Integrating IOT devices for Monitoring and Enhancing Working Conditions of Workers in India

Abhishek Ranjan
(SENSE)
VIT
Vellore, Tamil Nadu
abhishekranjansingh001@gmail.com

Rohan Joshi
(SENSE)
VIT
Vellore, Tamil Nadu
rohan155joshi@gmail.com

Rishita Jauhari
(SENSE)
VIT
Vellore, Tamil Nadu
jauharirishita@gmail.com

Tushar Pati Tripathi
(SENSE)
VIT
Vellore, Tamil Nadu
tushartripathi851@gmail.com

Aiyushi Srivastava
(SENSE)
VIT
Vellore, Tamil Nadu
aiyushisrivastava20@gmail.com

Dr. Sasikumar P
(SENSE)
VIT
Vellore, Tamil Nadu
sasikumar.p@vit.ac.in

***Abstract*— In recent years, the Internet of Things (IoT) has emerged as a transformative technology with immense potential to revolutionize various industries, including the field of labor welfare. IoT serves and motivates health monitoring systems where sensors are either worn inside or outside the human body. The sensors collect the information of physical and logical conditions and the movements of the patient. This research paper explores the integration of IoT devices to record and monitor the working conditions of workers in India, with the aim of improving their overall well-being and productivity. These sensors are incorporated and interfaced with Arduino UNO board, ESP8266 for wireless data transmission to Thing Speak. The outcome of the result on Thing speak is Data visualization. So that record of data can be stored and accessed over a period of time.**

Keywords— IOT, Health Monitoring, Heart Rate, Body Temperature, ARDUINO, Thing Speak ,Health Data workers, Safety Devices, Sensors, User Hazards Risks..

I. Introduction

India, being one of the world's largest labor markets, faces numerous challenges related to ensuring safe and conducive working environments for its workforce.[4] The implementation of IoT technology presents an opportunity to address these challenges by providing real-time data on various aspects of workers' conditions, such as temperature, humidity, air quality, noise levels, and ergonomics. By gathering such data, employers and regulatory bodies can gain valuable insights to identify potential hazards and take proactive measures to mitigate risks.

Over the past two decades, Bangladesh has experienced significant urbanization, with an annual rate predicted to be between 5 and 6%, leading to a projection that by 2025, half of the population will live in urban areas, up from the current 34%. The real estate industry, initially comprising just five enterprises in 1970, expanded rapidly to meet the
housing demands of urbanization. Currently, employing over 1500 people, it stands as a major job creator, second only to agriculture. However, the construction sector, integral to real estate, faces notable challenges, including high rates of nonfatal injuries and fatal accidents. Construction workers are exposed to various health and environmental risks, with exposure varying by trade, employment conditions, and time. Hazards, defined as events that may cause harm, impact workers' health depending on intensity, quantity, timing, and duration of exposure.[5]

II. Objective of the study

The main objective of this research paper is to shed light on the current state of working conditions in India, highlighting the prevalent issues faced by workers across different sectors. It then explores the potential benefits of IoT integration in this context, including improved occupational safety, enhanced worker productivity, and the potential to prevent workplace accidents and occupational diseases.[6]

Furthermore, the paper investigates the technical aspects of IoT deployment, such as sensor selection, data collection, communication protocols, and data analysis techniques. It also examines the challenges associated with IoT implementation, such as data privacy, security, and the need for robust infrastructure in both urban and rural areas. Overall, this research paper aims to highlight the integration of IoT devices as a means to record and monitor the working conditions of workers in India. Ultimately contributing to the development of safer and more productive work environments for the nation's labor force.

III. Current state of Indian Labour force

The Indian labor force faces significant health hazards that impact their well-being and pose risks to their physical and mental health. Some key problems related to health hazards faced by the Indian labor force include:

a) Occupational diseases: Workers in various industries are exposed to hazardous substances, chemicals, and pollutants, leading to the development of occupational diseases such as respiratory disorders, dermatological conditions, hearing loss, and musculoskeletal disorders. Lack of proper safety measures, inadequate training, and poor enforcement of regulations contribute to the prevalence of these diseases. [7]

b) Indoor and outdoor air pollution: Workers in industries such as manufacturing, construction, and mining are exposed to high levels of indoor and outdoor air pollution. Dust, fumes, and toxic gasses can lead to respiratory illnesses, cardiovascular diseases, and other health complications. Additionally, outdoor pollution in urban areas poses a risk to workers commuting and working in open spaces. [8]

c) Heat stress: Workers in sectors like agriculture, construction, and manufacturing often work in high-temperature environments, leading to heat stress-related illnesses. Prolonged exposure to high temperatures can cause heat exhaustion, heatstroke, dehydration, and other heat-related health issues.[10]

d) Noise-induced hearing loss: Workers in industries involving heavy machinery, construction, and manufacturing are often exposed to excessive noise levels. Prolonged exposure to loud noise without adequate hearing protection can result in noise-induced hearing loss, leading to long-term disability and decreased quality of life.[9]

Addressing health hazards in the Indian labor force requires comprehensive measures, including strengthening occupational health and safety regulations, promoting awareness and training programs on workplace hazards, ensuring access to healthcare services, providing personal protective equipment, and implementing measures to mitigate exposure to pollutants and ergonomics. [11] [12]

IV. BACKGROUND

This section reviews the basic concepts of IoT-based health monitoring, including remote health monitoring, IoMT, and health features.

A. State of the Art

Millions of people work in many areas of the economy in India, which serves as a hub for a variety of businesses, including manufacturing and services. Nevertheless, many of these industries' working conditions frequently fall short of international safety requirements, endangering the workers' health and wellbeing. By utilizing IoT technology to gather data in real-time and offer insights into working circumstances, this project seeks to close this gap and enable proactive steps to improve overall working conditions and safety. This project aims to demonstrate the feasibility and effectiveness of integrating IoT devices for monitoring and enhancing working conditions, ultimately contributing to a safer and more sustainable work environment for the workforce in India. [13]

This study paper's primary goal is to shed light on India's present working conditions by identifying the common problems that employees in various industries confront. The advantages of IoT integration in this setting are then discussed, including increased worker productivity, safer working conditions, and a possible reduction in occupational illnesses and accidents. [14]

The study also looks into the technical aspects of IoT adoption, including data collection methods, connection protocols, sensor selection, and data processing strategies. It also looks at the difficulties in implementing IoT, including security concerns, data privacy, and the requirement for reliable infrastructure in both urban and rural locations. The overall goal of this research study is to demonstrate how IoT devices may be integrated to record and monitor the working conditions of Indian laborers, helping to create safer and more productive work environments for the country's workforce. [15]

The following are the project's main goals:

- Monitoring in real-time: Use IoT devices to keep an eye on important variables like temperature, humidity, air quality, noise levels, and other pertinent elements.
- Data analytics: Process the gathered data, look for trends, and produce useful information about possible risks or locations where working conditions could be improved by using advanced analytics.
- Alert Systems: Provide alert systems to let management and employees know when dangerous conditions arise so that prompt actions and preventative measures can be taken.
- Worker Wearables: Investigate the usage of wearables with sensors to track personal health measurements and provide safety and well-being data for employees.
- Compliance Monitoring: Enable a safer and healthier work environment by integrating IoT solutions to monitor compliance with safety requirements and standards.

