Transactions of the Indian National Academy of Engineering (2020) 5:663–674
https://doi.org/10.1007/s41403-020-00164-0

ORIGINAL ARTICLE

The Role of Digital Technologies that Could Be Applied for Prescreening in the Mining Industry During the COVID-19 Pandemic

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Received: 21 July 2020 / Accepted: 22 August 2020 / Published online: 3 September 2020

Abstract
The novel COVID-19 (coronavirus disease of 2019) pandemic has caused global havoc and impacted almost every aspect of human life and the global economy. The mining industry is not immune to such impacts. The pandemic has accelerated the need for digital transformation in the mining industry and in the era of the fourth Industrial Revolution (4IR), there is further application of digital technologies in the early detection and prescreening of emerging infectious and viral diseases to keep mining areas and communities safer and less vulnerable. This paper aims to explore the application of smart digital technologies that could be applied for detection, prescreening and prevention of COVID-19 in the mining industry. The study will contribute, firstly, to demonstrate the utility and applications of digital technologies in the mining industry and, secondly, the development of a body of knowledge that can be consulted to prevent the spread of the disease in the mining industry.

Keywords COVID-19 · Coronavirus · Pandemic · SARS-CoV-2 · Digital technology · Mining industry · Fourth Industrial Revolution (4IR)

Introduction

The novel COVID-19 (severe acute respiratory syndrome coronavirus 2—coronavirus disease of 2019) pandemic has caused global havoc and impacted almost every aspect of human life and the economy. The effect of this viral disease on human health is evident from its easy and rapid spread from person to person resulting in infection and sometimes death (Worldometers 2020) and on the global economy. To date, more than 500,000 people have died from COVID-19, while the McKinsey Institute describes the pace of decline in economic activity to be the steepest since World War II (Craven et al. 2020). This effect is more prominent in resource-rich countries which are already struggling with their economies and where people have to physically work for their livelihoods. The current pandemic also has serious consequences on the short-, medium- and long-term future of the global mining industry, particularly where there is limited application of digital and automation technologies. An executive briefing by Craven et al. (2020) highlighting the implications of COVID-19 for business showed that the mining, oil and gas industry has the highest financial risk compared to all other industries in the USA (Fig. 1). The situation will not be different in South Africa because the extractive industries are considered essential for the economic stability of the country, despite being severely affected by the COVID-19 pandemic.

There are several challenges that the mining industry is currently facing under this pandemic, including a mandatory shutdown, lower demand for extractive products and slowdowns when managing the risk; these cause loss of production, income and growth. The production of the South African mining industry has also shown a sharp decline during these uncertain times of COVID-19. Mining production fell by 18% when the country's lockdown started in March 2020 and reached 47.3% in April 2020 due to COVID-19, as shown in Fig. 2.

In South Africa, the mines are expected to have COVID-19 infection rates of between 7 and 10% under normal

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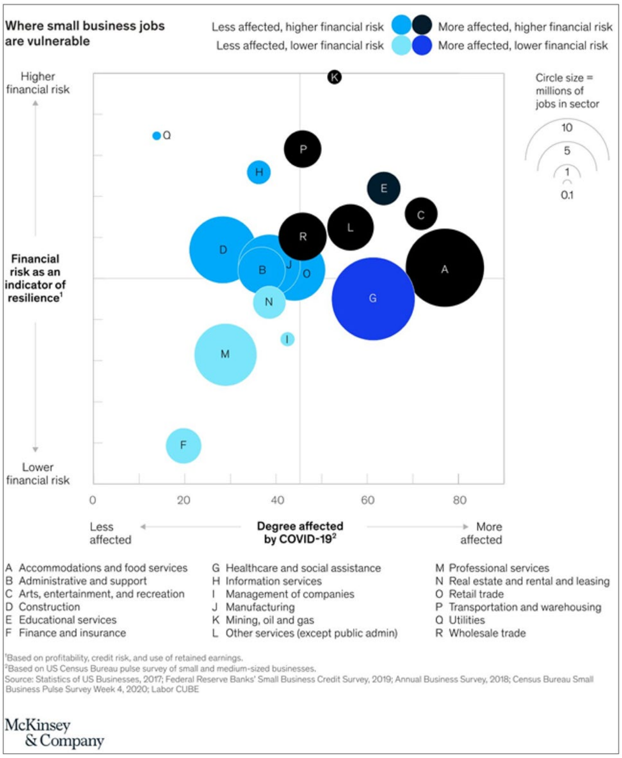

