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Innovative Safeguard: An in-Depth Analysis of Improvised Technologies in Coal Miner Safety Suits

Revolutionizing Workplace Safety Through Advanced Sensor Integration

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Abstract:
This comprehensive report delves into the development and implementation of an advanced safety suit tailored for coal miners, incorporating cutting-edge sensor technologies. The study explores the meticulous selection, calibration, and integration of sensors designed to enhance air quality monitoring, hazard detection, and physiological parameter tracking. With a focus on real-time data collection and IoT connectivity, the safety suit not only elevates situational awareness but also addresses the unique challenges faced by coal miners in hazardous environments. This report presents a detailed analysis of the suit's design, functionality, and its potential impact on improving workplace safety standards.

INTRODUCTION

Coal Mining is a very important sector in today's world. The majority of electricity generated in the world comes from coal. For example, 61% of electricity generated in India comes from coal. Therefore, coal mining is important, but it poses hazards for coal miners. Coal miners have to work in hot conditions, and at times there are harmful gases, such as methane, carbon monoxide, and nitric oxides, in the coal mines which can have serious impacts on the miners and overdose may lead to death. In addition, there is a high risk of coal miners falling from heights in mines while working. The list goes on. As it is high time to do something to make it safe, one potential solution is using a suit that has IoT-connected sensors that will report the data collected to the managers so that the managers can make safer decisions.

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HAZARDS

Coal miners face various hazards in coal mines, making their work environment challenging and potentially dangerous. Some of these hazards include:

Coal Dust and Respiratory Issues: Prolonged exposure to coal dust can lead to respiratory problems such as coal worker's pneumoconiosis (black lung disease). Fine coal dust particles can accumulate in the lungs and cause inflammation, leading to breathing difficulties and chronic lung diseases.

Methane and Coal Dust Explosions: Methane gas, which is often present in coal mines, can ignite and cause explosions when it reaches a certain concentration in the air. When combined with coal dust, these explosions can be highly destructive and pose a severe risk to miners' lives.

Fires: Fires can occur in coal mines due to various reasons, including spontaneous combustion of coal, electrical faults, or equipment malfunctions. These fires can be challenging to control and extinguish, leading to potential dangers for miners.

Roof and Rock Falls: Underground mining exposes miners to the risk of roof and rock collapses. Poorly supported or unstable roofs can cave in, leading to injuries or fatalities.

Gas Accumulation: Besides methane, other gases like carbon dioxide, carbon monoxide, and hydrogen sulfide can accumulate in the mine, leading to asphyxiation or toxic exposure.

Floods: Mines can experience flooding due to various factors, such as water ingress from nearby water bodies or heavy rain. Flooding poses a significant risk to miners' safety and can also damage equipment.

Noise and Vibrations: The operation of heavy machinery and equipment in coal mines can expose miners to high levels of noise and vibrations, potentially leading to hearing loss or other health issues.

High Temperatures and Humidity: Deep underground mines can become very hot and humid, especially in the absence of proper ventilation. Heat stress and dehydration are potential hazards for miners.

Confined Spaces: Working in confined spaces increases the risk of accidents and makes it difficult for miners to escape in case of emergencies.

Electrical Hazards: The presence of electrical equipment in coal mines poses a risk of electrical shocks and fires if not properly maintained and operated.

Chemical Exposure: Diverse chemicals used in the mining process may be exposed to miners; these chemicals can be dangerous if improperly handled.

CURRENT SAFETY MEASURES

As of 2017, Coal India Limited took various measures to improve the safety in coal mines. This includes the conduction of safety audits, implementation of Online Safety Monitoring System, Training, Safety Management Plans (SMPs), and Principal Hazards Management Plans (PHMPs).

Conduction of safety audit: A safety audit of mines was conducted by CIL to assess the safety status of mines and rectify the violations

Online Safety Monitoring System: The CIL Safety Information System is developed and uploaded on the CIL website where information from each mine is being uploaded continuously.

Training: Training is given to Mine Level Executives as well as Members of Safety committees of individuals to identify hazards and evaluate associated risks.

