

Intelligent comprehensive Occupational health monitoring system for mine workers

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Abstract:

The objective of this work is to present a comprehensive occupational health monitoring system which provides the current state of the occupational health for mine workers. The hearing threshold shift and dust exposure of each individual mine worker is monitored using this system. The data obtained from the system is transmitted via Internet of Things to storage which may be cloud or a server. The novelty of this model lies in its dual ability to monitor both Noise Induced Hearing Loss and Pneumoconiosis which is caused by inhalation of dust particles. The output of this dual system is further processed using Machine learning and artificial intelligence techniques. Recommendations are then provided to the mine worker with regards to their state of health. This system forms part of an early intervention system in the mines. The model was validated using real data from a Platinum mine in South Africa. Future improvement to this work would entail refinement of the current preliminary implementation plan and carrying out the first phase of the implementation.

Keywords: Health, Monitoring, Pneumoconiosis, Noise, Internet Of Things, Machine learning, Artificial Intelligence

1. INTRODUCTION

Occupational diseases and injuries have a negative impact on an individual and the society at large. Respirable dust and excessive noise is currently increasing in the mines due to depletion of minerals on the surface and use of sophisticated machines to go deeper to achieve required outputs. Respirable dust results into respiratory related diseases for instance pneumoconiosis while excessive noise may result in Occupational Noise Induced Hearing Loss (ONIHL). The impact of occupational diseases in the mines has been documented to be approximately 1 to 3 percent of the Gross Domestic Production (GDP) in different countries. These costs may be direct for instance compensation or indirect for example loss of income for dependants. Mining companies are also affected by losing workers to occupational disease, loss through their reputation being tarnished or loss of investors Hermanus (2007). There is therefore a need in development of integrated monitoring systems that can be used in conjunction with the existing systems to aid in minimizing the risks associated with excessive noise and respirable dust.

This paper is structured as follows: Section 1 is a brief introduction, followed by Section 2 which provides the

background. Section 3 provides the contextualization of this research to a specific mine in South Africa. System modelling is in Section 4 followed by the results. Recommendations and conclusions are provided in Section 5 of this paper.

2. BACKGROUND

When compared to other sectors for instance transport (Aviation, road or rail), construction and manufacturing, the mining industry is observed to be the most hazardous sector Hermanus (2007). Considering the environment mine workers are exposed to, they are at risk of being exposed to excessive noise and dust particles from various sources. Most mines have Hearing Conservation Programmes (HCP), however, this have not been successfully implemented due to several reasons. For instance existing myths in the mines as documented by Witt (2012), In South African mines for example, there are several mine stake holders who have to be in agreement prior to policies being implemented Chamber Of Mines Of South Africa Integrated Annual Review (2016). Further detailed reasons as to why the HCP do not work have been provided by Moroe (2018). Apart from ONIHL Miners are also at risk of developing lung diseases for example pneumoconiosis because of their regular exposure to airborne respirable dust.

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Pneumoconiosis implying the dusty lung can cause impairment disability and premature death Beckley (2010). Lung diseases among mine workers can be caused by exposure to rock dust, coal dust, silica dust,

2.1 existing health monitoring systems for underground mine workers

Pal A (2015) developed a device that can monitor heart pulse of underground worker to the system. The application of the wearable device is to monitor which mine workers are still alive in case of an accident in the underground mine. The developed device has an advantage of being wireless and cost effective. Srivastava (2015) designed a real time monitoring system using wireless network. Temperatures, humidity and multiple toxic gases are monitored by this system. The system included multiple sensors and it acts as an early warning system. Maheswari et al. (2019) proposed an efficient wearable low cost device that consumes lower power and continuously monitors the health of mine workers by monitoring the gas, temperature, heart rate and water sensor. Parks et al. (2019) developed an intelligent monitoring system for improved worker safety during plant operation and maintenance. Schellenberg and Steinbrucker (1985) proposed a health monitoring system for mine tunnelling machines. Operational parameters for example temperature, flow and pressure are measured, using the data to provide a prediction of possible failures. This health monitoring system assists with mine maintenance. The current health monitoring systems in mines focuses mainly on monitoring environmental elements of the mine for instance temperature, moisture content with a few measuring the heart rate with the main purpose of being able to locate mine workers incase of an emergency. Occupational diseases for instance Noise Induced Hearing Loss (NIHL) and respiratory disease still continue to be a burden to the mining industry. Most mine workers undergo extensive check up of their ears and chest once a year. A feedback noise monitoring matrix was developed by Madahana et al. (2019b,c,a), ? and Moroe et al. (2019). The developed system progressed from a static feedback system for monitoring to noise to a dynamic feedback system for monitoring noise. The proposed health monitoring system is an extension of this systems to include the respiration health of the mine workers hence forming the novel health monitoring system for mine workers. The main contribution in this paper is to present a system that can be used to monitor mine worker's state of health (Threshold shift and respiration) on a daily, weekly or monthly basis. This system is to be used to provide feedback to mine workers and administrators who can then provide an early intervention thus saving the mine worker from experiencing significant health issues in future. The system is beneficial to the mine workers because it aids in minimizing of health risks. This system is also beneficial to the mines because it helps to ensure that their employees health is a priority. Mines will also save on money that is used in compensation to victims when they encounter health related law suits.