Fig. 1 Impact of COVID-19 on different industries in the USA, source: Craven et al. (2020)

mining conditions. This rate can increase sharply when mine workers use public transport for commuting from different regions because of the migrant labor system in mining. The biggest challenge is re-starting operational activities after lockdowns, followed by the implementation of safety measures to curb the spread of COVID-19 when production resumes (Viljoen 2020). As of 02 July 2020, there has been a total of 2573 positive cases in the South African mining industry with 835 in gold, 1395 in platinum and 2573 in other mines. This pandemic has raised attention towards a much needed and necessarily required digital transformation in the mining industry—not only for its sustainability but also for a more stable economic performance of any country in times of crises. There can be a potential application of digital technologies in the early detection and prescreening of COVID-19 affectees to keep the mining areas and communities safe and ultimately stop the spread of the disease. The Guidelines for a Mandatory Code of Practice on the mitigation and management of COVID-19 outbreak, developed jointly by the Department of Mineral Resources and Energy and the Minerals Council South Africa, highlights the minimum requirements for the reduction and controlling of virus outbreak amongst mine employees returning to work (Msiza 2020). Besides that, the mining companies have developed action plans to manage the impact of the coronavirus in their communities. Smart, digital and appropriate personal protective equipment (PPE) further help prepare the mining industry for the COVID-19. An adequate production and supply of PPE is important during this pandemic. To overcome this issue, three-dimensional (3D) printing, a novel and innovative technology, can be used to fabricate complex architectures and biomaterials using computer-aided design (CAD) system. The objective of this article is to explore the application of smart digital technologies that could be applied for detection, prescreening and prevention of COVID-19 in the mining industry. This study is of interest to mineworkers, the mining industry, government and mine medical staff. This study will contribute, firstly, to demonstrate the utility and applications of digital technologies in the mining industry and, secondly, to the development of a pool of knowledge that can be consulted to prevent the COVID-19 pandemic for the mining industry. Potential digital technologies that could be applied to tackle various problems related to COVID-19 pandemic are artificial intelligence (AI), data analytics, Internet of medical things (IoMT), smart biosensors and sanitizing equipment. Ebel et al. (2020) at McKinsey Institute have proposed five

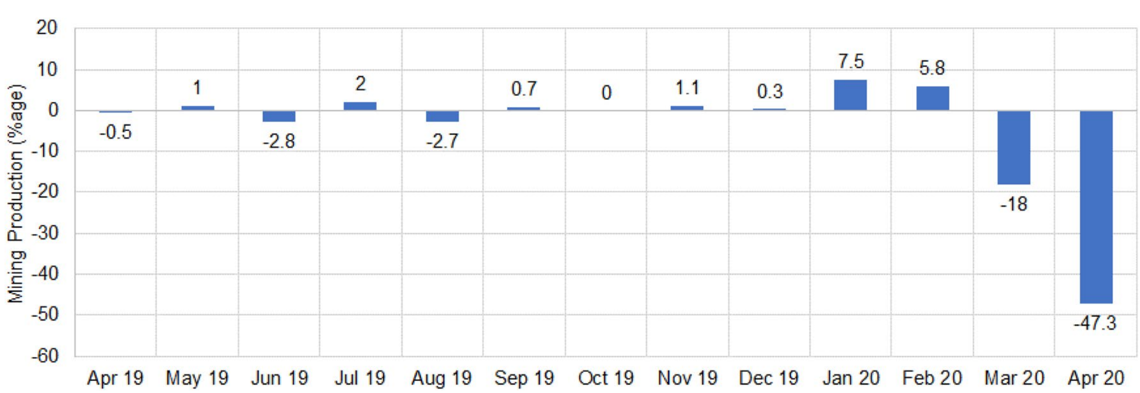

Fig. 2 South Africa mining production trend from April 2019 to April 2020, data source: Economics (2020)

steps for managing the overall risk, namely to build "always on" response systems, strengthen detection mechanisms, integrate current efforts, develop better health-care systems and accelerate research and development. This paper does not cover the range of options to government and industry to prevent the spread of infectious diseases like COVID-19, but rather focuses on one tiny aspect of the risk management process, which is to reduce the risk of the individual by wearing new-generation PPE to prevent the spread of the disease in the mining workplace. What follows is a discussion on several digital technologies which can be potentially used to overcome the COVID-19 negative impacts in the mining industry.

