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APPLICATION OF SAFETY SENSORS IN STEEL & POWER INDUSTRIES

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ABSTRACT

Ensuring work safety is considered to be one of the top priorities for various industries. Workplace injuries, illnesses, and deaths often entail substantial production and financial losses, governmental checks, series of dismissals, and loss of reputation. Wearable devices are one of the technologies that flourished with the industrial revolution, allowing employers to monitor and maintain safety at workplaces. The purpose of this article is to systematize knowledge in the field of industrial wearables' safety to assess the relevance of their use in enterprises as the technology maintaining occupational safety, to correlate the benefits and costs of their implementation, and, by identifying research gaps, to outline promising directions for future work in this area. We categorize industrial wearable functions into four classes (monitoring, supporting, training, and tracking) and provide a classification of the metrics collected by wearables to better understand the potential role of wearable technology in preserving workplace safety. Furthermore, we discuss key communication technologies and localization techniques utilized in wearable-based work safety solutions. Finally, we analyze the main challenges that need to be addressed to further enable and support the use of wearable devices for industrial work safety.

KEYWORDS: *Occupational health, Accidents, Employee safety & health, Rewards, Hazardous factors, Wearables, Smart devices*

INTRODUCTION

The workplace is fraught with many sources of danger, especially in enterprises with harmful work conditions. For a long time, the work safety issue has been relegated to the background by employers for the sake of labor productivity. Published by World Health Organization (WHO), statistics on industrial death accidents from 1970 to the present day have a shape close to Gaussian. The lack of statistics can explain this observation since only six countries maintained such a base starting from the 70th. However, the emergence of new technologies, including wearable devices, can also contribute to constraining mortality in industries nowadays.

Although the number of accidents per year tends to decrease, the level of mortality in workplaces is still considerable. According to the International Labor Organization (ILO), approximately 1.9 million people have work-related diseases, and 2.3 million people die from work accidents annually. Besides, these statistics reflect only reported

cases: not all enterprises openly register all cases, thus, not entailing inspections, sanctions, unrest among staff, loss of reputation, etc. Therefore, at least 4.2 million people suffer in the workplace per year, and 45% of countries have a population less than this number The problem of work safety in industrial environments is still on the crest of a wave. Worldwide statistics show a high rate of death and injury at

work, a variety of hazardous industries, and sources of danger [3].

With the advent of Industrial revolution and broad integration of the Internet of Things (IoT), employers are expected to achieve better safety mainly due to the emergence of various technologies.. This paper is primarily focusing on the smallest form-factor personal devices, namely, wearables, that also attempt to achieve the same goal as part of the Internet of Wearable Things paradigm. Further discussion will focus on the Industrial IoT (IIoT) that emerged to design, maintain, monitor, optimize, and analyze industrial operations to gain real-time insights, make effective decisions and maintain occupational safety.

Historically, the IIoT was at the initial stage of its development as of 2015. At this point, many entrepreneurs had doubts about the feasibility of introducing such an innovation due to the uncertainty about the impact that it will have on workers, labor processes, production, and, more importantly, profits. The situation has begun to change in the last 5 years

This paper aims to analyze and integrate information related to wearable devices and provides a comprehensive overview. of the different features of their use in maintaining and increasing work safety in potentially hazardous industries, as depicted in Figure 1.