3. CONTEXTUALISATION TO A SOUTH AFRICAN MINE AND DATA ACQUISITION

The developed model can be applied to any mining environment in the world. The contextualisation in this paper is only used to give the proposed system a background and to validate it. Platinum and gold are mined using similar methods. In mining both minerals, the surrounding rock is blasted and drilled. This research therefore uses raw data from a platinum mine in South Africa. The data used to validate both the ONIHL model, respiratory model and the health monitoring system in these studies was obtained from research work titled Occupational noise induced hearing loss in South African Large Scale Mines: From policy formulation to implementation and monitoring conducted by Moroe (2018). Information was collected via retrospective document review of the mine. All procedures applied to this research work observed the applicable national institutional guidelines for research on human subjects and adhered to the Helsinki declaration of 1975 revised in 2008. In addition to that, this research work has an ethical clearance certificate was from the Witwatersrand University Research ethics committee (Medical: Protocol number M160264) Moroe et al. (2019). From the larger data set provided, 400 subjects who have higher chances of exposure to occupational noise and dust in a platinum mine was used. The noise and dust exposure history of this mine workers was collected. Five features that influence hearing loss and respiratory diseases were extracted and used in the development of the predictive model.

4. SYSTEM MODELLING

4.1 Noise Induced Hearing loss system modelling

This system has already been discussed in detail in previous publications by Madahana et al. (2019b,c,a), Moroe (2018) and Moroe et al. (2019).

An important addition to model is that the actuator which is the hearing protection provided to platinum miners is a 3 M Peltor H9A 98 over the head ear muff. It has a Noise Reduction Rating (NRR) of 25dB CSA class A. The other type of hearing protection used is the personalised hearing protection custom made noise clippers.

4.2 Respiratory diseases system modelling

Reference or Baseline The S1 subsystem represents the baseline or the reference. The South African rules and regulations stipulate the following amounts as standard that should be followed by mines Health and Council (2014):

- Respirable dust should not exceed 1.5 mg per metre cubed
- Crystalline silica should not be greater than 0.05 milligram per metre cubed
- The coal dust should not be greater than 1.5 milligram per metre cubed.

This subsystem also has clean air (unpolluted air) in the following percentages:

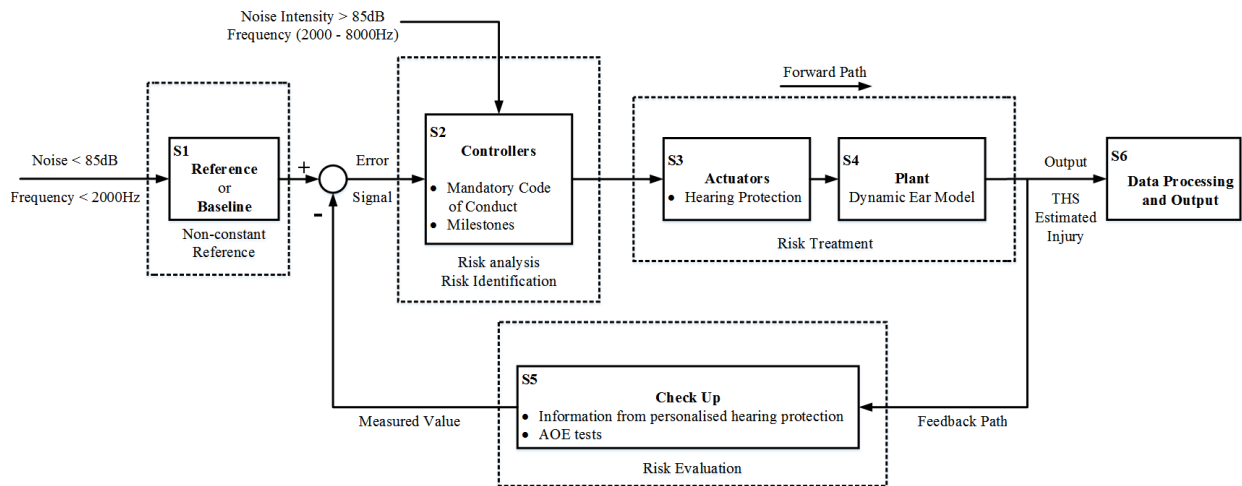


Fig. 1. Noise Induced hearing loss monitoring
 Madahana et al. (2019b,c,a)

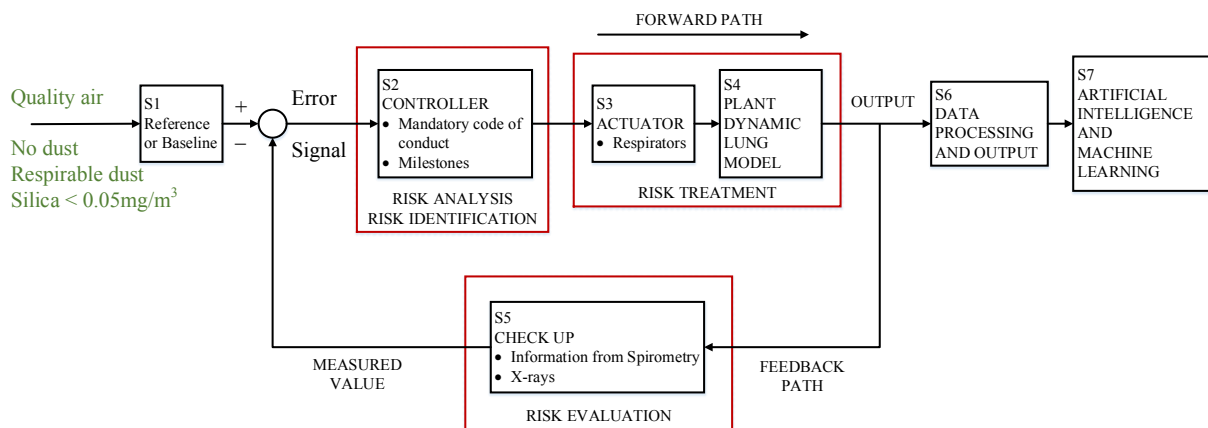


Fig. 2. Monitoring respiratory diseases

- 78.09 Nitrogen
- 20.95 Oxygen
- 0.93 Argon
- 0.04 Carbon dioxide
- 0.4 Water vapour
- Other gases

Controller S2 is a mandatory code of conduct imposed by the mine. The South African Mine Health and Safety Council(MHSC)has milestones for administrators to use as a target to ensure there is zero harm to the mine workers by the year 2024. These milestones act as a guideline on what the mine administrators should aim for. They are listed below for reference purposes Health and Council (2014).

- By December 2024: To Eliminate silicosis, the crystalline silica should be reduced to 0.05 milligram per metre cubed.
- To eliminate pneumoconiosis in platinum mines the respirable dust particulate should be less than 1.5 milligram per metre cubed.

These measures are an effort to eliminate silicosis, pneumoconiosis and any other respiratory disease.

Actuators The actuator is represented by the respirator that mine workers wear in order to minimize the dust particles that they are inhaling.

Dynamic lung model This is represented by a model of a lung. This could be a Finite Element model, electrical model or bondgraph model of the lung.

Check up This subsystem represents both:

- rapid check-ups to establish the respiratory health of a mine worker
- and elaborate annual check-ups that take place in the mine by thoroughly examining the mine workers and sometimes requesting for a chest X ray.

Data processing unit Data is processed in this Unit using Internet of Things. The methods proposed by Madahana et al. (2019b) are applied in the data processing unit.