The Indian labor force faces significant health hazards that impact their well-being and pose risks to their physical and mental health. Some key problems related to health hazards faced by the Indian labor force include:

1. Exposure to Dangerous Substances
2. Workplace Illnesses
3. Ergonomics and Physical Stress
4. Insufficient Safety Procedures
5. Low-quality air
6. Warm Stress
7. Noise Disturbance
8. Insufficient Facilities for Sanitation
9. Mental Health Difficulties
10. Insufficient Health Awareness

A comprehensive strategy is needed to address these health concerns, including the adoption of safety laws, enhanced working conditions, routine physical examinations, and educational programmes aimed at increasing workforce awareness of potential risks and preventive measures. [16]

Integrating IoT devices for monitoring and enhancing the working conditions of workers in India is a commendable initiative that can lead to improved safety, productivity, and the overall well-being of workers.

To guarantee the effective deployment of such a system, there are a few unmet needs that must be met.

1. Infrastructure Difficulties:

Network Connectivity: In certain isolated or rural locations, there may be no or very little network connectivity. Make sure the Internet of Things (IoT) devices can operate in places with poor connectivity, perhaps by implementing edge computing features.

Power Supply: Use low-power Internet of Things devices and look into alternate power sources like solar energy in locations where the power supply is erratic. [17]

2. Security and Privacy of Data:

Data Protection: Put strong security mechanisms in place to guard the information that Internet of Things devices gather. This is very important, particularly when handling private employee data.

Compliance: To prevent legal problems and safeguard employees' privacy, make sure that data protection laws in India, such as the Personal Data Protection Bill, are followed. [18]

3. Language and Cultural Considerations:

Language Diversity: India has a wide range of languages spoken there. It is imperative to provide multilingual training materials and user interfaces to accommodate employees with varying linguistic backgrounds.

Cultural Sensitivity: When putting monitoring systems in place, take into account cultural variances and sensitivities. Engage in dialogue with workers and local communities to learn about their preferences and concerns. [19]

4. Accessibility and Affordability:

Cost of Devices: In particular, in companies with narrow profit margins, make sure the IoT devices chosen are within the means of both employers and employees.

Education and Availability: Employees should receive training on how to operate and maximize the use of these devices. In light of the workforce's varied educational backgrounds, make sure the devices are easily accessible and intuitive to use. [20]

Need for a wearable device to monitor the health of the workers:

Ensuring the health and safety of workers is crucial in today's workplaces. Wearable technology has become an essential tool for keeping an eye on a variety of health indicators and environmental factors, which improves worker safety and well-being.

Monitoring environmental elements like temperature, gas, and smoke levels is essential. Particularly in sectors such as manufacturing or construction, extreme temperatures might present hazards including hypothermia or heat stress. Gas and smoke detection is essential in areas where there is a chance of coming into contact with fire or toxic substances. Wearable sensors enable early detection, facilitating swift evacuation or mitigation actions to avert mishaps or health problems.[21]

In settings where excessive noise might cause hearing impairment or stress-related problems, sound level monitoring is crucial. Elevated decibel levels, frequently encountered in sectors such as building and manufacturing, may have enduring health consequences if not appropriately addressed. Workers can employ protective gear or take essential precautions thanks to real-time data from wearable devices with sound level sensors.[22]

By identifying unexpected movements or falls, motion detection sensors provide an additional degree of security. For the purpose of providing early help and preventing injuries, it is essential to identify falls or accidents in businesses where workers handle heavy gear or do physically demanding jobs. In the event of an accident, wearables equipped with motion sensors can instantly notify emergency personnel or supervisors, speeding up response times and enhancing public safety.[23]

Workplaces can proactively monitor individual health indicators and environmental circumstances by integrating these various sensors into wearable devices. This all-encompassing strategy not only reduces short-term dangers but also enhances employees' long-term wellbeing. Furthermore, the information gathered from these devices may be examined to spot patterns, evaluate risk factors, and put preventative measures in place—all of which will help to promote a wellness and safety culture at work.

B. *Technological Advancements in wearable health monitoring*

The field of wearable health monitoring has experienced significant technological breakthroughs that have revolutionized how people track their personal health and interact with it. A notable advancement is the shrinking of sensors, which makes it possible to create wearables that are more discrete and svelte. Because of this downsizing, sensors may now be smoothly integrated into apparel or accessories, increasing application possibilities while also improving user comfort. The significant improvement in battery life, which solves a persistent problem in wearable technology, is another important development. Longer batteries also contribute to sustained monitoring capabilities. [24]

Furthermore, wearable technology has merged more and more with other smart gadgets to form a synergistic ecosystem. Real-time feedback and more thorough analysis of health data are made possible by seamless connectivity with smartphones, tablets, and even smart home appliances. Wearable health monitors, for example, may now sync data with health applications, giving consumers and medical professionals a comprehensive picture of a patient's health over time. These developments in technology highlight the potential for wearable health monitoring to become a necessary component of daily life, providing increased precision, convenience, and user involvement in the management of one's own health and well-being.[25]

