file. Then, when the internet connectivity is re-established, the cloud database server will be updated with the information, and the CSV file will be emptied. The temperature data is displayed to the client via a web browser, tablet PC or cell phone.

On the other hand, the system uses an Arduino board. It connects to the thermal sensor that reads the thermal image, and then sends this data to the mini–Raspberry Pi server and the database in the cloud.

The users utilize the Telegram application to request temperature or thermal information, and the system answers accordingly. Moreover, the users can also request an instant photo or video. That request is sent to the Raspberry Pi, and then to the web server in the cloud. The system answers to the user through messages in the Telegram social network. This image or video cannot be delivered to the user without connectivity, so it is stored locally on the Raspberry Pi board. Fig. 2 shows the system architecture, and next subsection describes its components.

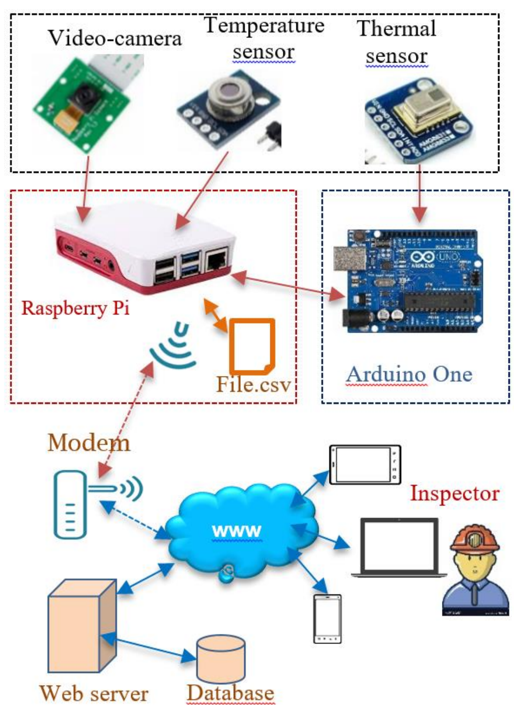


Fig. 2. System architecture.

C. Sensors and Devices

Table I shows the list of the sensors and devices required for the implementation of this prototype.

D. System Technology

The system programming was carried out using several languages, libraries and tools; the details are shown in Table II.

TABLE I. SENSORS AND CONTROLLERS

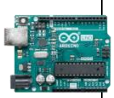
Component	Description	Image
Arduino One	It is a board based on the ATmega328P microcontroller. It has 14 digital input/output pins (6 of which can be used with PWM). It has six analog inputs, a 16Mhz crystal, a power jack connector, USB connection.	
Raspberry Pi 4 Model B	It has 4 GB of RAM (LPDDR), Dual Band Wireless LAN 802.11 b/g/n/ac, Bluetooth 5.0, 2 USB 3.0 ports, 2 USB 2.0 ports, Gigabit Ethernet Power-over-Ethernet, 40 GPIO connector pins, two micro-HDMI ports, CSI camera port, 3.5mm combo jack for analog audio and composite video, microSD card slot, USB-C connector.	
Temperature sensor (MLX90614)	It is an infrared thermometer to sense temperature (without direct contact but at a short distance). It has an internal 17-bit ADC; additionally, it has SMBus/I2C digital communication interface.	
Pi Camera	Camera v2 for Raspberry pi, has a Sony IMX219 sensor, is 8mpx, 1080P	
Termal camera (AMG8833)	It is an IR thermal camera sensor. It has an array of IR thermal sensors distributed in an 8-row by 8-column matrix.	