Artificial Intelligence Artificial intelligence is implemented via machine learning. The details of this subsystem are presented in detail in the later subsections of this paper.

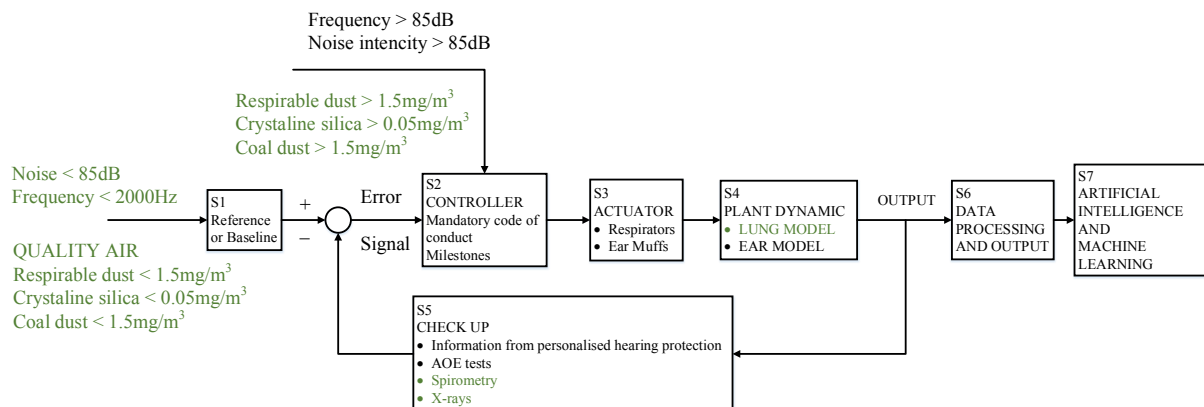


Fig. 3. Smart dual health monitoring system

4.3 Smart dual Occupational health monitoring system for mine workers

This system is an amalgamation of the NIHL system and the respiratory system. The subsystems that make up this system have been described in their respective subsections.

5. PRELIMINARY IMPLEMENTATION PLAN FOR THE MINE WORKERS HEALTH MONITORING SYSTEM

The details of the preliminary implementation plan of the health monitoring system are presented in the subsections that follow:

The Plant The plant is represented by the human ear which consists of the outer, middle and inner ear. This subsystem is the ear of the mine worker. The mine worker could be male or female. From the data set provided by the platinum mine, the youngest and oldest employees were 25 and 63 years old, respectively.

Charging points The mine workers in the evening have to leave their hearing protection on a charging point. In this subsystem, there is activation and transmission of Information. The ear muffs, while being recharged, transmit the data that has been collected through the day from the mine worker to any storage unit available. The storage Unit could be the organisation’s servers or to cloud.

Transmission Underground transmission of information requires an efficient and robust system. A good technology that can offer communication between surface and underground work station is critical. Internet Of Things (IoT) will be used to automate the underground-surface communication. The security of the information will be prioritized and included in the initial design stage.

Data storage The data will be stored on the cloud or a server. It will later undergo Extraction, Transformation and loading processes (ETL) and is then loaded on to computers.

Application of Artificial Intelligence to the data set In this subsystem, artificial intelligence and machine learning

is applied to firstly estimate the current threshold shift of an individual. The threshold shift is then compared to the standard threshold shift of the mine worker. The standard threshold shift is defined as the measured shift when an individual was first employed at the company. Artificial intelligence is used to estimate the threshold shift of mine workers using deep learning techniques. One of the techniques used is the Recurrent Neural Networks (RNN) Madahana et al. (2019b,c,a). This method is chosen because its suited for sequential data and has a memory. In this subsystem, there is also a health monitoring and recommendation subsystem which profiles incoming new employees using historical data that has been stored and then provides the correct recommendation on which tasks that employee can perform in the mine. For example a new employee who has high dust accumulation content in the lungs and high threshold shift would have recommendations to work in areas of the mine that are less noisy and have less dust. The methodology used for the health monitoring policy recommendation consists of data preparation or data wrangling, clustering, classification and final policy recommendation Madahana et al. (2019b,c,a). The purpose of clustering is to ascertain the properties of the data by establishing the various groups within the data. A new observation cluster label is predicted using classification. K-means is used for clustering while classification is performed using logistic regression, support vectors machines, decision tree and random forests in order to compare which method is best suited Madahana et al. (2019b). The sample data set are provided in table 1 while the Hearing threshold shift and Dust accumulation Cluster labels are in table 2. Table 1 and figure 1 are illustrations of how the sample data set can be used hence the number of subjects in table 1 are not matched to number of subjects in fig.6.