Safety Management Plans (SMPs) – Site-specific risk assessment-based SMPs have been prepared for each mine of CIL and are being updated continually

Principal Hazards Management Plans (PHMPs): As part of Safety Management, Principal Hazards Management Plans (PHMP) are also being created. SMP to prevent any mine disaster or major mine accidents accident

DISADVANTAGES OF THESE MEASURES

Despite various measures being followed, these measures have many shortcomings. Firstly, in-depth training is not given to coal miners which ultimately increases the risk of accidents while they are working in mines. Secondly, monitoring systems do not monitor every part of the mine leaving behind blind spots whose risk factors are unknown and can be more risky if a coal miner is working in that area. Lastly, despite having some real-time data, in situations of emergencies, the emergency response is time-consuming because operations will be taking place underground.

IMPROVISED APPROACH

One way to improve the quality of work for coal miners is by making and using IoT-based suits that will collect valuable real-time data from the sensors. The data collected will be related to various hazards listed above that they are facing down in the mines. Later, the data collected will be sent to the manager, who will monitor the working conditions. The system on which the data will be monitored will be programmed so that if the conditions start to become dangerous for miners like an increase in temperature more than a specific limit, then the manager will send an alarm in the coal mines to evacuate or take necessary steps to mitigate the impact of this.

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SUIT TECHNICAL DESCRIPTIONS AND DETAILS

All the sensors are connected to ESP32, a small microcontroller manufactured by Espressif Systems. The following sensors are embedded in the boiler suit that the coal miners will be wearing:
Optical Dust Sensor: This sensor measures the concentration of dust particles in the mine environment, providing real-time data on air quality and potential respiratory hazards for the miner.

Figure 1: Optical Dust Sensor

Acoustic Sensor: The acoustic sensor detects sounds in the mine, allowing the miner to be alerted to potential dangers, such as roof collapses or machinery malfunctions.

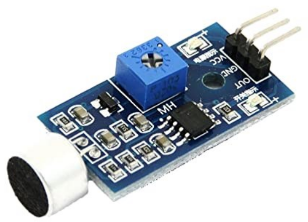

Figure 2: Acoustic Sensor

BMP280 (Pressure Sensor): The BMP280 monitors changes in atmospheric pressure, which can indicate shifts in the mine environment, such as gas leaks or changes in ventilation.

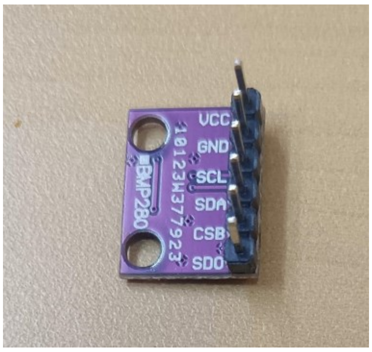

Figure 3: BMP280

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6 Axis Gyroscope and Accelerometer: This sensor combination tracks the miner's movements and orientation. It helps detect sudden movements, ensuring immediate alerts in case of falls or accidents.

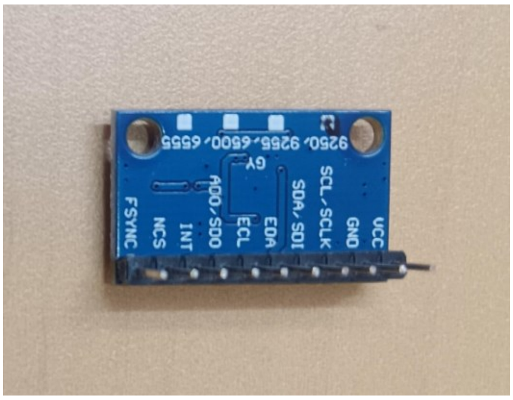

Figure 4: 6 Axis Gyroscope and Accelerometer

OLED Display: The OLED display provides real-time information to the miner, including gas levels, temperature, humidity, and alerts from other sensors, enhancing situational awareness.

