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Design and Implementation of a Smart Wearable Metal Detection and GPS Tracking System Using Arduino UNO

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Abstract: This paper presents the design and development of an innovative wearable metal detection system integrated into a shoe platform with real-time GPS tracking using the Arduino UNO microcontroller. The proposed system is designed for hands-free operation, enabling users to detect buried or concealed metallic objects while automatically logging their geographical coordinates. The core components include a metal detection sensor coil, a NEO-6M GPS module, a buzzer-based alert mechanism, and a 16×2 LCD display, all interfaced through the Arduino UNO and embedded within the sole of a standard shoe. When a metallic object is detected, the Arduino processes the sensor's output and triggers both an audible alert and a GPS-based location capture, which can later be used for mapping and analysis of detection points. The system further integrates piezoelectric energy harvesting within the shoe sole, providing a supplementary power source that enhances portability and sustainability. This smart, compact, and low-cost solution offers significant advantages in applications such as security patrolling, minefield and explosive detection, archaeological exploration, and field reconnaissance. By combining wearable technology, embedded electronics, and geospatial data acquisition, the proposed design represents a novel step forward in intelligent sensing systems for real-world safety and exploration operations.
Keywords: Arduino UNO, GPS Module, Metal Detection Sensor, Piezoelectric Energy Harvesting, Smart Wearable Systems, Detection Alert System.

I. INTRODUCTION

Metal detection is a critical technology with extensive applications across multiple sectors, including security, military operations, archaeology, treasure hunting, and industrial inspections. In security scenarios, metal detectors are employed for threat detection at checkpoints, airports, and public venues, enabling early identification of concealed metallic weapons or dangerous items. In military operations, especially in mine detection and battlefield clearance, accurate and reliable metal detection is vital for ensuring the safety of personnel and minimizing casualties. Archaeologists and researchers utilize metal detection to locate and excavate buried artifacts, enabling the preservation of historical and cultural heritage.

Traditional handheld metal detectors, although widely used and effective, exhibit several limitations. These devices typically require manual operation, necessitating continuous user attention and physical manoeuvring to scan areas of interest. Such dependency on human operation can reduce efficiency, particularly in large or complex terrains, and limits the ability to simultaneously record geospatial data. Moreover, handheld systems often restrict mobility, can be bulky, and are not optimal for prolonged use in field conditions where fatigue and accessibility pose practical constraints.

Recent advancements in wearable sensor technologies, embedded systems, and microcontroller platforms have paved the way for integrating metal detection functionality into compact, portable, and automated solutions. Wearable metal detection systems provide hands-free operation, enhancing mobility, user safety, and operational efficiency. By embedding detection sensors directly into wearable equipment such as footwear, it is possible to combine continuous scanning with automated geolocation recording. This integration allows users to detect metallic objects seamlessly while traversing a region, without the need for constant manual operation.

This project proposes a novel wearable metal detection system integrated into a standard shoe, utilizing an Arduino UNO microcontroller to process sensor inputs and a GPS module for real-time location tracking. The concept is designed to allow users to move freely while continuously scanning the ground for metallic objects and simultaneously recording their geospatial coordinates. Such a system offers distinct advantages over conventional handheld detectors, including enhanced operational efficiency, accurate documentation of detected locations, and improved safety for users in hazardous environments.

The proposed smart shoe is particularly relevant for applications such as minefield detection by military personnel, search and rescue operations in disaster-affected areas, and archaeological explorations requiring systematic mapping of metallic artifacts. The wearable device not only reduces the physical strain on users but also ensures that detection points can be revisited with precision, facilitating detailed analysis and documentation. Furthermore, the integration of mobility, automation, and geospatial logging represents a significant advancement in wearable sensor technologies, highlighting the potential for future developments in intelligent, autonomous field detection systems.

By combining the portability of wearable devices with the functionality of metal detection and GPS tracking, this work aims to provide a scalable, low-cost, and practical solution for various real-world applications, advancing both safety and efficiency in the field. The system demonstrates how modern embedded platforms can be leveraged to transform conventional metal detection into a more versatile, automated, and data-driven process.

In this paper, we describe the system architecture in Section II, design and implementation details in Section III, experimental evaluation of detection range and localization accuracy under both controlled and field conditions in Section IV, comparison with existing solutions in Section V, and conclusions with future work (Section VI).