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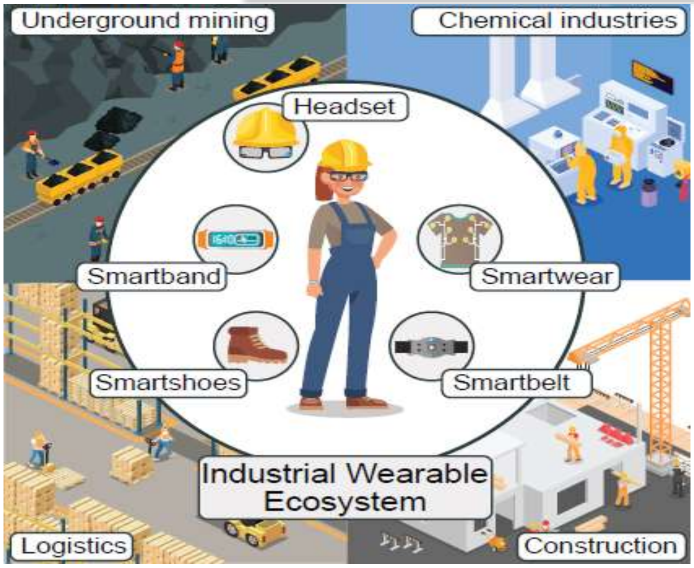

Figure 1. The concept of using wearable devices in industries to maintain work safety.

1. ORGANIZATIONAL SAFETY CULTURE

Safety culture plays a key function in determining an organization'ssuccess or failure and it's a part of organizational culture.

Organization with poor safety culture which are widespread, routine procedural violations, failure to comply with the company's own safety management system. Various steps have been used to improve the safety culture which are communicating the company values, demonstrate leadership, personalize safety outcomes, develop positive safety attitudes, engage and own safety responsibilities and accountabilities, increase the hazard awareness and preventive behaviors. Various factors in the safety climate terms have been used to measure safety culture: procedure, management commitment, visible management, safety attitudes, workmate's influences, employee's involvement, safety knowledge, management takes the initial work of identifying the hazard at the workplace by using various methods, HIRA (Hazard Identification Risk Assessment), JSA (Job Safety Analysis), work permit system etc. The aim of the management is to eliminate the hazard and minimize their risk at the workplace. Periodic evaluation, review of work at their workplace survey is a must.

1.1. Occupational safety and health controls hierarchy

In order to minimize the health and safety threats, several measures need to be taken to prevent and mitigate the potential hazards According to Occupational Safety and Health, a hierarchy of controls refers from the most effective to the least effective to the desired order of choosing control steps. The underlying principle is that first attempting to remove the danger is always best. When that becomes difficult, then the danger should be confined at the source first, then along the path, and finally at the individual level. The hierarchy of occupational safety and health controls is shown in Fig. 2 and described in detail in Table 1.

1.1.1. Step 1

Elimination: This step aims to eliminate the hazards and therefore makes it difficult to effectively remove all the potential incidents and ill health found. Without transferring it somewhere this step suggests that risk is eliminated. The ideal solution of risk management is to eliminatethe risk. This solution is permanent and should be attempted in the firstplace. Once the risk is eliminated, it will no longer need any othermanagement controls, such as monitoring and surveillance of the workplace, training, safety auditing and maintaining of records will no longer be a necessity.

1.1.2. Step 2

Substitution: This step aims to replace a hazard with one that poses a lower risk. The removal of one hazard is immediately integrated with a shift to another posing a much lesser risk. Often considered in the case of chemicals, the idea of 'replacing the dangerous by the non-dangerous or the less dangerous' is applicable here too. In the case of chemicals, replacing the same chemical with a safer form, rather than replacing the chemical, can give a feasible, safer alternative like replacing powder with pellets.

1.1.3. Step 3

Engineering Controls: This step aims to limit the hazard physically which can be incorporating structural changes in the work environment or work processes or introducing a barrier to block the path of transmission between the workers and hazards. A common example would be utilizing Local exhaust ventilation (LEV) to limit risks from dust or fume as it separates operators from the hazard from operators. It should ensure that these measures are not just limited to the individual level but should be implemented to protect collectively.

1.1.4. Step 4

Administrative Controls: Administrative controls are also defined as operational measures that minimize or remove the risk to a hazard by complying with procedures or instructions. Both, the necessary precautions and the controls to be followed in running the operation safely should be highlighted in documentation. Social networking is increasingly relevant as an outlet for the dissemination of safety messages and other information related to workplace safety and healthcare in the workplace, especially concerning younger employees. Improving workers' readiness by measures such as health education in the workplace may also be a helpful component of a holistic approach in prevention and protection.