Intelligent Camera System

One of the most effective and commonly used method for prescreening of individuals for COVID-19 is the sensing of body temperatures. However, the traditional body temperature measurements using glass mercury, ear or forehead thermometers are not only time-consuming and labor-intensive, but also has the threat of close contact, which can cause the risk of contamination. Besides that, the other disadvantage of conventional body temperature measurements is the lack of data collection for analysis, which is useful for further interpretation and evaluation. Artificial intelligence-based cameras are a hybrid of thermal, infrared and visible imaging, which can predict and provide near real-time updates of miner's body temperature and automatically send an alert to mine management in case of temperature anomalies. Real-time video analytics have already been used to monitor the health and safety parameters in both underground and surface mining environments (Dufour 2012; Zhang et al. 2019). Chun (2020) reported an intelligent video system that was installed at public transport stations in China to scan large crowd body's temperature. The cameras were placed at prominent positions with appropriate angles for good quality video capturing and body scanning. This type of scanning can be done at different stages at multiple locations in the mining environment (e.g., mine entrance, lamp room, waiting areas, workstations). Thermal camera scanning will probably not be an adequate approach in an underground mine because of the harsh environment. In addition, worker's PPE can alter the results and cause difficulty to differentiate temperatures coming from the worker's body, PPE and immediate surroundings (Carroll 2020). Scanning the inner tear duct and forehead give the most reliable results, so it should be done at the accessing locations of mines without covering eyes or head with any PPE. Dickson (2020) has described that thermal cameras produced by Chinese Baiduis firm can scan 200 people a minute and pinpoint the individuals with body temperature higher than 37.3 °C. The thermal infrared cameras were also placed at different hospital entrances around the world to identify any individuals (including visitors) with fever at the first point of entry. The system has proved to be very efficient in identification of potential COVID-19 patients in a large crowded space (Kung et al. 2020). Artificial intelligence-enabled cameras can be installed at a point of mine entry to ensure that workers obey COVID-19 protocols and wear proper PPE (Seo et al. 2015). An intelligent video system can also be used to assure proper self-quarantine of individuals (if necessarily required) as Chun (2020) reported that China had used AI-based camera system for citizens to ensure their self-quarantine. Such system has also been implemented in countries like the USA, UK and Israel for intelligent decision making and controlling of the COVID-19 spread (Dobrea and Dobrea 2020; Naik et al. 2020).

The other significant application of an AI-based video analytics system is to detect the abnormal respiratory patterns among individuals (Jiang et al. 2020; Wang et al. 2020b) which can also be implemented in the mining environment for prescreening of COVID-19 (Fig. 3).

Machine learning-based AI models can be trained on the characteristics of actual respiratory signals of mineworkers under different scenarios (with and without PPE, public places, sleep hours, office environment, underground mine with the harsh environment and family time). The capability of the trained models will be to detect unusual and unexpected patterns of breathing for identification of the COVID-19 affectees. In the research conducted by Koyama et al. (2019), the authors had developed a system using respiratory monitoring algorithms based on the minute-ventilation sensor to predict heart failure. The developed system can monitor and investigate the changes in breathing patterns that could eventually help to control heart failures. Another research conducted by Wang et al. (2020a) proposed portable and AI (deep learning architecture)-based intelligent health screening dual-mode camera (visible and thermal) that can be used for the detection of respiratory infection disease like COVID-19. The model identified the health status regarding respiration with the accuracy of 83.7%. Therefore, such a system is also recommended for the mining industry to detect workers with abnormal respiratory behavior. The major benefit of using the intelligent video system is obtaining a contactless screening of individuals for COVID-19 and other viral infections and then to separate them from other workers by not allowing access to the mine. By doing this, it will not compromise the health of, first, the person taking the measurements and, second, fellow mine workers inside the mine.

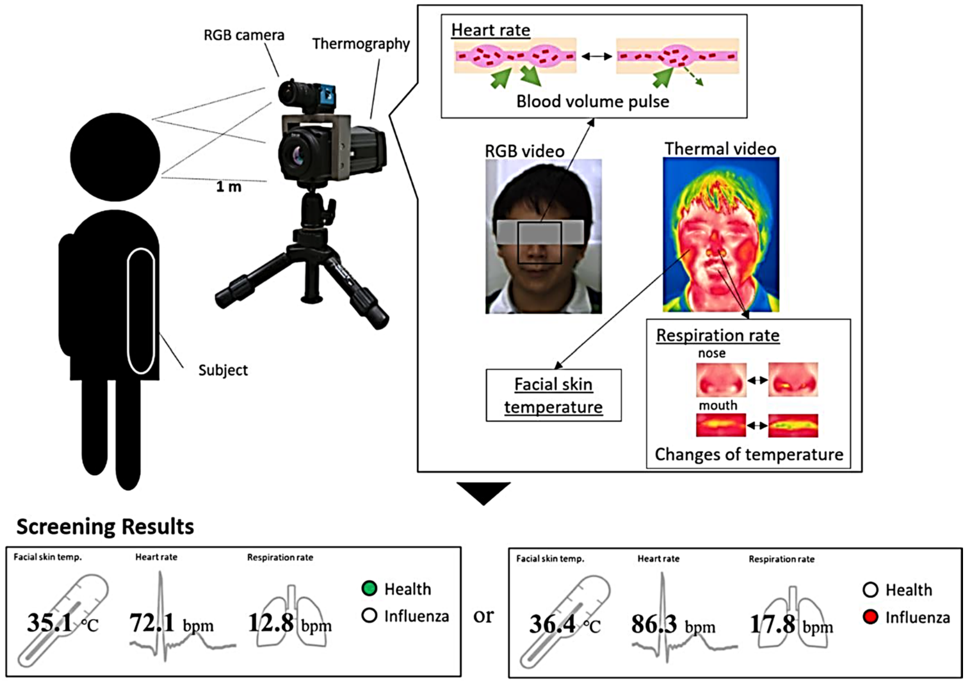

Fig. 3 Schematic representation of an artificial intelligence-based camera to sense and measure the multiple vital signs of COVID-19 along with prescreening results, source: Negishi et al. (2020)