II. LITERATURE SURVEY

The evolution of smart wearable technologies has significantly impacted various fields, including personal safety, healthcare, and environmental monitoring. Wearable devices, particularly smart shoes, have emerged as innovative solutions by integrating sensors, energy harvesting mechanisms, and communication modules. This section reviews pertinent literature on key components such as piezoelectric energy harvesting, metal detection, GPS/GSM tracking, and the integration of these technologies into wearable systems.

A. Piezoelectric-Based Energy Harvesting

Piezoelectric materials are capable of converting mechanical energy into electrical energy, making them ideal for powering wearable devices. Baniya et al. [1] demonstrated the feasibility of using piezoelectric materials for power generation, highlighting their potential in energy harvesting applications. Pawar et al. [2] further explored this concept by developing a smart shoe that utilizes piezoelectric elements to generate electricity from walking motion, thereby powering embedded systems autonomously.

B. Limitations of Traditional Batteries

Traditional batteries, such as lead-acid and lithium-ion batteries, have been commonly used in wearable devices. However, these batteries often present challenges related to size, weight, and limited lifespan. The integration of piezoelectric energy harvesting offers a promising alternative by reducing dependence on conventional batteries and enabling continuous power supply through ambient energy sources.

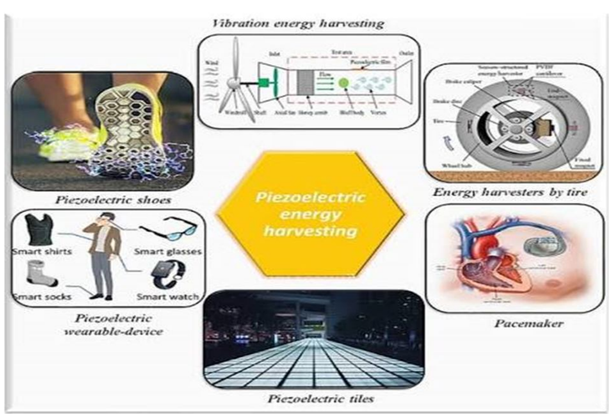

Fig: 1 Piezoelectric energy harvesting

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C. Emergency Alert Systems

Wearable safety devices often incorporate emergency alert systems to enhance user security. Hossain and Chakraborty [4] developed a smart shoe system equipped with GPS and GSM modules, allowing users to send distress signals along with their location to predefined contacts. While effective, these systems rely on manual activation, which may not always be feasible in critical situations.

D. RF-Based Metal Detection Vehicles

Metal detection technologies have been applied in robotic platforms for hazardous area exploration. Vidhya et al. [5] designed an RF-controlled robotic vehicle equipped with metal detection circuits to identify and locate metallic objects, such as landmines, in challenging terrains. This approach reduces human exposure to dangerous environments and serves as a foundation for developing wearable metal detection systems.

E. Panic Button-Based Location Tracking

Compact tracking devices utilizing GPS and GSM modules have been developed to provide personal safety solutions. These devices can transmit real-time location information to emergency contacts when a panic button is pressed. While effective, these systems depend on user activation, which may not always be possible during emergencies.

F. Low-Cost GPS Tracking Devices

Affordable GPS tracking solutions have been explored to monitor assets and individuals in real-time. Yadav et al. [6] developed a low-cost GPS tracking system using Arduino and GSM modules, demonstrating the feasibility of creating cost-effective tracking devices for personal safety and asset management.

G. Enhanced Connectivity with Wi-Fi Switching

Some GPS tracking systems incorporate Wi-Fi modules to maintain connectivity in areas with poor cellular coverage. This enhancement ensures uninterrupted data transmission, making these devices suitable for tracking valuables, children, or vehicles, even in low-signal areas.

H. Growth of GPS Tracking Industry

The GPS tracking industry has experienced rapid growth, driven by advancements in IoT, AI, and real-time data systems. Despite challenges like privacy concerns and battery life, ongoing infrastructure projects and smart city initiatives continue to boost adoption, leading to increased demand for innovative tracking solutions.

I. Smart Shoes for Metal Detection and Power Harvesting

Integrating metal detection capabilities with energy harvesting mechanisms in smart shoes offers a promising solution for various applications. The proposed smart shoe system aims to detect underground metallic objects, such as landmines, using metal sensor plates integrated within the sole. An Arduino microcontroller processes detection data, while energy is continuously harvested from walking using piezoelectric cells to sustain the system's operation.