3.1.5. Step 5

Personal Protective Equipment (PPE): When all other control mechanisms have been considered, PPE can be used only as a last resort whether as a short-term precaution during emergency/maintenance/ repair or as an extra safety measure. The effectiveness of this control relies on the right selection of the safety equipment, as well as the correct fit, worn at all times and properly maintained.

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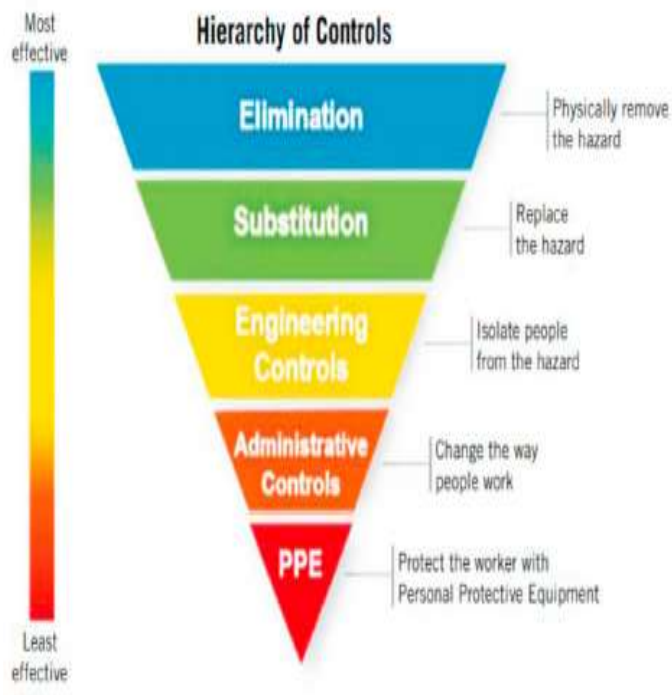

Fig 2 Hierarchy of occupational safety and health controls

Hierarchy of Control	Explanation	Example
Control at Source	Eliminating the hazard at source.	• Avoid keeping patients with highly infectious diseases at normal (non-infectious) healthcare facilities. • Killing or inactivating the virus in specimens for laboratory testing. • Destroying contaminated waste through incineration or autoclaving
Control Along Path	Creating a barrier between the hazard and the worker.	• Safety-engineered devices (for needle-stick injuries) [1] Containment (bubble) beds for clinical care [1] Negative Pressure Rooms [1] • Needleless intravenous systems [1]
Administrative Control	Documentation of well-defined standard operating procedures and policies. Also includes training of workers in safe working practices to avoid any risky behavior [1].	Training in: • Donning and doffing (putting on and removing) PPE. • Quarantine protocols. • Isolation Procedures. • Medical surveillance of workers at risk.
Control at the Person	Least effective measure. It involves wearing protective gear such as PPE, double gloves, etc. [1]	• Impermeable gown or coverall • Use of a Respirator • Careful use of a hood to cover neck and face • Protection of eyes facilitated through the use of goggles or a face shield.

Table 1 Details of the hierarchy of control.

Steel & Power Industrial safety is an important global issue, and in particular, the Steel industry is over represented in workplace injury and death statistics. Despite modernization, this industry is exposed to dynamic & high risk environments.
In India, there were around 190 injuries recorded in the preliminary data for 2013, which was the second highest number of fatalities of all industries. This corresponds to a injury rate of 7.35 injury per 1,00,000 workers, which accounts for 16% of injuries for all industries. In addition, for the last six years, the steel industry accounted for about 135 deaths per year on an average in the country. This figure is one of the highest compared to other countries.