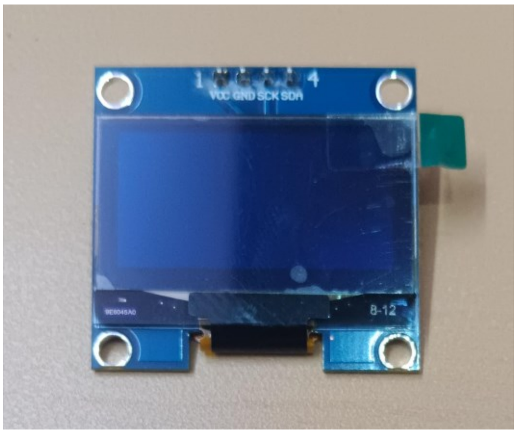

Figure 5: OLED Display

DHT11 (Temperature and Humidity Sensor): The DHT11 monitors the temperature and humidity inside the mine, ensuring the miner's comfort and safety.

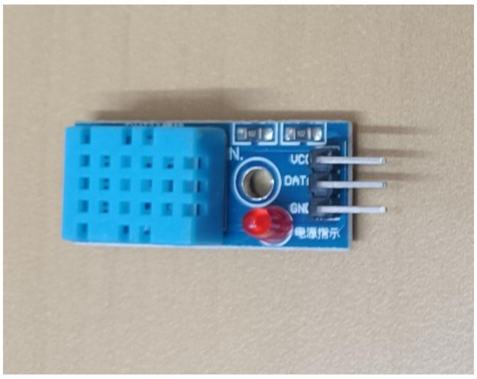
Figure 6: DHT11

Gas Sensor: This sensor detects harmful gases like methane and carbon monoxide, issuing warnings to the miner when gas concentrations exceed safe limits.

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Figure 7: Gas sensor

Heartbeat Sensor: The number of heartbeats per seconds is one of the most important indicators of one's health. So a Heartbeat sensor was added to the boiler suit to keep track of coal miners' heartbeats and unusual changes will alert the employer of some changes in the conditions.


Figure 8: Heartbeat Sensor

RFID Readers and Tags: RFID technology is used for positioning within the mine underground. The tags on the miner and readers at specific locations help track their whereabouts and provide essential location data.

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Figure 9: RFID Readers and Tags

ESP32 is programmed using Arduino embedded with C Language to collect the real-time data from the above sensors and then sends the data to the Local Raspberry Pi server over MQTT protocol. In the future, at the will of the manager, the local server can also be converted into a cloud server with the help of Nodered.

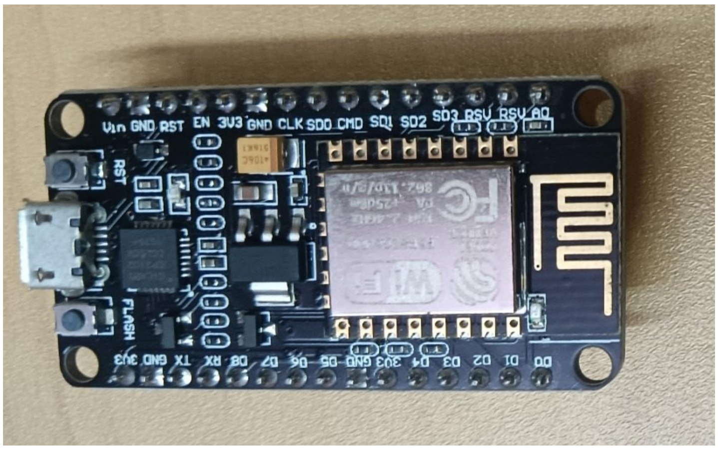

Figure 10: ESP32 microcontroller

Specific sensors were selected that would withstand mine conditions like high temperatures. Moreover, to avoid physical damage to the sensors once placed inside the suit, the area on the boiler suit, beneath which the sensors are placed, will be covered by Kevlar because of its strength and its lightweight nature.