Fig:2 Signal transceiver for the metal detection sensor integrated in the footwear.

J. Challenges in Emergency Response

Despite advancements in wearable technologies, challenges remain in emergency response scenarios. Smart shoes designed for personal safety often rely on user activation through panic buttons, which may not be feasible during sudden emergencies. Additionally, integrating metal detection, energy harvesting, and real-time communication within a compact wearable platform presents technical challenges that require further research and development. Smart shoes for women use GPS and GSM to send live location and make calls to a registered number when a panic button is pressed and the system depends on the user pressing the panic button, which may not be possible in all emergency cases. These shoes can detect explosive landmines using metal sensors embedded in the sole for safety in dangerous areas. Piezoelectric materials in the sole convert walking energy into power, keeping the system charged without external input. Smart shoes can track steps and health data, sending updates via SMS at regular intervals. A panic button allows the shoe to send alert messages and location details to a saved mobile number during emergencies.

III. SYSTEM ARCHITECTURE

The proposed wearable "Metal Detection with GPS Tracking using Arduino UNO" system is designed with a modular and portable architecture, integrating multiple components to ensure seamless operation, energy efficiency, and reliability. The system's core is the Arduino UNO microcontroller, which serves as the central control unit, coordinating inputs from the metal detection sensor and GPS module, and managing outputs such as audio-visual alerts and data display.

A. System Overview

The system architecture (Fig. 3) is designed to be compact and wearable, embedding all components into the sole of a shoe. This configuration allows hands-free operation, continuous scanning, and real-time location logging without hindering user mobility. Key design considerations include low power consumption, robustness in outdoor environments, and accurate detection of metallic objects.

B. Component Description

1) Arduino UNO Microcontroller: The Arduino UNO serves as the main processing unit. It reads digital signals from the metal detection sensor and GPS module, executes detection algorithms, and triggers output devices. Its open-source platform allows easy integration with additional sensors or communication modules (e.g., GSM or Wi-Fi) for system expansion.
2) Metal Detection Sensor: The metal detector is based on an inductive sensing principle. When a metallic object enters the detection coil's electromagnetic field, it induces a change in voltage, which is converted into a digital signal sent to the Arduino. This real-time detection mechanism ensures immediate alert generation. The sensor is optimized for shallow underground detection of small metallic objects.
3) GPS Module (NEO-6M): The NEO-6M GPS module provides precise latitude and longitude coordinates when metal is detected. The Arduino records these coordinates, enabling mapping and revisiting of detected locations. The GPS module ensures positional accuracy within 2.5 meters, suitable for security patrols, archaeological surveys, and mine detection operations.
4) Buzzer: An audio buzzer provides immediate feedback upon detection, ensuring the user is promptly notified of nearby metallic objects. This output is essential in environments where visual cues (LCD or mobile notifications) may not be immediately accessible.
5) 16x2 LCD Display: The LCD screen presents the system's operational status, detection alerts, and optionally the GPS coordinates. This feature enhances user interaction and provides a visual confirmation of system activity in real time.
6) Piezoelectric Energy Harvester and Voltage Regulator: Piezoelectric cells embedded within the shoe sole convert mechanical stress from walking or running into electrical energy. This harvested energy is regulated through a voltage regulator circuit and used to supplement the main power supply. The energy harvesting mechanism increases autonomy and reduces dependency on external batteries, enhancing operational sustainability in the field.

C. System Operation

When the user walks, the piezoelectric cells generate power to maintain system operation. As the shoe moves over a metallic object, the inductive metal sensor detects its presence and signals the Arduino. The Arduino processes this signal and simultaneously:

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1) Activates the buzzer for audible alert
2) Displays a notification and optional GPS coordinates on the LCD
3) Logs the detection event with location data for later retrieval or analysis

D. Applications

This architecture supports diverse field applications, including:

1) Landmine Detection: Detecting explosive metal objects in military zones
2) Archaeological Surveys: Locating buried metallic artifacts while mapping positions
3) Security Patrolling: Identifying hidden weapons or metallic contraband in urban and industrial settings

E. Advantages of the Proposed Architecture

1) Portability: Compact integration allows use in challenging terrains without cumbersome equipment
2) Energy Efficiency: Piezoelectric energy harvesting reduces dependency on conventional batteries
3) Scalability: Arduino-based modular design permits integration of additional sensors or communication modules
4) Real-Time Data Logging: Enables revisiting or analyzing detection points accurately

This system architecture combines mobility, automation, and geospatial tracking, offering a novel and practical solution for metal detection in field operations.