C. *Data Security and Privacy concerns related to wearable device*

The increasing use of wearable health monitoring devices in the workplace raises important questions about privacy and data security. Examining the possible weaknesses in the systems intended to protect this data is crucial as businesses gather and retain more sensitive health information from their employees. There is a greater chance of unwanted access, data breaches, and privacy violations due to wearable devices' interconnectedness and incorporation into corporate networks. To safeguard this abundance of health data, strong security measures that guarantee encryption methods, secure data transmission, and strict access controls must be put in place. The problem also includes addressing possible weaknesses in the equipment themselves, such as defense against hacking attempts or illegal physical access.[26] The problem also includes addressing possible weaknesses in the equipment themselves, such as defense against hacking attempts or illegal physical access. It is imperative that enterprises provide clear limits on the use, storage, and sharing of health data. The significance of user permission and transparent data usage policies cannot be stressed. Since these devices frequently follow the BYOD (Bring Your Own Device) model, it is crucial to make sure that staff members are aware of the security precautions in place. To reduce potential risks, organizations must constantly update their security architecture and be alert to the latest developments in cybersecurity threats.. Organizations may cultivate trust among employees and ensure that the integration of wearable health monitoring complies with ethical and legal requirements while improving occupational health and safety practices by placing a high priority on data confidentiality and privacy.[27]

D. *Human Factors and User Experience regarding wearable devices*

The successful integration of wearable devices into occupational health monitoring requires a comprehensive analysis of their effects on user experience, with a focus on critical human aspects that facilitate successful adoption in a variety of work environments. A key component of this assessment is the comfort level, which is a crucial factor in determining user acceptance and wearable technology adherence over the long term. Ergonomic design is essential for wearable technology to ensure that it fits comfortably into the user's everyday routine without restricting movement.[28] Usability, which includes features like simple navigation, intuitive interfaces, and low cognitive load, is just as important. Wearables' complicated health data presentation shouldn't make it difficult for users to understand, especially in hectic work settings. Effective communication and education are also necessary for wearable device adoption in the workplace since workers must be aware of the advantages these technologies offer in terms of their health and safety. This includes dispelling any misconceptions about the data gathered, outlining how it improves people's quality of life, and responding to any privacy or data usage issues. Furthermore, as wearables' aesthetic appeal can affect users' perceptions and willingness to adopt the technology, user experience considerations should also take into account aspects like device aesthetics. To ensure that wearables seamlessly integrate into a variety of work settings and maximize their efficacy in promoting occupational health and safety while fostering a positive and user-friendly experience for all users, a thorough evaluation of human factors and user experience is essential. [29]

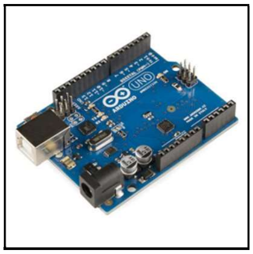
V. METHODOLOGY

Our design uses various kinds of sensors that are grouped together and connected to a wifi/bluetooth enabled microcontroller that helps in sending data collected from the microcontroller to a server base station from where it can be utilized for various other purposes. The below figure shows a block diagram representation of our model.

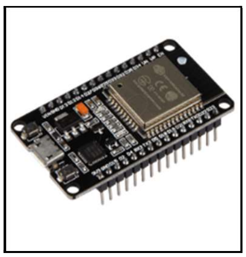
A. *About the Sensors*

1. **Arduino UNO *:*** Arduino UNO is a low-cost, flexible, and easy-to-use programmable open-source microcontroller board that can be integrated into a variety of electronic projects. The main reason for using Arduino UNO for this project is

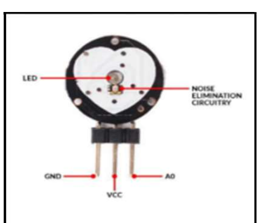
that it enables us to integrate all the required sensors into one microcontroller providing easy operability.



2. **ESP32 DevKit v1 *:*** The ESP32 DevKit v1 is a development board created to evaluate the ESP-WROOM-32 module. It's based on the ESP32 microcontroller, which supports Bluetooth, Wi-Fi, Ethernet, and low power.

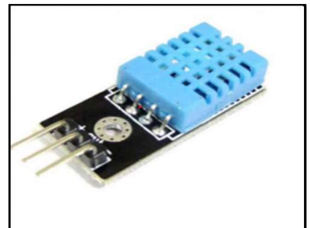


3. **Pulse Sensor** - The pulse sensor is a small and non-invasive device used to measure the heart rate and pulse of an individual. It typically consists of an optical sensor that detects blood flow through the capillaries in the fingertip or earlobe. The sensor emits light and measures the changes in light absorption caused by the pulsating blood. This data can be used for various applications, including fitness tracking, health monitoring, and biofeedback systems. The pulse sensor is easy to use, portable, and can be interfaced with microcontrollers or other devices for real-time heart rate monitoring.

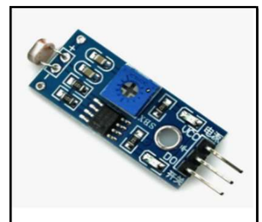


a Heart rate pulse sensor module

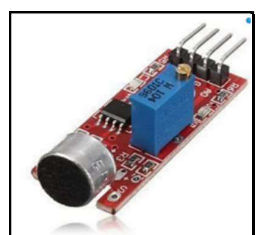
4. **DHT 11 Sensor -** The DHT11 is a basic, ultra low-cost digital temperature and humidity sensor. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air and spits out a digital signal on the data pin (no analog input pins needed).


DHT11 - Temprature and Humidity Sensor Module

5. **LDR Sensor*:*** An LDR (Light Dependent Resistor) sensor for Arduino is a module that detects and measures the intensity of light in the surrounding environment. It uses a light-sensitive resistor that changes its resistance based on the amount of light it receives. When connected to an Arduino microcontroller, the LDR sensor provides analog or digital output that corresponds to the detected light level.

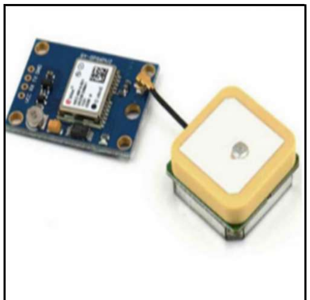

Light Detection Sensor Module

6. **Sound Sensor** - A sound sensor is a module used to detect and measure sound or noise levels in the environment. It consists of a sensitive microphone that converts sound waves into electrical signals. Sound sensors can be interfaced with microcontrollers like Arduino to analyze and process the detected audio input. They are commonly used in applications such as noise monitoring, sound-activated devices, acoustic measurements, and audio analysis.


Sound Detection Module Sensor

7. **Neo-6M GPS Module** : A GPS module is a device that receives signals from satellites to determine precise geographical coordinates, altitude, and time information. It uses a network of satellites in orbit around the Earth to triangulate its position. GPS modules are compact and can be easily integrated into various electronic devices. By connecting a GPS module to a microcontroller like Arduino, developers can create projects that track and log the location of objects or vehicles, enable navigation, and provide accurate timing

information. GPS modules have numerous applications in areas such as transportation, geolocation, and outdoor tracking.