Safety culture is a concept that is gaining traction within this sector as a useful concept to further reduce fatalities, injuries and incidents. It has been used by organizations seeking to improve industrial safety. Even after taking proper permits & use of PPEs, accidents do happen as a result of false energization of the same equipment, on which the maintenance work is being carried out. This also happens due to employeeunawareness/lack of knowledge of all the possible sources of energy, which in turn can prove fatal to the persons carrying out maintenance.

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2. Sensors in occupational health and safety

2.1. Sensors in physiological monitoring

Physiological data such as heart rate, breathing rate, body position, body speed, and body acceleration are automatically registered and evaluated using a Process Safety Management (PSM) system and a Global Positioning System (GPS) monitoring device to determine the health of the worker. An EKG/EKG (electrocardiogram) cardiac tracking sensor, an EMG (electromyography) sensor for monitoring muscle movement, a brain electrical sensor to track brain function, a brain pressure sensor, a trunk position tilt sensor, a breathing sensor for breathing, and a motion control sensor may be used in a broad collection of physiological sensors. The ECG/EKG sensors tend to be the most commonly used to monitor the physiological parameters. A test that monitors abnormalities in the electrical activity of the heart is an electrocardiogram (ECG or EKG). It displays the electrical activity of the heart as line tracings on a paper for easy interpretation.

A gyroscope is used to calculate the rotations of different parts of the body. Body rotation and angular velocity are the parameters that are monitored by a gyroscope. On the other hand, magnetometers help monitor the body's orientation concerning the earth's magnetic north.The gyroscope, accelerometer, and magnetometer sensors have their advantages. For example, a magnetometer has low accuracy for fast and rapid movement while a gyroscope reacts quickly to changes. Hence, sensors like gyroscopes, accelerometers, and magnetometers are often used in combination. Recently, these inexpensive in-chip inertial sensors like gyroscopes and accelerometers are being used in human motion analysis.

When these sensors are combined with the technology of Micro Electro Mechanical Systems (MEMS), there is a boost in the development of miniature/small and sensors with lower power to analyze human kinematics. Gyroscopes can be used as a wearable that can determine the peak of upper arm internal rotation, wrist flexibility, and shoulder rotation. In the calculation of angles, gyroscopes tend to be more effective, because they can more precisely distinguish practical events and evolving patterns of motion. Furthermore, it has been suggested that the most optimal activity control platform is created by the combination of various technologies.

Wearable sensors are employed for both physical parameters such as temperature, heart rate, blood pressure, etc. as well as for chemical or biological parameters such as pH, Uric Acid, Potassium, etc. The sensor relays the signal to a central microcontroller unit also known as a signal processing unit through an interfacing circuit. The signal is then transferred to a wireless communication module and finally to a computer.

3. Types of Safety sensors

3.1. *Sensors for the monitoring of physical parameters*

Sensors have found a wide array of applications in the monitoring ofvarious physical parameters such as temperature, heart rate, motion, etc. Accelerometers are widely employed for the measurement of the motion of the body. Accelerometers encompass various methods of transduction like variable capacitance, piezoelectric and piezoresistive . The orientation of a person's posture, detection of falls, body movement analysis is some of the widespread applications of accelerometers.

3.2. *Sensors for the monitoring of biochemical parameters*

Sensors in this space measure pH, various electrolytes, blood oxygensaturation, and kerato conjunctivitis sicca among many others. The sensors which are used for biochemical parameter monitoring are non-invasive. This means that these sensors do not penetrate the skin, making it an attractive option for monitoring biochemical parameters. Target analyte detection in bodily fluids like saliva, tears, and sweat is facilitated through the use of non-invasive sensors [19].