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CONNECTIONS:

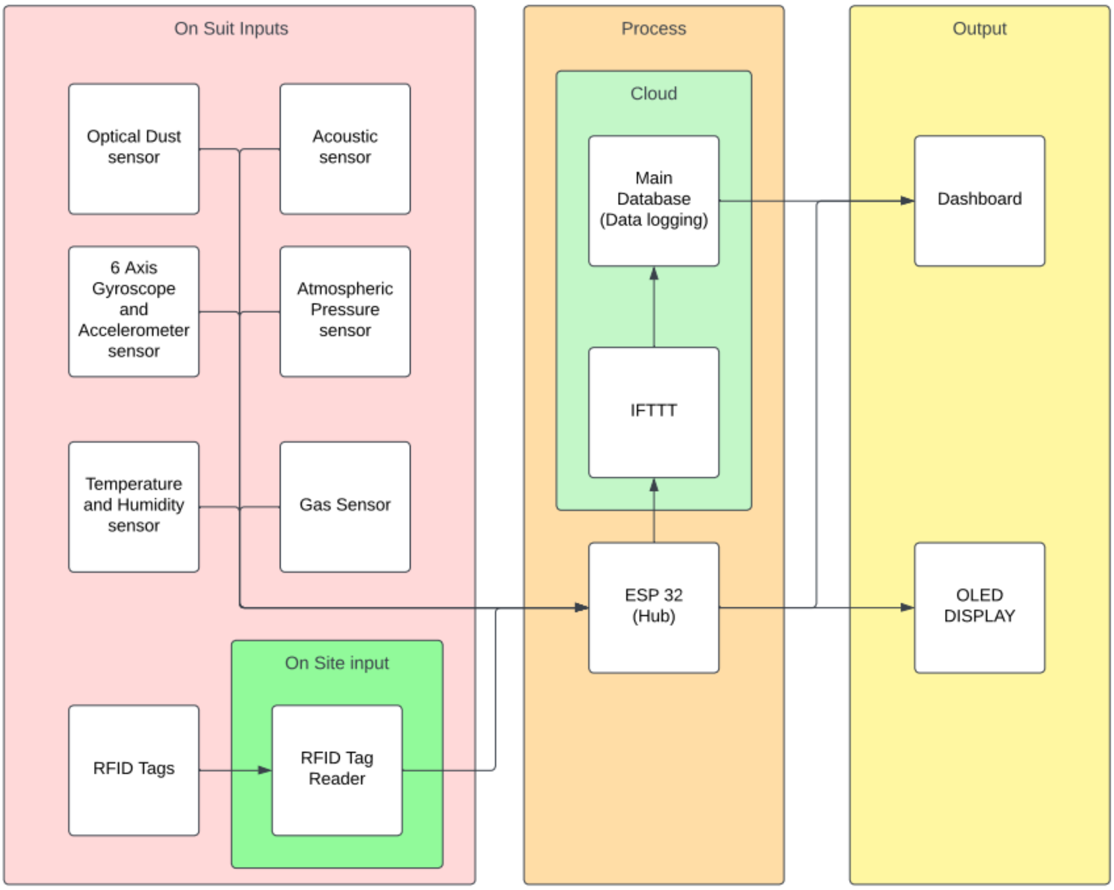

Figure 11: Connections of microcontrollers and sensors in the suit

Code of ESP32

```
#include <Wire.h>
#include "MAX30105.h"
#include "heartRate.h"
#include "spo2_algorithm.h"
#include <Adafruit_MPU6050.h>
#include <Adafruit_Sensor.h>
#include <Adafruit_BMP280.h>
#include <DHT.h>
#include <Adafruit_GFX.h>
#include <Adafruit_SSD1306.h>
#include <SoftwareSerial.h>
#include <TinyGPS++.h>
#define DUST_SENSOR_PIN A0

SoftwareSerial gpsSerial(2, 3); // RX, TX
Adafruit_BME280 bme;
TinyGPSPlus gps;
#define SEALEVELPRESSURE_HPA (1013.25) // hPa = Hecto Pascal
Adafruit_BMP280 bmp;
Adafruit_MPU6050 mpu;
DHT dht(D1, DHT11);
```