TABLE II. SOFTWARE PROGRAMMING LANGUAGES AND LIBRARIES

Tool	Description
Web application	
PHP	Back-end programming language
JavaScript	Front-end programming language.
HTML5	Markup language
CSS	Styles language
MySQL	Database for the web environment
Laravel	Open source PHP framework that implements the MVC pattern
Chart.js	Library for displaying graphics
Highcharts JS	Library for displaying interactive graphics
Arduino	
Arduino	Specific programming language for Arduino
Raspberry Pi	
CSV	Comma Separated Value file (CSV)
Raspbian	Mini-server operating system
Python	Programming language
MySQL	Database
Client	
Telegram	Social network mobile application to make queries to the system
Bot-API	Telegram API allows the creation of programs that interact with the regular Telegram application server
Web browser	A web browser that the client uses to make queries (Firefox, Chrome, Edge)

E. The Website for Monitoring Overheated Idlers

The URL https://polines.educaticss.com hosts the website and database of the system. On the left side, the menu has seven options (see Fig. 3): home, users, sensors, readings, alerts, reports, and settings.

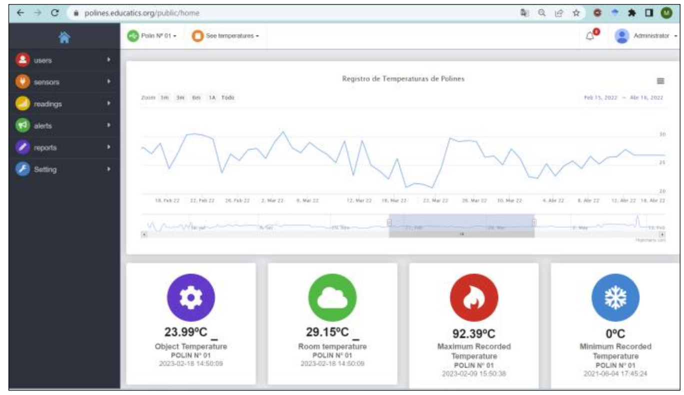


Fig. 3. The website panel for monitoring temperature.

The "home" option shows a graph with the evolution of the minimum and maximum temperatures of the idler rollers (polines). The "Users" option allows the management of the users and assigns the role to be played by each person. The "Sensors" option allows registering the sensors installed on the idlers. The "Readings" shows the idlers list, and the temperatures read in a specific time window. The "Reports" option allows the user to download (in Excel format) the data read between two dates. Finally, the "setting" option is used to configure particular variables, for example, the minimum and maximum temperature allowed on the pole. If the value read is out of this range, the system sends a warning to the conveyor belt operators through a Telegram message.

F. Notifications by Telegram Social Network

In order to make better control of the temperature in idler rollers, a module was implemented to send notifications to mobile devices of particular users (operators and eventually inspectors) via Telegram. This social network allows running bots, which are third-party applications that can be executed within the messaging application. Table III shows commands for the telegram social network.

TABLE III. COMMANDS FOR THE TELEGRAM SOCIAL NETWORK

Command	Description
/help	Command to show the commands
/temperature	Command to see the temperature
/photo	Command to take a photo
/video	Command to record a video
/ thermal-camera	Command to see color map image

The notification mechanism was programmed to control the temperature in the idler rollers when the temperature exceeds a maximum limit, for example, more than 70 °C. In this case, the system sends a notification to the user (responsible for monitoring the conveyor belt). This user can make better decisions, for instance, to schedule an immediate shutdown of the conveyor belt operation. The notification is a text message delivered to the cell phone, via Telegram or email. In addition, the system can take a picture or record a video to see the idler roller in real-time (e.g., review the amount of accumulated dust). Table II shows the commands in Telegram.

There is always a responsible for inspecting the operation of the conveyor belt. This person makes queries using his smartphone. Fig. 4 shows a thermal image or heat map requested by an inspector through Telegram social network.

Fig. 4. Heatmap image requested from Telegram.

IV. System Evaluation

A. The Location of the Conveyor Belt

The tests of the system were conducted conveyor belts located in two facilities. The first one was the "ECONSA" construction materials manufacturing company (crushed stone, sand and others), located in Pachachaca, Abancay, Apurimac, Peru (Lat: -13.708071; long:-72.915837). The second mining facility was the “MMG Las Bambas” copper mining company, located in Challhuahuacho, Apurimac Peru (Lat: -14.09815858865329, Long: -72.32647024732222). Fig. 5 and Fig. 6 show each location on Google Maps.