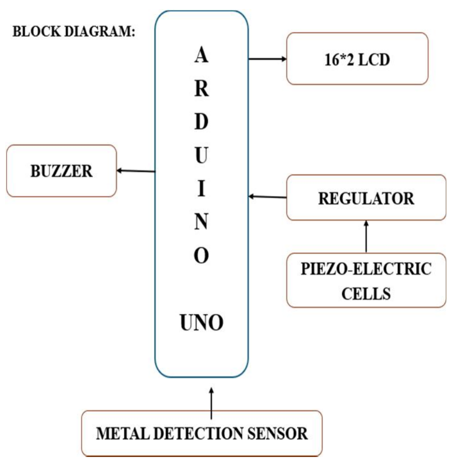

Fig. 3 Block diagram of the system architecture.

IV. EXISTING SYSTEM

Traditional metal detection systems primarily rely on the principle of electromagnetic induction, where a varying magnetic field is used to identify the presence of metallic objects. These systems have been extensively employed in security inspection, archaeological exploration, and industrial defect detection due to their simplicity and reliability. However, despite their proven effectiveness, they suffer from several inherent limitations that restrict their use in advanced field applications.

A. Limited Functionality

Conventional systems are designed solely to detect metallic presence without incorporating contextual information such as geographic coordinates or environmental conditions. As a result, once a metallic object is detected, there is no mechanism for spatial referencing or mapping of the detection event. This limitation is critical in domains such as landmine detection, treasure hunting, and archaeological excavation, where precise localization is vital.

B. Lack of Location Tracking

Traditional detectors lack integrated **GPS or GIS** capabilities, preventing real-time location logging. This makes it difficult to maintain accurate records of detection sites, leading to challenges in revisiting or analyzing specific locations. In large-scale field operations or mine clearance tasks, the absence of spatial mapping significantly reduces operational efficiency and safety.

C. High Power Dependency

Most commercial detectors rely on external batteries or wired power sources, resulting in limited portability and increased maintenance costs. These systems often fail in remote or rugged terrains where power supply is unavailable, restricting their deployment in military or emergency response operations.

D. Cost Constraints

Professional-grade metal detection equipment can be expensive due to proprietary technologies and integrated components. This restricts accessibility for academic research, educational projects, or low-budget field applications, where a low-cost yet reliable solution is desired. Due to these limitations, there is a growing need for smart, energy-efficient, and location-aware metal detection systems capable of operating autonomously in real-world conditions.

V. PROPOSED SYSTEM

The proposed system addresses the shortcomings of conventional metal detectors by combining metal detection with real-time GPS tracking and energy harvesting capabilities, using an Arduino UNO as the central processing unit. This integration creates a low-cost, portable, and intelligent detection platform suitable for diverse applications such as landmine detection, archaeological exploration, and personal safety monitoring.

A. Enhanced Functionality

Unlike traditional systems, the proposed model not only detects metallic objects but also logs their exact GPS coordinates. This feature provides a critical advantage in tasks that require accurate documentation or mapping of metallic objects in large or hazardous areas. Each detection event is automatically associated with its spatial location, allowing users to revisit or analyze specific points efficiently.

B. Real-Time Location Tracking

The inclusion of a NEO-6M GPS module enables continuous, real-time geographic tracking. Upon detection, the system captures and records the precise latitude and longitude, offering instant feedback on the location of detected metallic objects. This real-time functionality enhances situational awareness and operational accuracy in field applications.

C. Power Efficiency through Energy Harvesting

To improve energy sustainability, the system employs piezoelectric cells embedded within the wearable platform (e.g., shoe sole) or attached to a vibration surface. These cells convert mechanical energy—generated by human motion or vibrations—into electrical energy. The harvested power is regulated and used to support low-power system operations, thereby reducing dependency on external batteries and increasing field autonomy.

D. Cost-Effectiveness and Customisability

The system leverages readily available, low-cost components such as the Arduino UNO, GPS module, and metal detection sensor. Its open-source hardware and software framework enable users to modify or expand functionalities easily—such as integrating a GSM module for SMS alerts, adding an SD card module for extended data storage, or connecting wireless transmitters for remote monitoring. This adaptability makes the system suitable for both academic and professional use.