Smart Face Masks

Several studies have indicated that face masks can reduce the transmissibility of the virus by minimizing the spread of infected droplets in both closed and open environments (Eikenberry et al. 2020; Esposito et al. 2020). Low or no transmissibility could significantly reduce the death toll and economic impacts as a low-cost solution. The research conducted by Bae et al. (2020) showed that the different types of face masks have a different impact on curbing the COVID-19 pandemic. Surgical and respirator masks like N95 should be worn in public and workplaces as recommended by the World Health Organization (WHO) to minimize the spread. However, surgical face masks are less effective where the work needs to be done in harsh and confined environments such as mines and factories (Bailar et al. 2006; Steinle et al. 2018). The face masks in mining 4.0 should also be digitally smart, sensor based and equipped with an early warning system. 3D printed smart masks with biosensors can monitor the body's temperature, heart rate, blood oxygen levels and respiratory rate by placing sensors near the wearer's earlobes, nose and mouth (Fig. 4). These vital signs can be transferred in near real time to a mobile or desktop application to individuals, mine health care and management authorities for decision making.

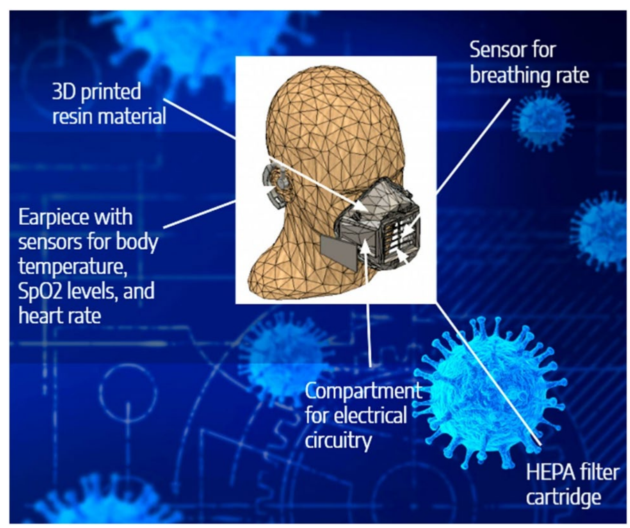

Fig. 4 AI-based smart masks for real-time health monitoring, source: Kelley (2020)

An AI Health Hackathon organized in February 2020 brought together students, research scientists and innovators from multiple disciplines to improve patient care by harnessing artificial intelligence and machine learning.

The team VitalMask used biosensors technology to make a smart respiratory mask that prevents the spread of airborne diseases while monitoring the wearer's vital signs (Kelley 2020). There is an extensive research and development required to test the suitability of the material that can be used to make the smart masks for harsh mining environment, but in all cases the material should be 100% PVC free and temperature resilient. The smart mask will not only help medical staff to prioritize patients, but also reduce the cost as it is a washable and reusable alternative to standard disposable masks. If adopted, it is recommended that companies should provide proper instructions or training to workers on how to wear, maintain and clean their face coverings to ensure the safety of individuals.

Smart Face Shields

Face shield is another important PPE to minimize the spreading and associated negative impacts of viral and other diseases such as COVID-19. Chu et al. (2020) conducted a review of 172 observational studies, and they concluded that face shields have proven to be a good and inexpensive PPE in the reduction of COVID-19, Middle Eastern respiratory syndrome coronavirus (MERS-CoV) or severe acute respiratory syndrome-related coronavirus (SARS-CoV) infections among the individuals. Usually, several types of face shields are available; however, all provide a transparent plastic blockade that covers the face. For ideal protection, the shield should be extended below the chin, to the ears sideways, with no gap between the forehead and the shield's headpiece, as shown in Fig. 5.

For the mining industry, the standard face shield design requires adjustment (Cawley and Homce 2007), to accommodate the standard miner's helmet and cap lamp as shown in Fig. 6.

The producers of mine safety equipment should design an arc-rated face shield adjustable with hats to overcome the spread of COVID-19 as per the mining industry and other national standards. If the mine workers use simple face shields that are not adjustable with the hard hats, then it should be used in addition to other PPE such as face masks and safety goggles. Roberge (2016) reviewed face shields for infection control and concluded that it should not be used as solitary face/eye protection, but rather as adjunctive to other PPE like face masks, due to lack of a good facial seal peripherally that can allow for aerosol penetration. Several mining companies have already acquired the face shields as a basic PPE to protect their workers and staff from the COVID-19 pandemic. Sibanye-Stillwater, a leading international precious metals mining company based in South Africa, has also started a project in collaboration with