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```
#define RATE_SIZE 4 // Increase this for more averaging. 4 is good.
byte rates[RATE_SIZE]; // Array of heart rates
byte rateSpot = 0;
long lastBeat = 0; // Time at which the last beat occurred
float beatsPerMinute;
int beatAvg;
#define SCREEN_WIDTH 128
#define SCREEN_HEIGHT 64
#define OLED_RESET    -1
Adafruit_SSD1306 display(SCREEN_WIDTH, SCREEN_HEIGHT, &Wire, OLED_RESET);
void setup()
{
  Serial.begin(115200);
  // Optical Dust Sensor setup
  pinMode(A5, INPUT);
  pinMode(12, OUTPUT);
 // Sound Sensor setup
  pinMode(A0, INPUT);
  // BMP280 Sensor setup
  if (!bmp.begin(0x76))
  {
    Serial.println("Could not find a valid bmp280 sensor, check wiring!");
    while (1);
  }

  // Gyroscope and Accelerometer setup
  if (!mpu.begin())
  {
    Serial.println("Failed to find MPU6050 chip");
    while (1)
      delay(10);
  }
  mpu.setAccelerometerRange(MPU6050_RANGE_8_G);
  mpu.setGyroRange(MPU6050_RANGE_500_DEG);
  mpu.setFilterBandwidth(MPU6050_BAND_21_HZ);
  delay(100);

  // DHT11 setup
  dht.begin();

  // Heart Rate and Spo2 setup
  if (!particleSensor.begin(Wire, I2C_SPEED_FAST))
  {
    Serial.println("MAX30105 was not found. Please check wiring/power.");
    while (1);
  }
  particleSensor.setup();
  particleSensor.setPulseAmplitudeRed(0x0A);
  particleSensor.setPulseAmplitudeGreen(0);

  // OLED display setup
  if(!display.begin(SSD1306_I2C_ADDRESS, OLED_RESET))
  {
    Serial.println(F("SSD1306 allocation failed"));
    for(;;);
  }
  display.display(); // Display splash screen
  delay(2000);
```

```
  display.clearDisplay();
}
 gpsSerial.begin(115200);

  if (!bme.begin(0x76)) {
    Serial.println("Could not find a valid BME280 sensor, check wiring!");
    while (1);
  }
}

void loop()
{
  // Read dust sensor data
  int dustValue = analogRead(DUST_SENSOR_PIN);

  // Read GPS data
  while (gpsSerial.available() > 0) {
    if (gps.encode(gpsSerial.read())) {
      if (gps.location.isValid()) {
        float latitude = gps.location.lat();
        float longitude = gps.location.lng();

        // Publish data to MQTT
        Serial.print("Dust: ");
        Serial.print(dustValue);
        Serial.print(" | GPS: ");
        Serial.print(latitude, 6);
        Serial.print(", ");
        Serial.println(longitude, 6);
        delay(5000); // Adjust the delay based on your needs
      }
    }
  }
}
{
  // Optical Dust Sensor
  digitalWrite(12, LOW);
  delayMicroseconds(280);
  float voMeasured = analogRead(A5);
  delayMicroseconds(40);
  digitalWrite(12, HIGH);
  delayMicroseconds(9680);
  float calcVoltage = voMeasured * (5.0 / 1024);
  float dustDensity = 0.17 * calcVoltage - 0.1;
  if (dustDensity < 0)
  {
    dustDensity = 0.00;
  }

  Serial.print("Dust Density: ");
  Serial.println(dustDensity);

  // Sound Sensor
  int soundValue = analogRead(A0);
  Serial.print("Sound Sensor Value: ");
  Serial.println(soundValue);

  // BMP280 Sensor
  float temperature = bmp.readTemperature();
  float pressure = bmp.readPressure() / 100.0F;
```

```
float altitude = bmp.readAltitude(SEALEVELPRESSURE_HPA);

  Serial.print("Temperature: ");
  Serial.print(temperature);
  Serial.print("°C | Pressure: ");
  Serial.print(pressure);
  Serial.print("hPa | Altitude: ");
  Serial.print(altitude);
  Serial.println("m");