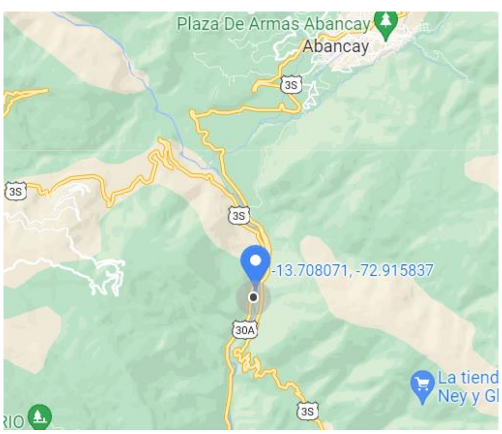


Fig. 5. Location of Econsa construction materials manufacturing company.

Fig. 6. Location of MMG Las Bambas copper mining company.

B. The System Prototype

As shown before, the system prototype has electronic devices, integrated circuits, connection cables, among others, which were covered by a casing that has ventilation. The case was built with a 3D printer that uses filament for printing. The 3D case for the prototype was printed in the Makerbot 3D printer. Fig. 7 shows the calibration of the 3D printer.

Fig. 7. 3D printer calibration.

This casing should have certain characteristics to ensure proper functionality and protection of the device, for example, the casing material should be heat-resistant to withstand the temperatures reached in the mining environment, and the design should allow for easy access to the components of the roller heating detection system for maintenance and troubleshooting. The final prototype of the system is shown in Fig. 8.

Fig. 8. Final prototype.

Installing the prototype in the conveyor belt was not easy, because only two telecom operators provided Internet connectivity in these areas. Fig. 9 shows the installation processes of the prototype on the conveyor belt.

Fig. 9. Installing the prototype in the conveyor belt of ECONSA company.

C. Cost of the System

Next table shows reference prices of the proposed system. Taking into account that this system monitors expensive mining machinery, this system can be considered a low-cost solution. Moreover, it represents just a small fraction of the cost of commercial equipment to perform this online monitoring activity. Table IV shows prices of the system components.

TABLE IV. PRICES OF THE SYSTEM COMPONENTS

Device	*Cost (USD)*
Arduino One	73.68
Raspberry Pi 4 Model B	163.16
Temperature sensor MLX90614	42.11
Camera Pi	57.89
Thermal sensor AMG8833	128.95
3D printing	36.84
Modem	60.53
Installation and configuration	78.95
Others	15.79
Total	*657.89*

D. The Testing Periods

This project was tested from March to May 2022 in ECONSA company, and then in November and December 2023 in MMG Las Bambas Company. To carry out the tests, the prototypes were installed on conveyor belts, one at ECONSA company and the other at MMG Las Bambas company.

In both cases, queries were delivered through the Telegram. The inspectors were able to ask for the temperature, thermographic image, photo and video of the idler rollers. Moreover, they verified that the temperature using the system had a difference of ±2ºC compared to the readings of analog thermometers. Fig. 10 shows an inspector comparing the temperatures in the field.

Fig. 10. The inspector comparing the temperatures in an idler roller.

V. SYSTEM EVALUATION INSTRUMENT AND RESULTS

For measuring the usability of the proposed system, the “Perceived Usefulness and Ease of Use” (PUEU) questionnaire [16] was applied. It measures the perceived "usefulness" and "ease of use" of a technological product to be created or launched, according to TAM (Technology Acceptance Model).

The questionnaire has twelve (12) items that are answered by the evaluators using a five-point Likert scale. The I1-I6 evaluate the perceived "usefulness" of the system, and the items I7-I12 rate the "Ease of Use" criteria (perceived usability). Table V shows the evaluation questionnaire.