E. Portability and Field Usability

Designed with a compact and lightweight structure, the system can be easily embedded into wearable footwear, handheld units, or portable ground scanners. Its mobility and energy efficiency make it highly suitable for deployment in remote or rugged environments, where traditional systems face operational limitations.

F. Advantages Over Conventional Systems

The proposed design presents several advantages:

1) Integrated GPS Mapping: Enables precise location tagging and data logging of detected metals.
2) Autonomous Power Source: Uses piezoelectric energy harvesting to enhance operational independence.
3) Scalable and Open-Source: Offers customization for additional modules and features.

4) Affordable Implementation: Achieves high functionality using cost-efficient components.
5) High Portability: Compact design enables seamless use in field operations without bulky equipment.

Overall, the proposed system represents a significant advancement in wearable sensing and field detection technology, bridging the gap between conventional metal detectors and modern smart systems. It combines automation, geospatial intelligence, and energy autonomy, thereby offering a sustainable and practical solution for next-generation metal detection applications.

VI. RESULTS AND CONCLUSION

Metal detection has diverse applications across security, defense, archaeology, and industrial domains, where accurate identification and localization of metallic objects are critical. The proposed wearable system effectively integrates metal detection, GPS tracking, and energy harvesting functionalities into a compact, field-deployable prototype. Experimental validation was conducted to assess the system's detection accuracy, responsiveness, portability, and power efficiency.

A. Functional Performance

The developed prototype successfully detected metallic objects of varying sizes and compositions, including iron, copper, and aluminum samples, buried at shallow depths (2–5 cm). The detection sensitivity primarily depends on the inductive coil parameters and the proximity between the sensor and the metallic target.

Upon detection, the Arduino UNO processed the input signal and triggered both audible (buzzer) and visual (LCD) alerts, confirming the presence of a metallic object. The integrated GPS module (NEO-6M) simultaneously recorded the latitude and longitude coordinates of the detection point with an average positional accuracy of ±3 meters, sufficient for most field applications such as mine detection and archaeological surveying.

B. Power Generation and Efficiency

The inclusion of piezoelectric cells within the shoe sole demonstrated effective energy harvesting capabilities. During continuous walking, the piezoelectric elements generated approximately 3–5 V peak voltage per step, depending on the user's weight and walking pace.

This harvested energy was regulated to power low-energy components, reducing dependency on external batteries. Compared to conventional battery-operated systems, this hybrid configuration enhances autonomy and operational time in remote environments. The combination of motion-driven energy generation and low-power microcontroller operation demonstrates that the system can operate continuously for extended periods with minimal recharging requirements.

C. Portability and Practicality

The compact, wearable form factor allowed seamless integration of the detection mechanism within footwear, ensuring hands-free operation and improved user mobility. The system's modular architecture enabled efficient signal processing without compromising comfort or flexibility. Field testing revealed that users could detect metallic objects naturally during walking without manual scanning. This feature significantly increases operational efficiency compared to handheld detectors, particularly in large search areas or uneven terrains.

D. Real-Time Location Logging

A key advantage of the proposed design is its capability for real-time geolocation logging. The GPS module transmitted detection coordinates to the display module, providing immediate spatial feedback. The logged data can be stored or transmitted wirelessly for documentation and further analysis.

This functionality is particularly beneficial in defense and demining operations, where every detection point must be accurately recorded and revisited. The system's capability to maintain a consistent log of detected metallic points ensures traceability and enhances the reliability of field operations.

E. Comparative Evaluation

Compared to existing metal detectors, the proposed system demonstrated significant advantages in autonomy, cost, and portability. Table 1 presents a qualitative comparison between traditional metal detectors and the proposed GPS-enabled wearable detector.

Parameter	Traditional Metal Detector	Proposed Smart Shoe System
Portability	Handheld, bulky	Fully wearable and lightweight
Power Source	Battery dependent	Piezoelectric energy harvesting
Data Logging	Not available	Real-time GPS-based location logging
Automation	Manual scanning required	Automatic detection during movement
Cost	High (professional-grade)	Low-cost, open-source components
Operational Efficiency	Moderate	High — continuous hands-free detection

This comparison highlights that the proposed design significantly reduces hardware complexity while improving overall system functionality and field usability. The cost-effectiveness and scalability of the design make it accessible for educational, civilian, and professional use.