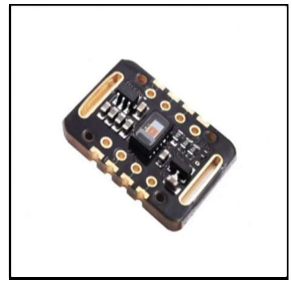


NEO-6M GPS Module

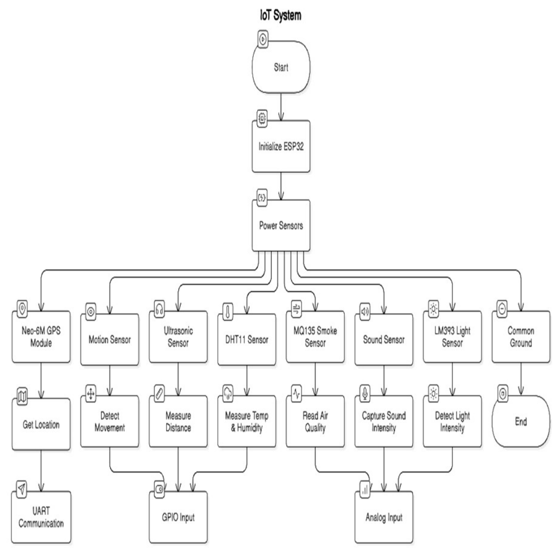
8. **Air Quality Gas Sensor** - An air quality sensor for Arduino is a module that measures and monitors the quality of the air by detecting various pollutants and gasses present in the environment. These sensors interface with Arduino microcontrollers, providing accurate readings of air quality parameters such as particulate matter (PM2.5, PM10), volatile organic compounds (VOCs), carbon monoxide (CO), and more. By integrating air quality sensors with Arduino, users can create indoor air quality monitoring systems, smart home applications, and environmental monitoring devices that enable real-time tracking and analysis of air pollution levels, promoting healthier and safer living environments

MQ135 - Air Quality Gas Sensor Module

9. **MAX30100 Pulse Oximeter Sensor -** The MAX30100 sensor is used as both a heart rate monitor and a pulse oximeter. This sensor's design, which includes two LEDs, a photodetector, improved optics, and low noise signal processing components, makes these features possible. It may be readily utilized to create an oxygen saturation and heartbeat device that is effective using microcontrollers like Arduino, ESP32, NodeMCU, etc.



B. Working(By using ESP32 DevKit)



1. **Initialization:** When the ESP32 DevKit starts up, it initializes all connected sensors and modules. 2.**Sensor Data Acquisition:** Each sensor continually gathers data at predetermined intervals, such as heart rate, temperature, humidity, sound levels, light intensity, air quality, blood oxygen saturation, and GPS locations. 3.**Data Processing:** The ESP32 processes incoming sensor data, conducting the necessary computations and analysis to produce meaningful results. 4.**Health Monitoring:** The Pulse Sensor and MAX30100 Pulse Oximeter measure the worker's heart rate, blood oxygen saturation, and other important indications. Any deviations from typical values generate warnings that notify workers and managers.

5. **Environmental Monitoring:** The DHT11 Sensor, Sound Sensor, LDR Sensor, and Air Quality Gas Sensor all measure temperature, humidity, noise levels, light intensity, and air quality, respectively. Abnormal readings trigger notifications to address potential safety issues. 6. **Location Tracking:** The Neo-6M GPS Module records the worker's location in real time, allowing managers to monitor their activities and ensure they remain in specific zones.

7.**Warning System:** When irregularities or hazardous situations are detected, the warning system activates. Alerts might take the form of visual indications, audible alerts, or notifications delivered to supervisors' cell phones or a centralized monitoring system.

8. **Data Logging and Transmission:** The ESP32 records sensor data and timestamps for future study. It may also send real-time data to a cloud server for remote monitoring and analysis.

9. **Power Management:** The gadget is powered by a rechargeable battery, and power-saving technologies have been added to help extend battery life. Low battery notifications need recharging or battery replacement.

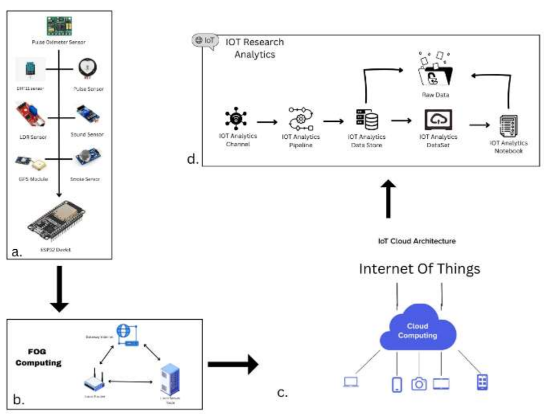


Fig. shows Project Architecture where ; a.) show the hardware implementation ; b.)shows the fog computing ; c.) shows the Cloud computing used in the research; d.) IOT Research analytics

C. Reason for using ESP32 instead of Arduino Uno

1. Built-in Wi-Fi and Bluetooth Connectivity: The ESP32 has Wi-Fi and Bluetooth capabilities, allowing for easy wireless connectivity with other devices and the internet. This feature allows for remote monitoring, data transmission to cloud servers, and interaction with smartphones or other IoT devices, which increases the wearable device's utility and versatility.

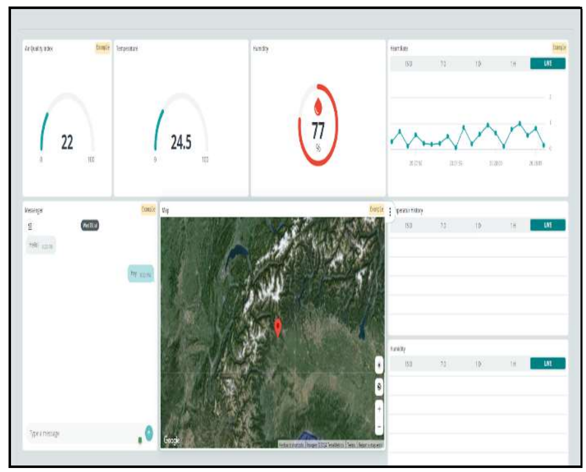
2. More Processing Power and Memory: The ESP32 generally has more processing power and memory than the Arduino Uno. This additional horsepower enables more complicated data processing, analysis, and multitasking capabilities, which are useful for managing various sensors.