  // Gyroscope and Accelerometer
  sensors_event_t a, g, temp;
  mpu.getEvent(&a, &g, &temp);

  float accelerationX = a.acceleration.x;
  float accelerationY = a.acceleration.y;
  float accelerationZ = a.acceleration.z;

  float gyroX = g.gyro.x;
  float gyroY = g.gyro.y;
  float gyroZ = g.gyro.z;

  // Display values on OLED
  display.clearDisplay();
  display.setTextSize(1);
  display.setTextColor(SSD1306_WHITE);
  display.setCursor(0, 0);
  display.print("Acc X: "); display.println(accelerationX);
  display.print("Acc Y: "); display.println(accelerationY);
  display.print("Acc Z: "); display.println(accelerationZ);
  display.print("Gyro X: "); display.println(gyroX);
  display.print("Gyro Y: "); display.println(gyroY);
  display.print("Gyro Z: "); display.println(gyroZ);
  display.display();

  // DHT11 Sensor
  float humidity = dht.readHumidity();
  float temperatureDHT = dht.readTemperature();

  Serial.print("Humidity: ");
  Serial.print(humidity);
  Serial.print("% | Temperature: ");
  Serial.print(temperatureDHT);
  Serial.println("°C");

  // Gas Sensor
  int gasValue = analogRead(A1);
  Serial.print("Gas Sensor Value: ");
  Serial.println(gasValue);

// Heart Rate and Spo2
  long irValue = particleSensor.getIR();
  if (checkForBeat(irValue))
  {
    long delta = millis() - lastBeat;
    lastBeat = millis();
    beatsPerMinute = 60 / (delta / 1000.0);
    if (beatsPerMinute < 255 && beatsPerMinute > 20)
```

```
    {
      rates[rateSpot++] = (byte)beatsPerMinute;
      rateSpot %= RATE_SIZE;
      beatAvg = 0;
      for (byte x = 0; x < RATE_SIZE; x++)
        beatAvg += rates[x];
      beatAvg /= RATE_SIZE;
      Serial.print("Heart Rate: ");
      Serial.println(beatAvg);
    }

    int32_t bufferLength = 100;
    for (int i = 0; i < bufferLength; i++)
    {
      while (particleSensor.available() == false)
        particleSensor.check();

      redBuffer[i] = particleSensor.getRed();
      irBuffer[i] = particleSensor.getIR();
      particleSensor.nextSample();
    }

    maxim_heart_rate_and_oxygen_saturation(irBuffer, bufferLength, redBuffer, &spo2, &validSPO2, &heartRate,
&validHeartRate);
    if (validSPO2)
    {
      Serial.print("SPO2: ");
      Serial.println(spo2);

      // Display Spo2 on OLED
      display.clearDisplay();
      display.setTextSize(1);
      display.setTextColor(SSD1306_WHITE);
      display.setCursor(0, 0);
      display.print("SPO2: "); display.print(spo2); display.println("%");
      display.display();
    }
  }