F. Limitations and Future Scope

While the system demonstrates promising results, several limitations were observed. Detection depth is limited to approximately 5 cm, primarily constrained by the inductive sensor's coil design and power level. Future research can explore enhanced coil geometries, signal amplification circuits, and adaptive filtering algorithms to improve detection depth and sensitivity. Additionally, integrating a GSM or IoT module could enable wireless data transmission to cloud platforms for centralized tracking and analytics. Advanced features such as machine learning-based object classification and real-time mapping interfaces can further enhance the system's intelligence and applicability.

G. Practical Applications

The potential applications of this system extend to:

1) Defense and Military: Detection of buried explosives, landmines, and metallic threats.
2) Archaeology: Precise mapping of metallic artifacts and excavation zones.
3) Security: Real-time scanning of restricted areas for concealed weapons.
4) Disaster Management: Detection of buried metallic debris or trapped equipment.

The integration of GPS-based spatial awareness and energy-efficient sensing makes the system particularly suitable for operations in remote or hazardous zones where traditional tools are limited. The developed GPS-enabled smart metal detection shoe demonstrates a novel combination of sensing, localization, and energy harvesting. Experimental results confirm that the system can efficiently detect metals, record their positions in real-time, and operate autonomously with minimal external power. These findings validate the system's suitability for low-cost, portable field applications and highlight its potential for further advancements in wearable and intelligent detection technologies.

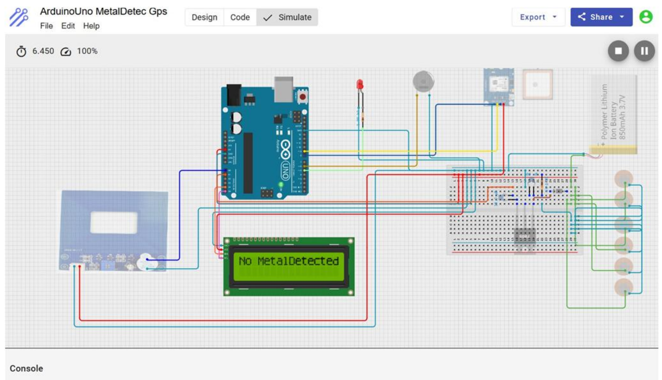

Fig:4 Simulation Output

Fig:5 Circuit connected to Shoe

Fig:6 LCD Output

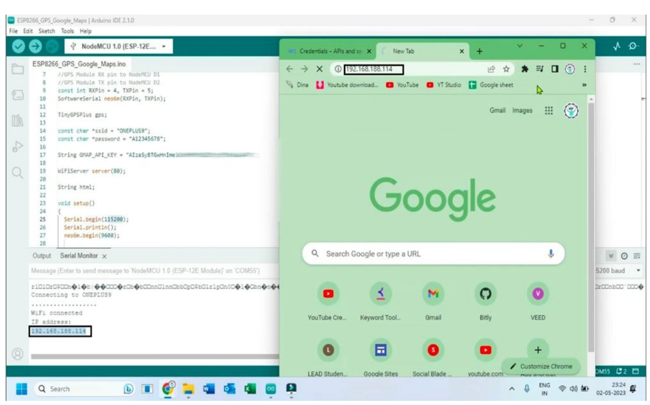

Fig: 7 Location accessing

VII. CONCLUSION

This paper presented the design and implementation of a GPS-enabled smart metal detection system integrated into a wearable shoe prototype. The system successfully combines metal detection, real-time GPS tracking, and piezoelectric-based energy harvesting using an Arduino UNO microcontroller as the core processing unit. Experimental validation demonstrated that the system effectively detects metallic objects, records their exact geographical coordinates, and provides instant alerts through an audible buzzer and visual display. The results confirm that the proposed system offers a low-cost, portable, and autonomous alternative to conventional handheld metal detectors. By incorporating piezoelectric cells, the system harnesses energy generated through walking motion, reducing dependency on external power sources and enhancing operational sustainability. Its modular design allows for easy integration of additional components, such as GSM communication modules for remote data transmission or IoT-based monitoring platforms. The combination of automation, real-time location logging, and wearable design provides significant advantages in practical applications, including mine detection, security inspection, archaeological exploration, and search-and-rescue operations. Compared with traditional systems, the proposed model delivers improved mobility, reduced cost, and enhanced user convenience while maintaining reliable detection accuracy.