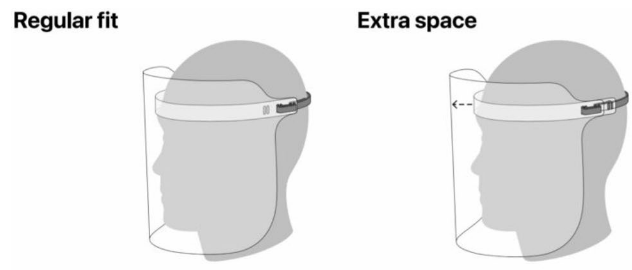

Fig. 5 General design of face shields that should cover the complete face

Sibanye-Stillwater Digital Mining Laboratory (DigiMine) at the Wits Mining Institute (WMI) for the production of 300 face shields per day for the company's staff and workers. Also, the surplus face shields can be distributed to mining communities, government bodies and other health-care service providers in the region (Mahboob 2020).

On the other hand, researchers at the crop science division developed digital smart face shields that can track and monitor the vital health signs of health-care professionals. The face shields use IoTs technology to track temperature, atmospheric humidity, respiratory pattern, heart rate and blood oxygen level, alerting health-care workers through an attached LED, if they need to stop and check for symptoms (Das 2020). Smart bio-sensor-based face shields can also be used in the mining industry, not only for protection purposes, but also as display screens to highlight any critical information related to the miner's health and safety. The suggested face shield design with an adjustable cap lamp and ear protection is shown in Fig. 7.

Face shields provide several advantages, e.g., they can be reused for a long period and are washable with household cleaners or other common sanitizers. Other advantages are that people can easily communicate with each other while

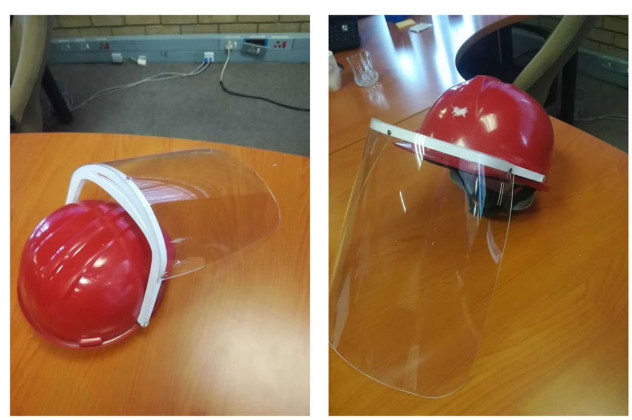

Fig. 6 Adjustable face shield with the standard miner's cap lamp for the mining industry

Fig. 7 Digital face shield for the mining industry to manage and control the impacts of COVID-19, source: Das (2020)

having the face shields on, which also allows for visibility for facial recognitions and expressions.

Smart Boots

Smart boots is another digital technology that can be useful to prevent infectious viruses like COVID-19 by providing the worker contact tracing and ensure social distancing (Fig. 8). The contact tracing can also be possible with the use of smartphones, when combined with physical distancing. The usage of smartphones has already been proven as a powerful asset in controlling the spread of COVID-19 worldwide. However, according to the data from the mining industry, not more than 15% of the miners have their own smartphones. Also, in the mining area, the miners have limited access to their mobile phones and usually are not allowed to bring on site due to health and safety issues. Therefore, relying only on mobile phone technology means more than 80% of the population (miners and mining area community) could slip through the cracks. Hence, the principle of smart boots is to attach a sensing device to the boots which alerts the person through a vibrating signal when the individual is in close contact with another person (minimum 2 m distance). When the mine worker gets this signal, he/she can either put

Fig. 8 Smart boots to prevent infectious viruses like COVID-19 by contact tracing, geo-fencing and social distancing alerts, source: Camas (2020)

a face cover or move away from other nearby worker(s). This will reduce wearable time because research conducted by Bauchner et al. (2020) concluded that wearing a face shield or mask is challenging for a whole day or a shift. However, the addition of smart boots in PPE can ensure that workers keep a safe distance during the shift (from access to exit). Another advantage of smart boots is that it can monitor the miner's activities like location, while collecting other data of the environment. The boots can also assist with extending the underground communications network, communicating alerts by beeping or flashing in high-risk areas, and sending emergency signals to the control room for possible assistance—along with the location of the (missing) person.

Smart Health Bands

The Internet of medical things (IoMT), also known as the health-care IoT-based wearable health devices, are playing an important role in real-time monitoring of health conditions of individuals (Qureshi and Krishnan 2018). During the current COVID-19 pandemic, several innovators, medical authorities, and government entities are looking for potential usage of IoMT technology to lessen the load on the health-care systems. These devices have already been applied in COVID-19 conditions, not only to gather digital health data, but also to ensure that people obey certain lockdown and quarantine regulations. The research conducted by Rahman et al. (2020) revealed that real-time data collected with IoT-based health devices were used to predict the COVID-19 outbreak with a confidence level of more than 80%. Also, the study conducted by Tripathy et al. (2020)

Fig. 9 IoT-Q-Band system for real-time monitoring of the health condition of individual and ensure social distancing to prevent the spread of COVID-19 virus, source: Singh et al. (2020)

concluded that smart Easy Band health device could be used effectively to control the growth of new positive cases of COVID-19 with auto-contact tracing and by ensuring critical social distancing. Similarly, an IoT-Q-Band system is another low-cost, smart health-care wearable used during the COVID-19 pandemic—illustrated in Fig. 9 (Singh et al. (2020).