TABLE V. TAM EVALUATION QUESTIONNAIRE

ID	*Evaluation Item*
I1	Using the system in my work would allow me to perform tasks more quickly
I2	Using the system would improve my job performance
I3	Using the system at work would increase my productivity.
I4	Using the system would improve my work efficiency.
I5	Using the system would make it easier for me to do my job.
I6	I would find the system useful in my work.
I7	Learning to operate the system would be easy for me.
I8	It would be easy for me to get the system to do what I tell it to do.
I9	My interaction with the system would be clear and understandable.
I10	I would find the system flexible to interact with.
I11	It would be easy for me to learn to use the system.
I12	I would find the system easy to use.

The questionnaire was applied to 20 persons experienced operating or inspecting conveyor belts that involve idlers rollers. Some of these people belonged to ECONSA, and others to MMG Las Bambas company. All of them were experienced working in metal and non-metal mining environment and computing applications.

Before the evaluation process, we explained the functionality of the prototype for approximately 30 minutes. Then, they use the system for a month, and filled the questionnaire after that. The questionnaire results were processed, and the obtained results were the following:

A. Perceived Usefulness

According to the participants, 93% (65+28) of them consider the system useful for monitoring the idler rollers in a conveyor belt. The Fig. 11 shows the results of the perceived usefulness.

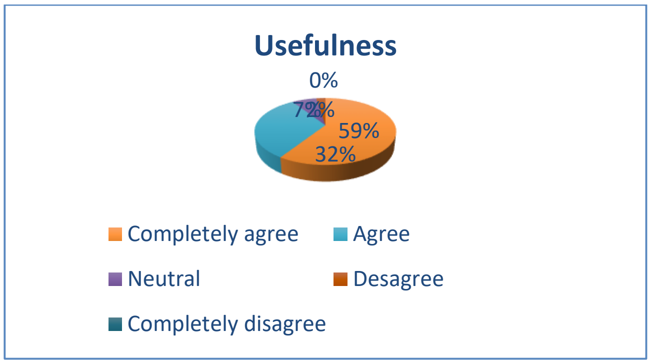


Fig. 11. Perceived usefulness of the system.

B. Perceived Usability

On the other hand, according to the participants' opinion, 95% (60+35) of them consider that the system has "Ease of Use" to monitor the pollinator in a conveyor belt. The Fig. 12 shows the results of the usability.

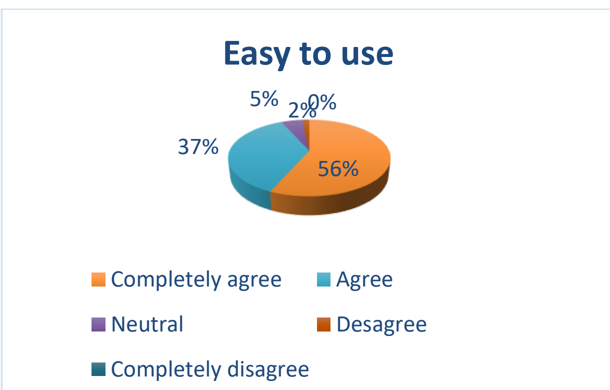


Fig. 12. Perceived usability of the system.

VI. Conclusion and Future Work

This paper presents a system prototype that was designed and developed for monitoring the temperature of idler rollers on conveyor belts. The system can measure the temperature, take photos, record videos and take thermographic pictures of these rollers. This functionality supports the monitoring activity performed by the inspectors in mining facilities.

These users monitor the operation conditions of the conveyor belts doing online queries from a mobile device, using a bot and the Telegram API, or asking for information through a web page. Using these mechanisms it is possible to see the temperature evolution per hour, day, week, month, and year. Moreover, this system autonomously sends warnings through Telegram, e.g., when the temperature exceeds a preset limit (when a idler roller starts to heat up).

On the other hand, after applying the PUEU evaluation questionnaire to 20 experienced operators and inspectors in two mining companies in Peru, it was possible to verify that 91% of these people consider the system useful for detecting the overheating of the idler rollers in a conveyor belt; and 93% of them perceive the solution as easy to use. Therefore, the users show their satisfaction with the system.