3. Incorporated Low-Power Modes: The ESP32 has incorporated low-power modes and optimisation features, making it more energy efficient than the Arduino Uno. This is critical for wearable devices designed for long-term use since it increases battery life and minimizes the need for regular recharging or replacement.

4. Advanced Peripheral Support: The ESP32 supports a variety of advanced peripherals and protocols, including SPI, I2C, UART, ADC, DAC, and SDIO. This adaptability enables easy interface with a variety of sensors, displays, communication modules, and external storage devices, making it suited for a wide range of IoT applications, including the Smart Safety Wearable.

5. Cost-Effectiveness: Despite its extensive functionality, the ESP32 is frequently offered at a comparable or slightly higher price range as the Arduino Uno. Given its extra features and performance advancements, the ESP32 may provide better value for specific projects, such as IoT wearables that require connection and processing power.

D. About Arduino cloud



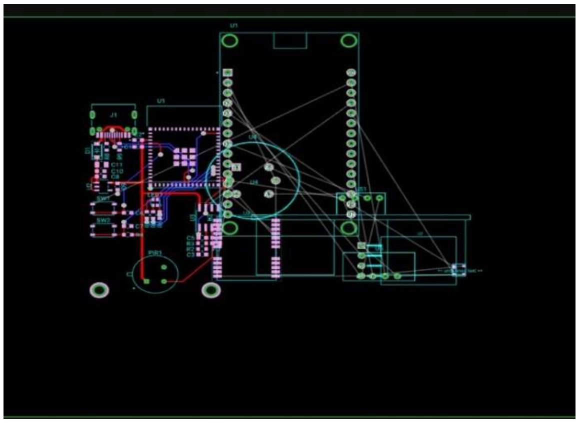
Arduino Cloud is a platform offered by Arduino that allows you to effortlessly connect your IoT (Internet of Things) devices, such as Arduino boards or similar microcontrollers like the ESP32, to the cloud. It provides a set of tools and services for easily building, monitoring, and managing IoT projects.

Arduino Cloud facilitates the development and deployment of IoT applications by offering a full platform for device connection, data administration, visualization, and automation. It's ideal for enthusiasts, makers, educators, and professionals who want to develop IoT applications spanning from home automation to industrial monitoring and beyond.

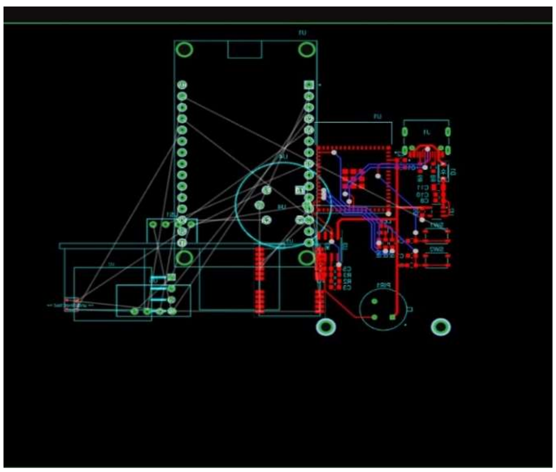
https://cloud.arduino.cc/how-it-works

E. Proposed Design

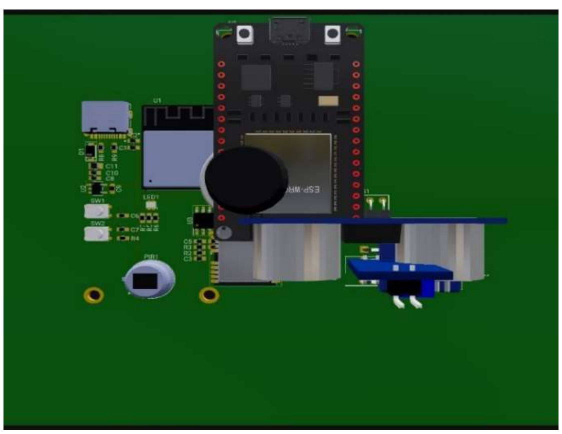
PCB Top View in 2D



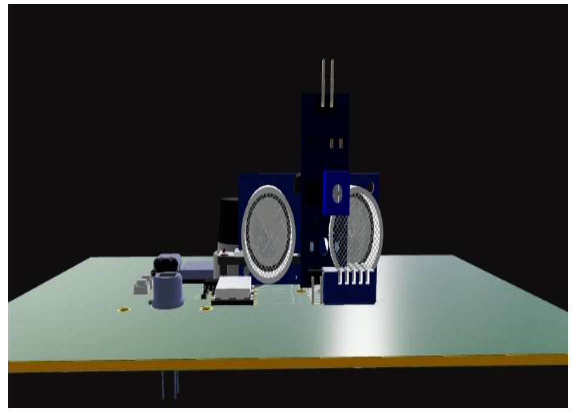
PCB Bottom View in 2D



PCB Top View in 3D



PCB Front View in 3D



F. Battery Usage info and solution

1. ESP 8266: The power consumption of the ESP8266 varies depending on the operating mode and usage scenarios. The ESP8266 can consume around **70-170 mA** during active WiFi transmission or reception.The ESP8266 can consume around **15 mA** in light sleep mode and less than **1 mA** in deep sleep mode.In standby mode with WiFi disabled, the ESP8266 can consume less than 10 µA.The ESP8266 is known for its relatively high power consumption during WiFi transmission, which can drain the battery quickly if not managed efficiently.

2. Adafruit Feather nRF52 Bluefruit LE: The power consumption of the Adafruit Feather nRF52 Bluefruit LE is optimized for low-power IoT and wearable applications. Active Mode: The nRF52832 microcontroller typically consumes around **10-20 mA** during active operation, depending on the specific tasks and peripherals enabled. Sleep Mode: The nRF52832 microcontroller can achieve sleep currents as low as **1-5 µA** in various sleep modes, conserving power during idle periods. BLE Communication: The BLE module consumes around **5-15 mA** during active transmission and less than 1 µA in sleep mode. Note: The Adafruit Feather nRF52 Bluefruit LE is designed with low power consumption in mind, making it suitable for battery-powered wearable devices that require wireless connectivity.