Wearable bands are energized with a lightweight battery (for comfortable wear) and can be worn on the hand, arm, or leg and wirelessly connected to the communication point via a Bluetooth link. The processing unit continuously sends the data to:

1. check the status of whether the wearable band is working or tampered;
2. check if people maintain their social distance of 2 m from others; and
3. monitor duration per activity during the shift.

A designated person or mine hospital doctor can also monitor workers via a web interface, where the alerts can be generated using data analytics technology. Besides the health bands, the usage of telemedicine services can also be explored to facilitate the remote location communities. However, in case of the mining industry, it is mandatory for each mine to have its own independent small- to medium-scale hospital not only for workers, but also for the nearby communities. Usually, the workers have access to the community hospital and its associated facilities where medical staff can easily access the data as received from the health bands of the workers.

Smart Disinfection Tunnels

Smart disinfection tunnels or walkthrough sanitization gates can be installed at the entry and exit points of mines to sterilize the clothing and body of mineworkers. Usually, these tunnels spray the disinfectant chemicals through nozzles arranged in a way to shower the complete body. The ideal disinfectant chemical to be used in these gates or tunnels should be non-volatile, non-toxic, odorless, colorless, quick spray, harmless to skin and other body parts in compliance with all health and safety regulations (Biswal et al. 2020). Walkthrough gates or tunnels should be automatically activated using a passive infrared sensor to detect movement and measure a person's body temperature (Fig. 10). Proving popular since the outbreak of COVID-19 in South Africa, indoor turbines, which atomize and distribute disinfectant using powerful fans and high-pressure nozzles, have been successfully used in warehouses and factories to make disinfecting liquid airborne and sanitizing vast areas for up to 18 h. However, there is not enough clinical evidence on the efficiency of these walkthrough gates or disinfection tunnels to prevent COVID-19 (Mallhi et al. 2020). The National Academies of Sciences, Engineering and Medicine reported that ultraviolet (UV) light-based walkthrough gates possibly could eradicate the coronavirus that contains the deadly

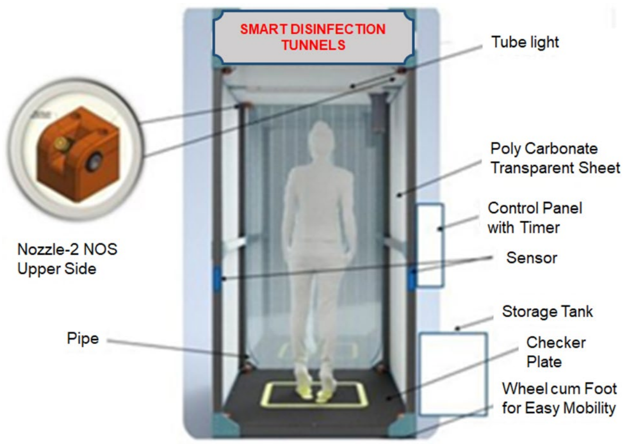

Fig. 10 Recommended smart disinfection tunnel to curb the spread of COVID-19 for the mining industry, source: Robonauts (2020)

MERS-CoV and SARS-CoV. However, the WHO has advised that people should not use UV lamps to disinfect their hands or other areas of skin, as UV radiation can cause skin irritation and can damage eyes (Leung and Ko 2020).

Nonetheless, disinfection tunnels without UV radiations and with harmless sanitizers has application in crowded working environments such as mines to disinfect the people and control the novel COVID-19 pandemic.

Dashboard Analysis of Data from PPE

Dashboard is a significant technology for the management and visualization of various real-time digital datasets. Tracking of COVID-19 with the help of interactive dashboards makes it possible to forecast the effects of a pandemic on the industry and to assess several economic and health consequences related to it under different scenarios. There are several international dashboards for mapping of COVID-19, e.g., Johns Hopkins University Center for Systems Science and Engineering dashboard, the WHO coronavirus disease (COVID-19) dashboard shown in Fig. 11 (Dong et al. 2020). Besides that, there are several national-level dashboards, i.e. COVID-19 South Africa Dashboard developed by Wits University, COVID-19 ZA South Africa Dashboard developed by the University of Pretoria, Corona Stats by University of Cape Town, etc.

The purpose of all these dashboards is to track the spread of COVID-19 and to evaluate different case scenarios to understand the spread and to determine future impacts. Mining companies can develop their own dashboards to monitor the spread of the virus in the mines and surrounding regions, which can also be linked with other national and international dashboards for public awareness and information dissemination. Dashboards for the mining industry can bring together location and time-dependent events in association with the disease spread, providing travel and movement alerts for their employees.