Table 1. Sample data set

| Starting age | Years of exposure (per Day) | Intensity of exposure | Respirable dust (mg/m ³) |
|--------------|-----------------------------|-----------------------|--------------------------------------|
| 25 | 10 | 110 | 0.541 |
| 30 | 15 | 107 | 1.624 |
| 18 | 40 | 108 | 0.267 |
| 23 | 30 | 110 | 0.272 |
| 40 | 10 | 107 | 1.624 |

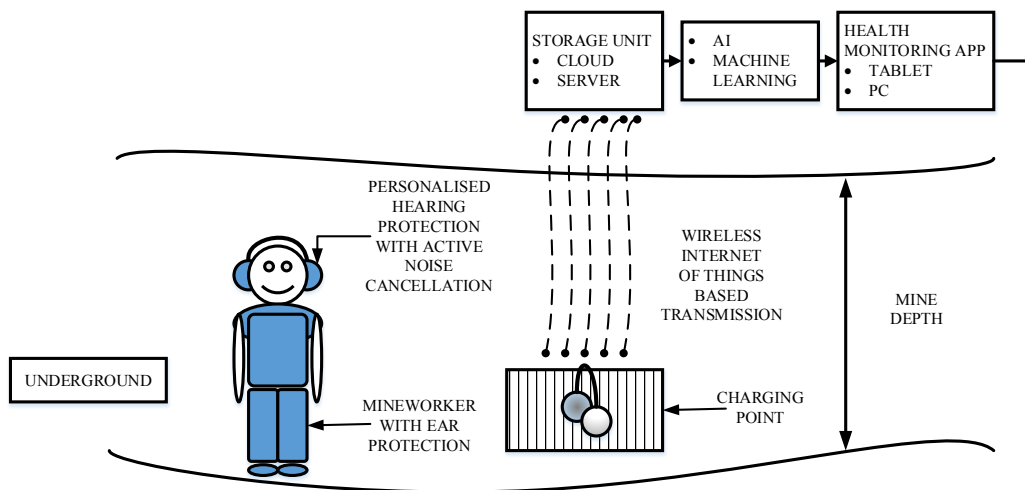


Fig. 4. Pictorial representation of the implementation plan

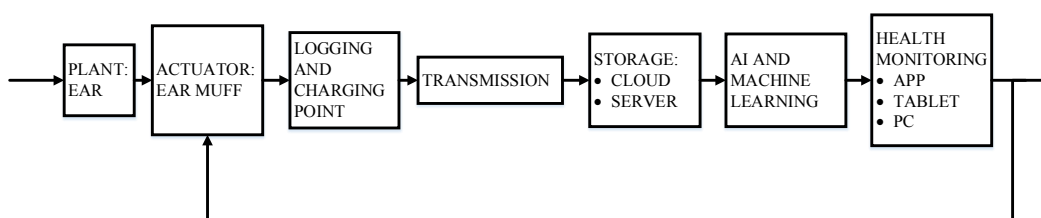


Fig. 5. Preliminary Implementation Plan

Table 2. Hearing threshold shift and Dust accumulation Cluster labels

| Hearing loss cut-off | Respirable dust accumulation (per Day) | Priority |
|----------------------------------|--|----------|
| Threshold shift ≤ 40 | Dust accumulation ≤ 0.5 | Low |
| $40 >$ Threshold shift ≤ 60 | $0.5 >$ Dust accumulation ≤ 1.0 | Moderate |
| $60 >$ Threshold shift ≤ 90 | $1.0 >$ Dust accumulation ≤ 1.5 | High |
| Threshold shift > 90 | Dust accumulation > 1.5 | Extreme |

Data visualization In this subsystem, suitable data presentation are provided according to the current technology and what the mine administrators find suitable. Information can be presented on a health monitoring App, tablet or computers. Business Intelligence is applied to present the information in a format that is easy for anyone to understand and interpret for example graphs, tables or pictures. The mine worker will also be provided with recommendations based on the outcome of the measurements provided. For example if a mine worker's threshold has not shifted significantly, they will be provided with a message that congratulates them for using hearing protection or respirators correctly and urged to continue with that practice. If there is a slight shift in their hearing threshold shift, the mine worker will be asked to check that their hearing protection or respirator is fitting correctly and to ensure that they wear them at all times.

administrators may choose to display all the results at the same time or one at a time.