3. The **ESP8266** is known for its higher power consumption during active WiFi operation compared to the **Adafruit Feather nRF52 Bluefruit LE**, which utilizes a more power-efficient BLE communication protocol.

In terms of standby power consumption and sleep mode efficiency, both boards offer low-power options, but the Adafruit Feather nRF52 Bluefruit LE may have an edge due to its optimized low-power design.

For battery-powered IoT and wearable applications where wireless connectivity is required, the Adafruit Feather nRF52 Bluefruit LE may offer better power efficiency and longer battery life compared to the ESP8266, especially during periods of wireless .

G. Estimates and Calculations

1. **DHT11 (Temperature and Humidity Sensor)**

Power Consumption: The DHT11 typically consumes around 1.5 mA during active measurement and less than 100 µA in standby mode. Assuming periodic measurements every 5 minutes:
Active Power Consumption: 1.5 mA * (1/12 hours) = 0.125 mA-hours per measurement
Standby Power Consumption: 100 µA * (11/12 hours) = 0.0916 mA-hours per hour (assuming 1-minute active measurement time and 11-minute standby time per measurement cycle).

2. **LDR (Light Dependent Resistor):**
Power Consumption: The power consumption of an LDR is minimal as it acts as a variable resistor in a voltage divider circuit.
Assuming continuous monitoring:
Power Consumption: Negligible for practical purposes

3. **Sound Sensor:**
Power Consumption: The power consumption of a sound sensor depends on the specific model and operating conditions.
Assuming periodic measurements every 5 minutes:
Power Consumption: Varies depending on the sensor model and measurement method, but typically ranges from a few mA during active measurement to a few µA in standby mode.

4. **NEO-6M GPS Module:**
Power Consumption: The NEO-6M GPS module typically consumes around 20-50 mA during active acquisition and less than 20 mA in standby mode.
Assuming periodic measurements every 30 minutes:
Active Power Consumption: 50 mA * (1/120 hours) = 0.4167 mA-hours per measurement
Standby Power Consumption: Assuming negligible standby consumption due to short measurement intervals.

5. **MQ Air Quality Sensor:**
Power Consumption: The power consumption of an MQ sensor depends on the specific model and operating conditions.
Assuming periodic measurements every 5 minutes:
Power Consumption: Varies depending on the sensor model and measurement method, but typically ranges from a few mA during active measurement to a few µA in standby mode.

6. **MAX30100 (Heart Rate and Oxygen Sensor):**

Power Consumption: The MAX30100 typically consumes around 1.8 mA during active measurement and less than 1 µA in standby mode.
Assuming periodic measurements every 5 minutes:
Active Power Consumption: 1.8 mA * (1/12 hours) = 0.15 mA-hours per measurement
Standby Power Consumption: 1 µA * (11/12 hours) = 0.000917 mA-hours per hour (assuming 1-minute active measurement time and 11-minute standby time per measurement cycle)

Different proposed working modes to get maximum battery life.
Assuming that the battery used is 150 mAh the current consumption details are as follows.
Battery Capacity: 150mAh
Current Consumption: –

ESP8266:
Active WiFi Transmission: 100mA
Deep Sleep Mode: 1mA

Adafruit Feather nRF52 Bluefruit LE:
Active Mode: 15mA
Deep Sleep Mode: 5µA

DHT11:1.5mA during active measurement, negligible standby
LDR: Negligible
Sound Sensor: Varies, assuming 1mA during active measurement, negligible standby

NEO-6M GPS Module:50mA during active acquisition, negligible standby
MQ Air Quality Sensor:Varies, assuming 1mA during active measurement, negligible standby
MAX30100:1.8mA during active measurement, negligible standby.

1. Standard Mode
Active Mode: Assuming all sensors active simultaneously

- Total Current Consumption = 100 mA + 1.5 mA + 1 mA + 1 mA + 50 mA + 1 mA + 1.8 mA
- Total Current Consumption ≈ 156.3 mA
- Battery Life = 150 mAh / 156.3 mA ≈ 0.96 hours

Deep Sleep Mode: Assuming all sensors are in standby

- Total Current Consumption = 1 mA + 1 mA + 1 mA + 1 mA + 1 mA + 1 mA + 1 mA
- Total Current Consumption = 7 mA
- Battery Life = 150 mAh / 7 mA ≈ 21.43 hours

2. Adafruit Feather nRF52 Bluefruit LE Scenario
Active Mode: Assuming all sensors active simultaneously

- Total Current Consumption = 15 mA + 1.5 mA + 1 mA + 1 mA + 50 mA + 1 mA + 1.8 mA
- Total Current Consumption ≈ 71.3 mA

- Battery Life = 150 mAh / 71.3 mA ≈ 2.10 hours

Deep Sleep Mode: Assuming all sensors are in standby

- Total Current Consumption = 5 µA + 5 µA + 5 µA + 5 µA + 5 µA + 5 µA + 5 µA
- Total Current Consumption = 35 µA
- Battery Life = 150 mAh / 0.035 mA ≈ 4285.7 hours

Solutions to reduce battery consumption and improve battery life

- IoT devices save battery life through various sophisticated techniques, ensuring that these devices can operate efficiently for extended periods without frequent recharging or battery replacement. Here are some of the key strategies employed:

- **1. Low-Power Hardware**
- **Energy-Efficient Microcontrollers and Sensors:** IoT devices use specialized microcontrollers and sensors designed to operate at minimal power levels. These components are optimized to perform necessary functions without consuming excessive energy.
- **Component Selection:** Choosing hardware components that are inherently low-power helps in reducing the overall energy consumption. For example, low-power wireless modules, low-energy consumption sensors, and efficient data processing units are preferred.

- **2. Duty Cycling**
- **Power Management Techniques:** Duty cycling involves turning off or reducing the power to certain components when they are not in use. For instance, sensors and communication modules can be powered down during periods of inactivity and only activated when needed.[30]
- **Sleep Modes:** Many IoT devices are equipped with various sleep modes that consume very little power. The device can enter a deep sleep mode when idle and wake up periodically or upon a specific trigger to perform its tasks.[31]

- **3. Efficient Communication Protocols**
- **Low-Power Communication Standards:** Utilizing communication protocols that are designed for low power consumption is crucial. Standards like Zigbee, Bluetooth Low Energy (BLE), and LoRa are commonly used in IoT devices because they consume significantly less power compared to traditional communication methods.[32]
- **Reduced Data Transmission:** By minimizing the frequency and volume of data transmission, devices can save a considerable amount of energy. Techniques such as compressing data before transmission and only sending essential information can help reduce power usage.