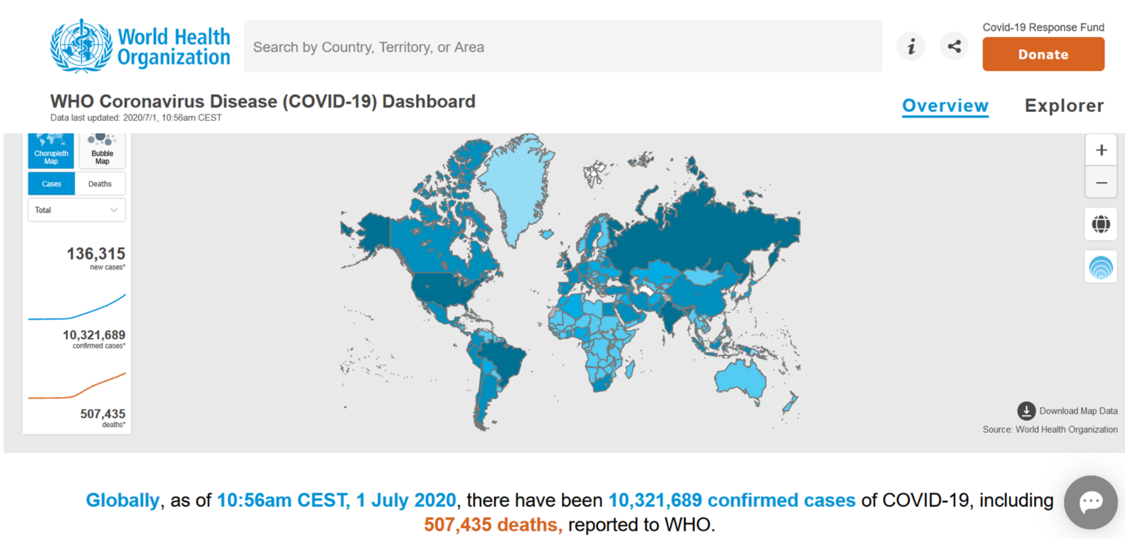

Fig. 11 WHO coronavirus disease COVID-19 dashboard, source: WHO (2020)

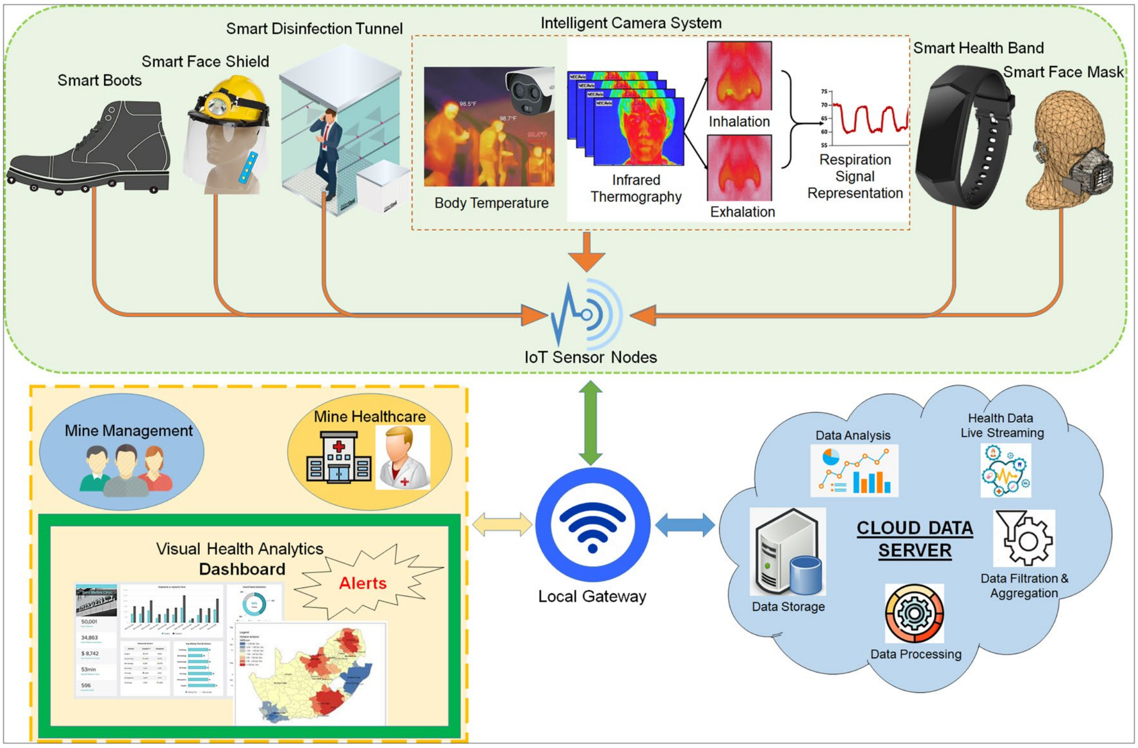

Fig. 12 Framework of smart digital technologies developed in this study for prescreening, early warning and to prevent the mineworkers from COVID-19

Similarly, the dashboards can assist in the allocation of resources as per their need and urgency in the mining environment.