As future work, we will continue improving the robustness of the system. Moreover, we plan to use a solar panel so that the system is currently autonomous and works only with sunlight. In this way, the use of solar panels will contribute to reduce cost of electricity.

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References

[1] R. Krol and W. Kisielewski, "Research of loading carrying idlers used in belt conveyor--practical applications," Diagnostyka, vol. 15, no. 1, pp. 67–73, 2014.

[2] Y. Liu, C. Miao, X. Li, J. Ji, and D. Meng, "Research on the fault analysis method of belt conveyor idlers based on sound and thermal infrared image features," Measurement, vol. 186, p. 110177, 2021.

[3] M. Vasić, B. Stojanović, and M. Blagojević, "Failure analysis of idler roller bearings in belt conveyors," Eng. Fail. Anal., vol. 117, p. 104898, 2020.

[4] A. Grincova, M. Andrejiova, and D. Marasova, "Failure analysis of conveyor belt in terms of impact loading by means of the damping coefficient," Eng. Fail. Anal., vol. 68, pp. 210–221, 2016.

[5] S. Honus, P. Bocko, T. Bouda, I. Ristović, and M. Vulić, "The effect of the number of conveyor belt carrying idlers on the failure of an impact place: A failure analysis," Eng. Fail. Anal., vol. 77, pp. 93–101, 2017.

[6] X. Liu, "Prediction of belt conveyor idler performance," T2016/14, 2016.

[7] R. Zimroz, M. Hardygóra, and R. Blazej, "Maintenance of belt conveyor systems in Poland--an overview," in Proceedings of the 12th International Symposium Continuous Surface Mining-Aachen, pp. 21–30, 2015.

[8] P. Dabek, J. Szrek, R. Zimroz, and J. Wodecki, "An Automatic Procedure for Overheated Idler Detection in Belt Conveyors Using Fusion of Infrared and RGB Images Acquired during UGV Robot Inspection," Energies, vol. 15, no. 2, p. 601, 2022.

[9] J. Szrek, J. Wodecki, R. Błażej, and R. Zimroz, "An inspection robot for belt conveyor maintenance in underground mine—Infrared thermography for overheated idlers detection," Appl. Sci., vol. 10, no. 14, p. 4984, 2020.

[10] Y. Pang and G. Lodewijks, "The application of RFID technology in large-scale dry bulk material transport system monitoring," in 2011 IEEE Workshop on Environmental Energy and Structural Monitoring Systems, pp. 1–5, 2011.

[11] X. Liu, Y. Pang, G. Lodewijks, and D. He, "Experimental research on condition monitoring of belt conveyor idlers," Measurement, vol. 127, pp. 277–282, 2018.

[12] G. Fedorko, P. Liptai, and V. Molnár, “Proposal of the methodology for noise sources identification and analysis of continuous transport systems using an acoustic camera,” Eng. Fail. Anal., vol. 83, pp. 30–46, 2018.

[13] J. Chamorro et al., “Health monitoring of a conveyor belt system using machine vision and real-time sensor data,” CIRP J. Manuf. Sci. Technol., vol. 38, pp. 38–50, 2022.

[14] M. Meza Arroyo, "Behaviour of three techniques for growing hydroponic lettuce in Echarati-La Convención-Cusco,” (In Spanish). Engineering Thesis. Universidad Nacional de San Antonio Abad del Cusco, 2018.

[15] D. Marasova, M. Cehlar, L. Ambrisko, V. Taraba, and N. Staricna, “Innovations in Monitoring Conveyor Belts with Implemented RFID Technology,” in E3S Web of Conferences, 2019, vol. 105, p. 3002.

[16] F. D. Davis, “Perceived usefulness, perceived ease of use, and user acceptance of information technology,” MIS Q. Manag. Inf. Syst., vol. 13, no. 3, pp. 319–339, 1989.