3.3. *Sensors in environmental sensing*

The nature of many workplaces can pose both health and safety risks for workers especially when the events are outdoors which exposes the workers to not just weather elements but also to harmful materials like chemicals, gases, or solids. The automated sensing of these harmful materials is necessary More commonly, a multitude of issues, including air pollution, barometric pressure, carbon monoxide**,** capacitance, color, gas leaks, humidity, hydrogen sulfide, temperature, and light, can now be measured using environmental sensors. Integrated environmental sensors are now available that enable a wide variety of new high-potential applications, such as navigation, barometric air pressure, humidity, monitoring functions for ambient air temperature, and measuring air quality. Few of these sensors can be used in workplaces when integrated with different applications on mobile devices and wearable technology. When doing their daily job, workers can be tracked and the same time being able to see highly localized, real-time data on parameters such as temperature, dangerous gases, and airborne particulate levels and even detect harmful chemical leakage The social health and safety of the working class of people can be ensured by deploying robust environmental monitoring sensors.

Pollutant monitoring is one of the critical applications of environmental sensing. There are three major classes of pollutants that impose a threat to the occupational safety of working professionals, these include air pollutants, environmental nuisance, and meteorological data. Particulate matter, sulphur dioxide, and ozone among many others contribute to air pollution and have a direct impact on human health.

Environmental nuisance can be described as any alteration in the environment caused by human activities which have an adverse impact on the health of humans

3.4 *Sensors in reducing fall accidents*

Previously, camera-based and ambient systems were used for fall detection which was based on the observable changes in body movement and poses detection in movement inactivity, and head motion analysis.

However, few limitations like obstruction of capture volume, privacy, false alarms, and battery life have been observed. Wearable technology in various populations is being introduced and is also being utilized to measure physical human activity. More precisely, because of its high sensitivity, low time investment, simple accessibility, feasibility, and administration, the preferred choice of technology for fall tracking and detection are the wearable or body-worn sensors. Inertial measurement units (IMUs), accelerometers, gyroscopes, magnetometers, pedometers, electric goniometers, and foot pressure monitors are among these wearable gadgets. These real, wearable sensors have been used more often along with smartphones and apps to provide a powerful device and framework for wearable fall detection.

3.5 *Sensors to detect stress levels*

The stress response helps the body to resolve challenges and brace for risks, but one's health may be affected by prolonged forms of stress. Till now stress has been calculated via physical assessments and questionnaires which mainly focus on the data inputted by the user, and maybe subjective and wrong. Recently, to analyze the amount of stress the body encounters an analytical identification of biomarkers associated with stress response has been developed. As a part of wearable, flexible applications, innovative stress sensing devices rely on cortisol sweat sensing. These systems promise a real-time ongoing database of stress data that can be used for clinical diagnosis or tracking and mediation of personal stress. Many teams are choosing to build soft and flexible sensors that can remain on the skin surface to progress beyond rigid circuits and electronics for wearable devices. Cortisol-specific MX210 antibodies immobilized on a gold nanostructured surface were used by a system designed to make the functioning electrode in their design. Antibodies of high density were able to optimize their design sensitivity and produced a lower detection limit of 1 pg/mL and a 1 pg/mL-1 µg/mL dynamic range. This working electrode was used as a part of a flexible, wearable lab-on-a-patch platform built with polydimethylsiloxane that used redox mediator reagent reaction and faradaic electrochemical impedimetric spectroscopy to detect microfluidic sweat collection.

A system called SKINTRONICS, using electrodermal sensing of galvanic skin reaction combined with temperature measurement to assess stress levels was recorded in addition to cortisol sensing. This flexible hybrid electronic interface is skin-compliant, precise, sensitive,and enables stress-related data to be collected in real-time. SKINTRONICS is a multi-layer system with a maximum wear time of 7 hours.