- **4. Energy Harvesting**
- **Renewable Energy Sources:** IoT devices can incorporate energy harvesting methods to recharge their batteries. This includes using solar panels, capturing thermal energy, or converting kinetic energy into electrical energy. These methods supplement battery power, reducing the need for frequent recharging.[33]
- **Environmental Energy Utilization:** In some cases, IoT devices are designed to capture and utilize ambient energy from their surroundings, further enhancing their battery life.

- **5. Optimized Software**
- **Efficient Coding Practices:** Writing software that is optimized for power efficiency is crucial. This includes minimizing the number of instructions the microcontroller must execute and reducing the overall processing time.
- **Power-Saving Algorithms:** Implementing algorithms that intelligently manage power usage based on the device's activity and environmental conditions can significantly enhance battery life.

- **6. Adaptive Sampling and Reporting**
- **Dynamic Sampling Rates:** Adjusting the sampling rate of sensors based on the context or environmental changes helps in saving power. For example, sensors can increase their sampling rate during critical periods and reduce it during idle times.
- **Event-Driven Reporting:** Instead of constant data transmission, devices can be programmed to report only when significant changes or events occur. This reduces unnecessary communication and conserves battery life.

- **7. Edge Computing**
- **Local Data Processing:** By processing data locally on the device itself, the need for frequent communication with a central server or cloud is minimized. This reduces the power consumed in data transmission, as only essential data is sent at less frequent intervals.[32]
- **Reduced Data Transfer:** Edge computing enables devices to filter and process data locally, sending only aggregated or necessary information to the cloud. This reduces the overall data transfer, conserving power.

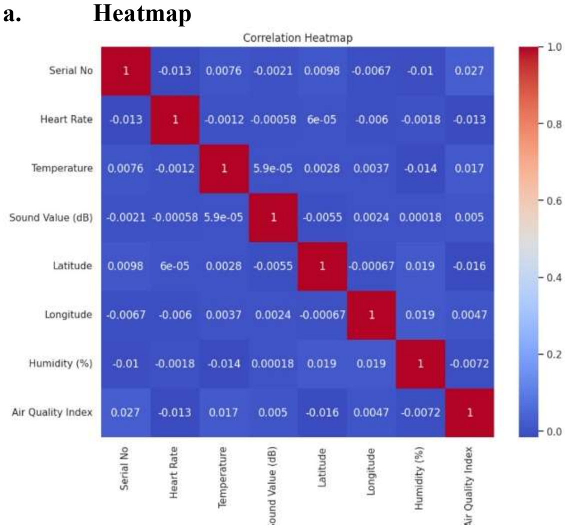
- **8. Battery Management Systems**
- **Smart Battery Management:** Advanced battery management systems monitor and optimize the charging and discharging cycles

of the battery. These systems ensure that the battery is used efficiently, prolonging its lifespan and maintaining optimal performance.[33]

- **Energy Storage Optimization:** Efficiently managing energy storage and ensuring that the battery operates within optimal parameters can prevent premature battery degradation and extend its usable life.
- By combining these techniques, IoT devices can achieve significant reductions in power consumption, thereby extending their operational life on a single battery charge. This is especially critical for devices deployed in remote or hard-to-reach locations where frequent battery replacement or recharging is impractical

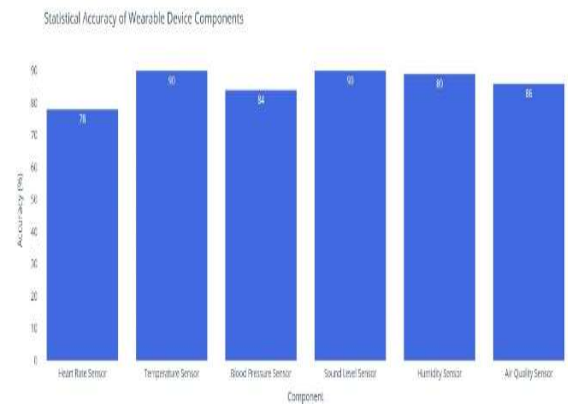
- **8. Research Analysis and Evaluation**

a. Heatmap



- The associations between the following variables are shown in the graph, which is a correlation heatmap: Serial No., Heart Rate, Temperature, Sound Value (dB), Latitude, Longitude, Humidity (%), and Air Quality Index. The correlation coefficients are represented on the heatmap by a color scale that runs from blue to red, where red denotes a perfect positive correlation (1.0) and blue denotes no correlation (0.0).
- As can be seen from the heatmap, most variables have relatively weak associations with one another, as seen by the majority of blue colors and values that are near to 0.
- - A perfect correlation of 1.0 is shown in red on the heatmap diagonal, which represents the correlation between each variable and itself.
- - The low correlations imply that there isn't a strong linear link between the variables in the dataset.
- Although there aren't any obvious strong connections in this instance, this heatmap is helpful for rapidly discovering any significant correlations between the variables.

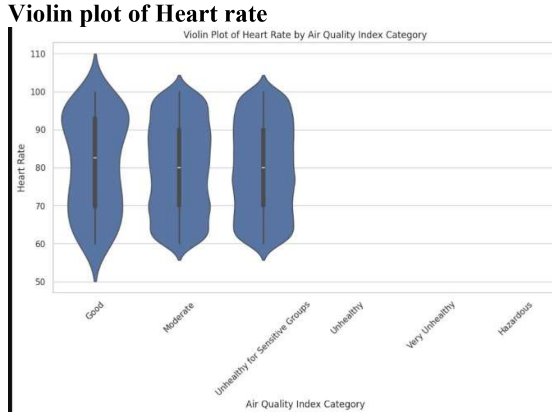
b. Statistical analysis of wearable device components



- The statistical correctness of the several wearable device components is displayed on the graph. The sensors that monitor blood pressure, temperature, heart rate, humidity, sound level, and air quality are among those that are measured.

- - The accuracy of the *Heart Rate Sensor* is 78%.
- - With 90% accuracy, the *Sound Level Sensor* and the *Temperature Sensor* have the best accuracy.
- - The accuracy of the *Blood Pressure Sensor* is 84%.
- - The accuracy of the *Humidity Sensor* is 89%.
- - The accuracy of the *Air Quality Sensor* is 86%.
- The accuracy of each sensor is shown as a bar chart on the graph, with percentages shown above each bar. The temperature and sound level sensors are the most accurate, according to the data, while the heart rate sensor is the least reliable.