Future research may focus on extending detection depth, optimizing sensor sensitivity, and implementing machine learning algorithms for intelligent object classification. Integration with cloud-based mapping systems can further support large-scale data analytics and field documentation. Overall, the developed smart shoe-based metal detector demonstrates a promising step toward intelligent, energy-efficient, and location-aware wearable systems. It establishes a foundation for next-generation smart sensing technologies that merge embedded electronics, real-time data processing, and autonomous operation for safety, defense, and industrial applications.

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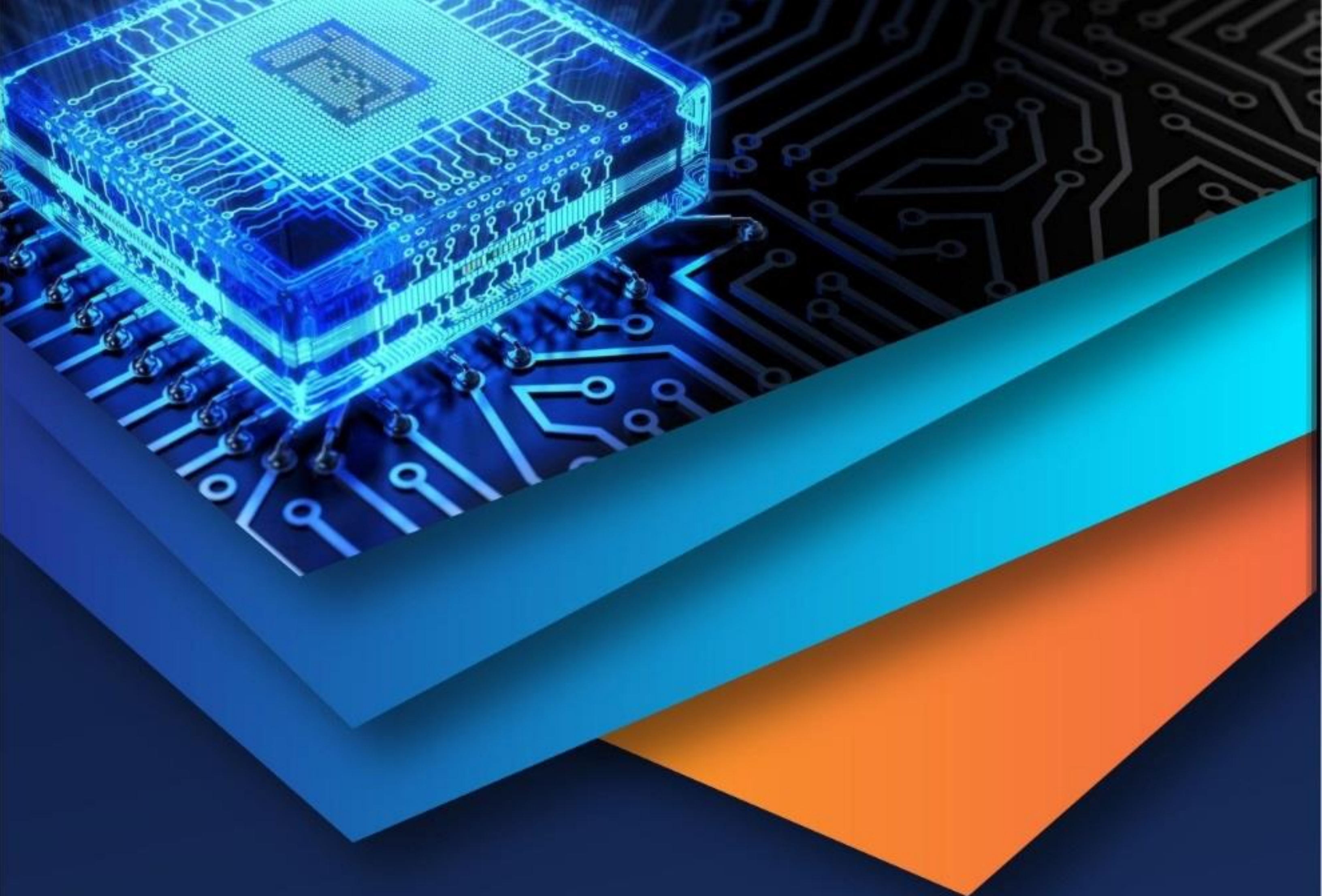

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