TYPE OF DEVICE	SPECIFICATIONS
Safety Helmet	Microcontroller – Arduino Wireless Communication – ZigBee Sensor – Gas, Air Density, Humidity, Temperature
Wireless IoT based device	Microcontroller - ATmega328p from Atmel Corporation Wireless Communication - LoRa technology Sensor – Harmful environmental pollutants
Multi-Layer Multi-Sensor Environmental Monitoring for Gas and Noise (Smart Watch)	Microcontroller - Nordic nrf51822 Wireless Communication – BLE Sensor - Multi-Layer Multi-Sensor Environmental Monitoring for Gas and Noise
Multi-pollutant monitoring system (Wrist Wearable)	COTS Sensors
MyPart portable particulate sensor	Microcontroller - Nordic nrf51822 Wireless Communication – BLE 400 mAh Li–Po battery

Table 2 Examples of Safety sensors

4. Examples of safety Sensors applicable for Steel & Power Industries.

Sensors are used for measuring, monitoring, and recording environmental conditions or properties, such as barometric pressure, relative humidity, luminosity, temperature, dust, and water level.

Light sensors (see Figure 3a) that can be used to detect light are widespread inscientific applications and everyday consumer products, such as motion light sensors, ambient light sensors, outside lights, security lights, and traffic light sensors.

Sound sensors or microphones (see Figure 3b) are employed to determine the sound intensity of an environment. They come in multipleforms including condensers, ribbons, carbon, and dynamic microphones. The most common type consists of dynamic microphones that measure noise levels in decibels at frequencies to which humans are sensitive.

A humidity sensor (see Figure 3c) measures the relative humidity in the air for use in moisture and temperature measurements. These are sometimes referred to as humidity/dew sensors, andcan be found in heating, ventilation, or air conditioning systems in buildings.

Flame sensors (see Figure 3d) are used to detect open flames or fire, and are more sensitive and accurate than commonlyused smoke or heat detectors.

Fume sensors (see Figure 3e) perform a similar function in detecting smoke, alcohol, and other harmful airborne gases.

Various types of sensors are used in wearable devices depending on the intended application. Many manufacturers around the world produce such sensors for individuals or professional developers. Because sensors are important components of wearable devices best-suited to the Steel & Power industry

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Fig 3a. Light Sensor

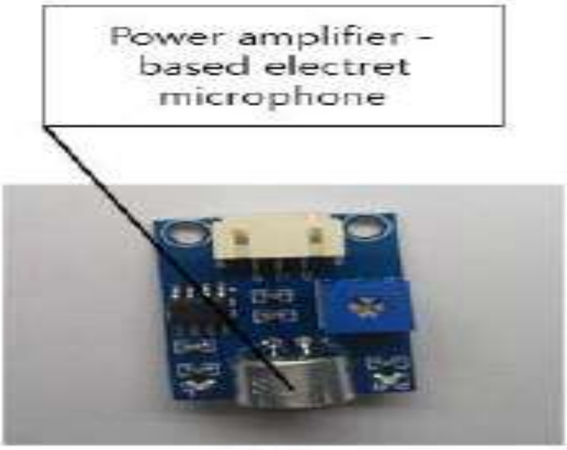

Fig 3b. Sound Sensor

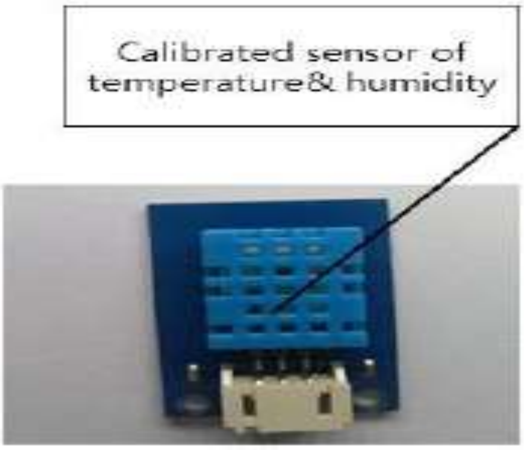

Fig 3c. Temperature Sensor

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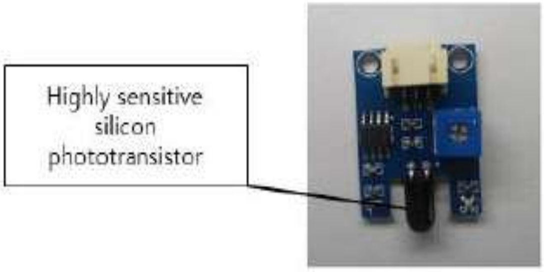