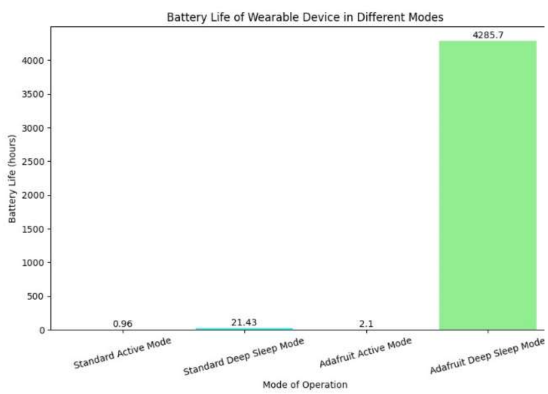
c. Violin plot of Heart rate



- The distribution of heart rates across the various air quality index (AQI) categories is shown by the violin plot graph. The AQI categories that each violin symbolises are "Good," "Moderate," "Unhealthy for Sensitive Groups," "Unhealthy," "Very Unhealthy," and "Hazardous."

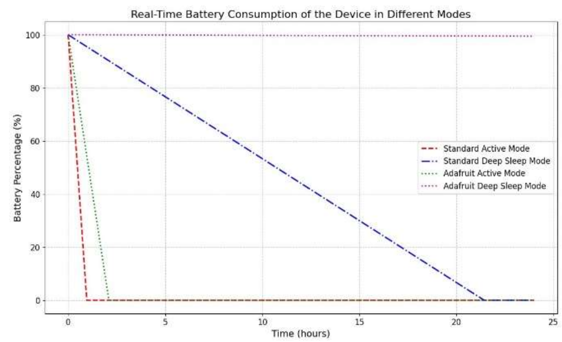
- *X-Axis:* The various AQI categories are displayed on the horizontal axis.
- - *Axis Y:* Heart rate measurements are displayed on the vertical axis and range from 50 to 110 beats per minute.
- Wider sections imply a larger concentration of data points. The width of each violin shape represents the density of data points at various heart rate levels. A boxplot is shown inside each violin, with the median heart rate (shown by the white dot), the interquartile range (shown by the thick black bar), and the total range of data.
- The graphic shows that most heart rates are concentrated between around 70 and 90 beats per minute, and that the heart rate distributions across the various AQI categories are somewhat similar. Heart rates do not significantly change as the air quality deteriorates from "Good" to "Hazardous."

d. Battery Life of wearable devices



- The graph, which is a bar chart, contrasts a wearable device's battery life under various operating modes.
- - *X-Axis:* The various operating modes, such as "Standard Active Mode," "Standard Deep Sleep Mode," "Adafruit Active Mode," and "Adafruit Deep Sleep Mode," are displayed on the horizontal axis. To make the labels easier to read, they have been slightly rotated.
- - *Axis Y:* The battery life is shown on the vertical axis as hours, with a range of 0 to 4500 hours.
- The various modes have a substantial difference in battery life:
- - *Standard Active Mode:* Has the lowest battery life, lasting 0.96 hours.
- - *Standard Deep Sleep Mode:* 21.43 hours is a longer battery life.
- - *Adafruit Active Mode:* At 2.1 hours, the battery life is somewhat greater than in Standard Active Mode.
- - *Adafruit Deep Sleep Mode:* Compared to all other modes, this one has a much longer battery life, reaching 4285.7 hours.
- The graph demonstrates the effectiveness of the "Adafruit Deep Sleep Mode," which provides much longer battery life than the other modes—especially when compared to the active modes.

e. Real time Battery consumption of the Device



- The graph shows how much battery a device uses in real time when running in various settings over the course of a day. The battery percentage is shown on the y-axis, which goes from 0% to 100%, and the time is shown on the x-axis in hours.
- Four modes are visible:
- 1. The battery drains quickly in *Standard Active Mode* (red dashed line), reaching 0% in less than two hours.
- 2. *Standard Deep Sleep Mode* (blue dash-dot line): This mode allows the battery to drain more gradually; it lasts for around 20 hours before becoming completely dead.
- 3. *Adafruit Active Mode* (green dotted line): This mode drains the battery faster than the Standard Active Mode, reaching 0% in less than two hours.
- 4. *Adafruit Deep Sleep Mode* (purple dotted line) - Throughout the course of the 24-hour period, the battery consumes very little and stays nearly completely charged.
- The graph illustrates how the device's mode significantly affects battery life; deep sleep modes, like the Adafruit Deep Sleep Mode, are very effective at saving battery life.

CONCLUSION

The integration of IoT devices for monitoring and enhancing the working conditions of workers in India presents a transformative approach to improving workplace safety, health, and overall productivity. The numerous advantages and useful applications of IoT technology in diverse industrial and vocational contexts have been investigated in this study.

Employers may obtain real-time insights about environmental elements like temperature, humidity, air quality, and noise levels by utilizing Internet of Things sensors and devices. By enabling prompt remedial action to reduce possible dangers, this continuous monitoring lowers the likelihood of accidents and occupational diseases. Furthermore, wearable IoT devices may monitor health indicators of employees, including heart rate, stress levels, and physical activity, allowing for prompt and proactive interventions in the form of proactive health management.

IoT technology use in the workplace also makes it easier to gather and analyse data, which improves decision-making and strategic planning. Optimizing resource allocation, streamlining processes, and enhancing compliance with health and safety laws are all possible with the data-driven approach. Additionally, IoT-driven automation may free employees from dangerous and boring jobs, promoting a safer and more effective workplace.

Nevertheless, a number of issues must be resolved for IoT solutions to be implemented successfully, such as protecting data privacy, handling technological complexity, and giving staff and management the necessary training. Creating strong cybersecurity defences is essential to safeguarding confidential information and preserving employees' faith in technology.

In conclusion, there is a great deal of promise for revolutionizing Indian workers' working circumstances through the integration of IoT devices in the workplace. IoT technology has the potential to create a more sustainable and affluent industrial landscape by improving efficiency, productivity, and safety. To achieve these advantages and promote an innovative and healthy work environment in India, it would be essential to keep investing in IoT infrastructure and to engage with stakeholders and support legislation.

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Unless there are six authors or more give all authors' names; do not use "et al.". Papers that have not been and element symbols.

For papers published in translation journals, please give the English citation first, followed by the original foreign-language citation [6].

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