  delay(1000);
}
```

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Figure 12: Sensor Integrated boiler suit

SUIT LIMITATIONS AND PROPOSED IMPROVEMENTS

1. High Initial Cost

The integration of IoT technology into safety suits incurs a substantial upfront cost, potentially impeding adoption, especially for smaller mining operations. Explore cost-effective sensor options, seek government subsidies, and foster industry collaboration to mitigate financial barriers. Additionally, emphasizes long-term cost savings and improved safety as compelling incentives for investment.

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2. Maintenance Challenges:
The harsh conditions in coal mines may lead to accelerated wear and tear, necessitating frequent maintenance checks and potentially disrupting regular operations. Design robust and durable sensors, implement predictive maintenance strategies, and conduct regular checks to address issues proactively. Additionally, provide comprehensive training to maintenance personnel for efficient troubleshooting.

3. Data Privacy and Security
Collecting and transmitting personal and environmental data raises concerns about potential privacy breaches and unauthorized access. Implement robust encryption protocols, anonymised sensitive data, and adhere to data protection regulations. Regular security audits should be conducted to identify and address vulnerabilities, ensuring data integrity and user privacy.

4. Resistance to Adoption**:**
Miners and management may exhibit resistance to adopting new technologies, possibly due to unfamiliarity, scepticism, or concerns about job disruption. Engage in transparent communication, involve miners in the technology selection process, and provide thorough training. Highlight the tangible benefits of increased safety, emphasizing the augmentation, rather than replacement, of traditional mining practices.

5. Environmental Factors**:**
Extreme environmental conditions in coal mines, including temperature variations and exposure to chemicals, may impact the performance and longevity of sensors and electronic components. Use ruggedized and sealed sensor enclosures, conduct thorough environmental testing during development, and design components to withstand harsh conditions. Regular maintenance checks should include assessments of component integrity in challenging environments.

About Us:

Vishwajit Patil:

Driven by an unwavering passion for science and technology, I have one goal – leveraging innovation to create a safer world and enhance the well-being of individuals. During our exploration into the conditions of coal mines, we swiftly recognized the perilous and life-threatening nature of the work faced by coal miners. Motivated to make a meaningful impact, we collectively decided to pioneer a solution, culminating in the conception of a sensor-based smart safety suit. In my role within the project, I dedicated myself to researching various hazards prevalent in coal mines and identifying some suitable sensors to collect relevant data. Additionally, I played a crucial part in the assembly of these sensors onto the safety suit, meticulously establishing the necessary connections between the sensors and microcontrollers. As the project reached its fruition, I assumed the responsibility of crafting the project paper, documenting our innovative journey towards creating a safer and more secure working environment for coal miners.

Satej Shinde:

I took on a crucial position within the project, focusing extensively on sensor selection, programming, and calibration. My responsibilities extended to managing the hardware aspects, including all sensors and the boiler suit, with a primary emphasis on enhancing the suit's reliability for field deployment with my friend. My experience includes participation in a hands-on Arduino microcontroller workshop, providing valuable insights into working with a variety of sensors available in the market. Additionally, I've immersed myself in two Internet of Things (IoT) workshops, where I deepened my knowledge of protocols, network management, Node-RED, and MQTT, and gained hands-on experience with Raspberry Pi and ESP32. This diverse skill set has been instrumental in shaping the project's technical foundation, ensuring its robustness, and adapting it to real-world applications.

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Arjun Khamkar:

Hello there! I'm Arjun Khamkar, and I am passionate about the fascinating realms of Artificial Intelligence (AI) and Machine Learning (ML). My journey into the world of technology began with a profound curiosity that led me to explore the depths of these cutting-edge fields. My expertise lies in the intricate domains of Deep Learning, Computer Vision, and Natural Language Processing (NLP). I have delved into the complexities of creating intelligent systems that can perceive, understand, and interact with the world in a manner that mimics human cognition. From image recognition to language processing, I have honed my skills to harness the power of AI to solve real-world problems. Venturing into the exciting world of Arduino Robotics, I have not only embraced the theoretical aspects of AI but also translated my knowledge into tangible, hands-on projects. Being a Junior Robocon winner has been a significant milestone in my journey, where I applied my skills to design and build robots that showcase the synergy of creativity and technology..

Viraj Wagule:

I have played a key role in our project, focusing primarily on selecting, programming, and calibrating sensors. My responsibilities also encompassed managing the hardware components, particularly the sensors and boiler suits, to improve their functionality in real-world situations. I have participated in an Arduino microcontroller workshop, which provided me with a deeper understanding of the various sensors in the market. Additionally, I have engaged in two Internet of Things (IoT) workshops, enhancing my knowledge of protocols, and network management, and gaining practical experience with Raspberry Pi and ESP32. In June 2023, I completed a three-month internship at Innovista Automation, contributing to a joint project. This diverse range of experiences has been crucial in building a solid technical foundation for the project and ensuring its effectiveness in practical applications.

Tara Desai:

I have contributed to the research paper by sharing general research findings mainly on the nature of the mining activity and common hazards faced by coal miners. I have covered subtopics such as physical hazards and chemical hazards within the mine that pose a threat to not just the miners, but also the surrounding ecosystem. Contributed subtopics include risks such as Dust explosions, flooding, and malfunction of equipment. All in all has been a contributor to general risks, harm caused by equipment, and post-hazard consequences.

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