Fig 3d. Flame Sensor

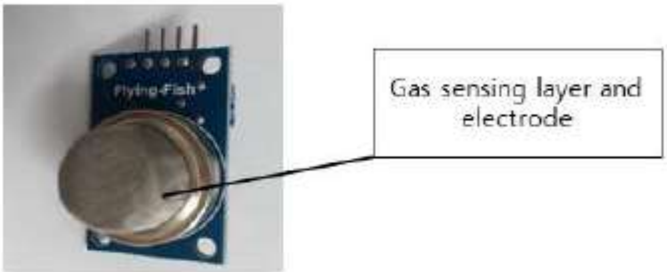

Fig 3e Fume Sensor

Biosensors
The scope of biosensors has expanded with the increasing demand for health monitoring. These sensors allow people to be aware of their health status at all times, and are used by healthcare
professionals in the early diagnosis and prevention of disease. Examples include body temperature sensors, heart-rate-monitoring sensors, electrocardiogram (ECG), electroencephalography
(EEG), electromyography (EMG) sensors, blood pressure sensors, and glucose level sensors. A heart-rate-monitoring module (Figure 3f) can be used to measure the electrical activity of the
heart, and is intended for use in extracting, amplifying, and filtering bio-potential signals to generate the heart rate. Typically, heart monitors require the use of biomedical sensor pads and cables.
The finger-clip heart rate sensor shown in Figure 3g is a high-performance optical biosensor that measures the change in the movement of blood in the body.

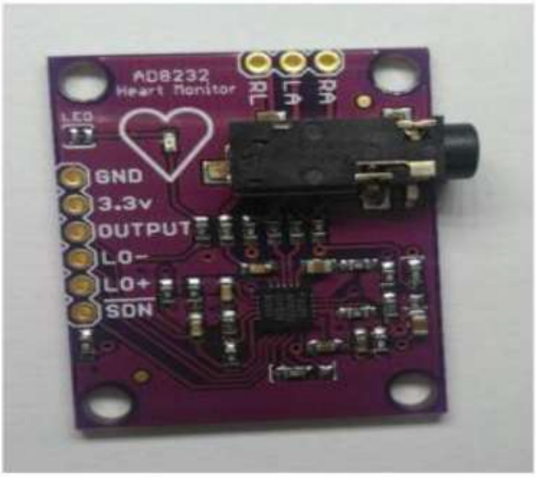

Fig 3f. Heart rate monitoring module

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Fig 3g. Finger clip heart rate sensor

Position & Location Tracking sensors

Location- and position-tracking sensors (i.e., GPS, altimeter, magnetometer, compasses, and accelerometers) are the most common type of sensors on wearable devices, such as activity trackers, smartwatches, and even medical wearables where they are used to check the physical activity and health of patients.

A GPS module (see Figure 3h) is a three-axis sensor used in spatial navigation that can determine location, altitude, and speed at any time and in most weather conditions. However, in the Steel & Power industry, there are few examples of the use of GPS (only in outdoor open-pits) modules for tracking purposes. Because signals needed for GPS modules are not available indoors, they are considered unsuitable for underground tracking systems.

A compass (see Figure 3i) is a simple magnetometer that defines the direction of the climatic magnetic field. A magnetometer sensor can be used to measure the magnetic field at a specific location. As it can detect ferrous metals, it can be used for tracking metallic vehicles and human body motions (when jointly used with accelerometer and/or smartphones). Another common type of inertial sensor is an accelerometer, which has an extended range of sensing capability. They are available in

one-, two-, three-, or six-axis implementations (see Figure 3j), and have high capability in fall detection and safety management applications. measures the change in the movement of blood in the body.