Finally, by preparing the data for dashboard analysis it becomes information for effective sharing and informing workers on risks, while management can further analyze data through (numeric) modeling and integration with, e.g., mine ventilation information to better understand the behavior of COVID-19 in the mining environment.

The graphical and tabular summary of all the potential digital technologies discussed in this paper is given in Fig. 12 and Table 1, respectively. This is further proof that digital technologies can make mining both safer and more profitable.

Conclusion

Many governments have implemented national lockdown and social distancing strategies to mitigate the spread of COVID-19 and to give their health-care systems and the economy time to prepare for the disease. In addition, there are non-pharmaceutical interventions that reduce human contact within the population and therefore constrains the spread of COVID-19. Digital technologies provide a new-generation solution that allows governments and companies to collect, transfer, store, analyze, monitor, predict and visualize the COVID-19 related data for better decision making. This research discussed the various digital technologies that provide innovative methods for monitoring and management of the COVID-19 pandemic, in addition to ensuring the safety of the mineworkers. This paper provides a useful summary of currently available personal protective equipment for mine workers to prevent the spread of infectious and viral diseases in the mining workplace.

Table 1 Significant digital technologies that can help the mining industry to control the spread of COVID-19 pandemic

Technology	Significance	Challenges	Cost of implementation
Artificial intelligence	Artificial intelligence (AI) has been advancing at an exponential pace which can also be very useful against the COVID-19 pandemic for the assessment of risks, infection and screening of mine workers. An artificial intelligence-based real-time video analytics system can be used to remotely monitor the individual's health status (body temperature and respiratory rate) and assure the implementation of safety protocols, both in underground and aboveground of the mining environment	Significant training and skills are required Setup is quite expensive due to the costs of implementation, customization, maintenance, networking topologies, security features, etc. High computation is required	High
Data analytics	Data analytics technology can be highly useful for analysing and forecasting the reach and impact of the COVID-19 on mines. The health monitoring devices can collect near real-time data and consequently provide updated information with an early warning to the mine management, doctors and policymakers for better decisions to manage and fight against the virus	Data quality, scalability and privacy can be an issue Industry-wide data integration is a big challenge High computation and maintenance is required	Medium to high
Internet of medical things (IoMT)	The IoMT can be applied in COVID-19 pandemic not only to gather the digital health data, but also to assure the implementation of social distancing strategies by monitoring the location and activities of mineworkers along with other environmental condition	Data security and privacy is a big issue Integration of multiple devices and protocols Seamless data communication Micro- and nano-electronics Bandwidth power consumption	Medium to high
Smart biosensors	This technology is sensitive and cost-saving, which can provide highly accurate data related to the health of mine workers. The biosensors-based face masks and face shields can be used in the industry for the real-time recording of the temperature, electrocardiogram (ECG) tracing, and respiration rate, which can further be employed for the early detection and monitoring of the COVD-19 symptoms	Data confidentiality Effect of electromagnetic radiations on human health Frequency interference Low power communication Extensive wireless telecommunications infrastructure	Low to medium
3D printing	3D printing is an emerging technology that can help the mining industry by producing recyclable and reused face mask and face shields. This technology is cost-effective and can produce many versions of the same product in lesser time	Designing skills Energy inefficiency Scarcity of printing materials	Low
Smart disinfectant tunnels	Smart disinfectant tunnels or walkthrough sanitization gates can be installed at the entry and exit points to sterilize the whole body of mine workers to prevent/stop the spread of viral disease. The system can be automatically activated by detecting movement and measure a person's body temperature and can also record the information about the number of individuals entering or leaving the area	Less scientific research about the potentially harmful effects of this technology on the human body Currently not recommended by WHO	Medium

Table 1 (continued)

Technology	Significance	Challenges	Cost of implementation
Interactive intelligent dashboard	The tracking of COVID-19 with the help of interactive dashboards have provided an edge not only to forecast the pandemic in the industry, but also to assess several economic consequences related to it under different scenarios. Dashboards for mining industry can help to visualize the near real-time information of the mineworker's location and health status. It can also assist in the allocation of resources as per their need and urgency in the mining environment	High data storage Data security and sharing protocols Data quality	Medium

Acknowledgements The work presented here was conducted as part of the postdoctoral fellowship at the Wits Mining Institute (WMI), University of The Witwatersrand, Johannesburg, South Africa. The authors would like to thank and acknowledge the financial support provided by the Sibanye-Stillwater Digital Mining Laboratory (DigiMine), WMI.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflicts of interest or competing interests.

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