6. RESULTS AND DISCUSSION

The results of the health monitoring system are shown in Figures 6 and 7. Both respiratory and NIHL data is logged on at the same time. The mine workers or mine

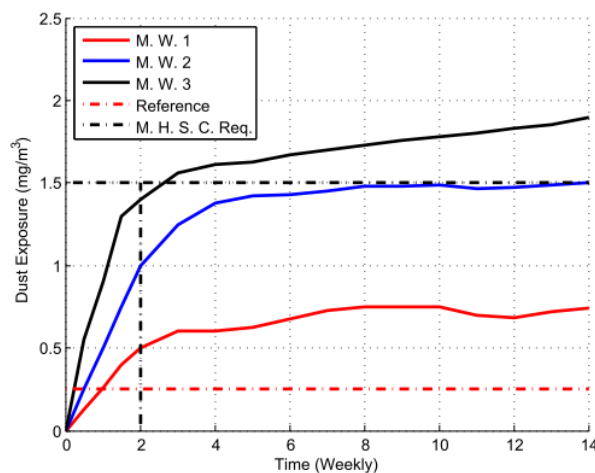


Fig. 6. Respiratory monitoring

From the results in Figure 6, the reference represents the minimum amount of dust accumulation a mine worker

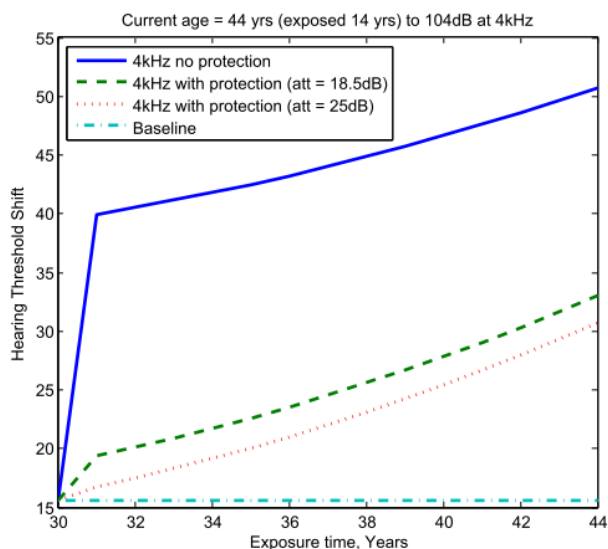


Fig. 7. Threshold shift Monitoring

might already have prior to employment. The main goal of this system is to ensure the dust accumulation in the lung of the mine worker tracks the reference. This will be achieved by application of the actuator (respirators) and closely monitoring the mine worker to ensure that there is no increase in dust accumulation in the lungs. M.W.1 represents the first mine worker whose respiratory health is fine and attempts to track the reference. M.W.2 is the second mine worker who has not violated the Mining Health and Safety Council (MHSC) requirements but still needs to be closely monitored to ensure that their wearable respirator is not faulty and that it is being worn correctly. There could be other reasons for an increase in the respirable dust. These should be provided and corrected so that the mine worker does not violate the MHSC requirements. M.W.3 represents a mine worker whose respiratory health has violated the MHSC requirements. This mine worker's case should be treated as an emergency and measures to prevent any further harm (to the mine worker), should be taken by the mine administrators. Figure 7 shows how the system can be used to predict future threshold shifts of a mine worker and appropriate actions can be taken by the administrator to mitigate the risks of the mine worker encountering significant threshold shifts that could result in permanent loss of hearing.

7. RECOMMENDATIONS AND CONCLUSION

Future work would include the first stage of implementation and inclusion of other factors that affect deep underground mining workers for instance cigarette smoking. In conclusion a novel dual smart health monitoring system for mine workers has been presented. IoT is used in transmission of Information from underground to the surface for storage. This system, includes machine learning and artificial intelligence for estimation of hearing threshold shift and also for providing recommendations.

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