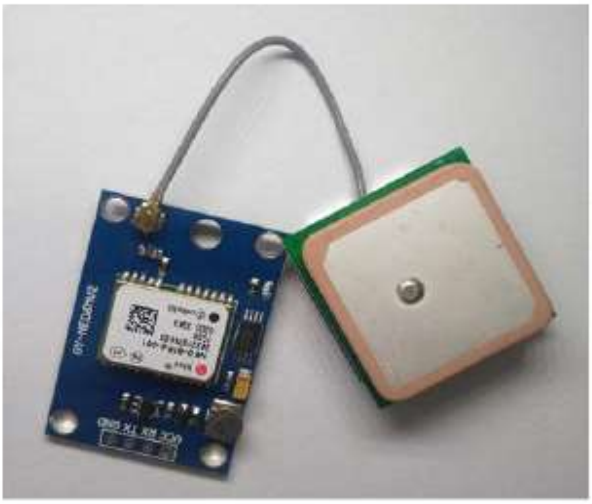

Fig 3h. GPS module

Fig 3i Digital Compass

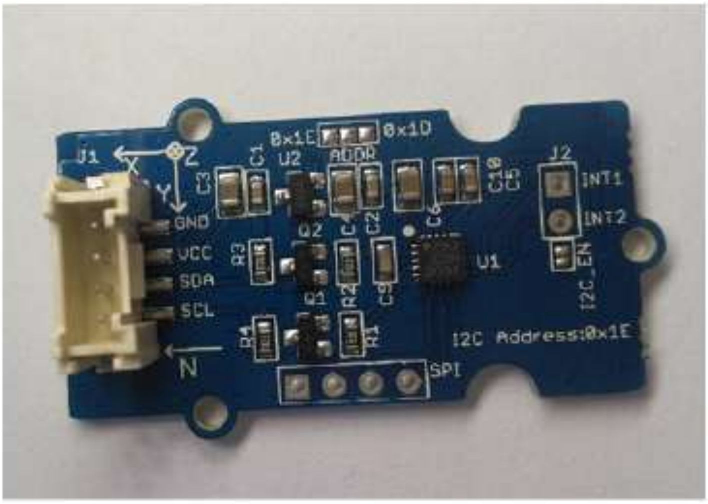

Fig 3j Accelerometer

Other Sensors

Other sensors include a variety of detectors and sensors available on the market, usually found on consumer wearable devices. Wearable cameras and smart glasses are often described together with camera sensors as the main part of these devices. Communication sensor modules (i.e., Bluetooth, Radio-Frequency Identification (RFID),Wi-Fi, etc.) provide communication and data exchange features to wearable devices. These sensors are being adopted in the mining industry for tracking and other purposes. Motion sensors, speed sensors, inertial measurement unit (IMU) sensors (compound unit of accelerometer, gyroscope, and, sometimes, magnetometers), ultrasonic sensors, and infrared receiver (IR) sensors (small microchips with photocells to catch infrared light) are also used as electronic components of wearable devices

Fig 4. Application of sensors

5. CONCLUSION

The field of occupational health and safety has become a topic of importance in the past decades due to the increasing number of occupational accidents. Every worker expects safety in the workplace environment. Any organization must identify the hazards and determine the risk associated with them and design facilities to reduce these risks. In this review, various types of hazards have been discussed ranging from biological to chemical to physiological. However, to better understand and prevent occupational hazards it is important to implement the concept of wearable technology. Technology has the potential to solve every problem faced by society. The same can be observed in the field of occupational health and safety. Wearable technology has played a crucial role in reducing workplace accidents. This paper facilitates the prioritization of integration of wearable technology with appropriate risk management to ensure occupational safety to all the workers regardless of the workplace.

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