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VIBERSHIELD: An Intrusion Detection System

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Abstract: Dramatic increase in unlawful intruder movements throughout the countries boundaries demands design and development of unified border surveillance and intruder detection system. The purpose of this research aims to analyse the factors which affects the detection of vibrations that originates from underground or the ground surface resulting from footsteps, vehicles and animals. It also aims to detect and differentiate the vibrations and alarming the base camp using geophones and LORA communication.
Keywords: seismic sensor, current amplifier communication.

I. INTRODUCTION

Trespassers and terrorists are jeopardising the country's peace and harmony. The deaths and disruptions caused by the contemporary Uri assault in an Indian Army camp highlights the necessity for a unified border surveillance and intruder detection system capable of tracking and identifying unlawful intruder movement throughout the country's boundaries. The intrusion in any restricted area is a problem for all the countries. The intrusion detection method, currently adopted by military is by patrolling the border after a certain interval. Patrolling is repeated daily in scheduled time. The traditional way of securing a restricted area is to put a barb wire around border or the simplest way is to make a big wall around it. Traditional methods of border security take lot of human efforts and it requires huge expenses.

Design and development of border surveillance system using wireless sensor networks is a long-standing problem and still a challenging issue. Substantial research has been carried out to develop border surveillance system for intrusion detection.

Many researchers started working to develop border surveillance system using wireless sensor networks. Arjun D et al. [1] discussed the various wireless sensor network techniques for border surveillance and intrusion detection. KEES faber et al. [2] explained the mechanism of geophone element that produces the resonance. It also focussed on the methods of recording absolute precise frequencies.

James M. Sabatier et al. [3] proposed the footstep signature analysis method using seismic sensors. Human footstep seismic signals for three unique kinds of walking (regular, gentle, and stealthy) were monitored, on an outdoor ground in tranquil and metropolitan regions. The average value of background vibrations in the 5-50 Hz frequency range was 37 dB lower in the less crowded area than in the crowded area.

This study helped us to understand the range of footstep vibrations**.** Tianjin et al. [4] analysed the stepping frequency and velocity of people while walking on bridges and parks, which differentiated the frequency range of human footsteps in foot bridges, shopping malls and parks. Trang et al. [5] analysed the connectivity of wireless underground sensor networks. The researchers provided useful guidelines for designing of reliable wireless underground sensor networks. Ari et al. [6] presented comprehensive review of challenges in designing wireless sensor networks', Gokhan et al. [7] proposed the design of low-resolution ADC for seismic sensor board coupled with wireless node.

Alexander E. Ekimov et al. [8] accomplished discrimination between human and other moving targets by analysing the envelopes of footstep signatures. Priyanka et al. [9] presented extensive survey on hole problem in wireless sensor underground networks. Vuran et al. [10] proposed advanced channel model to characterize the underground wireless channel. This paper also addressed the issues associated with communication of electromagnetic waves through soil. Javaid et al. [11] used Deep Neural Network (DNN) to predict the stiffness and lambda parameters which are two critical factors for the evaluation of rocks. Daley et al. [12] proposed Modular borehole monitoring with distributed acoustic sensors and geophone.

Gan et al. [13] used distributed structural vibration sensed by ultra-weak Fibre-optic Brag Grating (FBG) sensing technology to identify ground intrusion in underground constructions. Dina et al. [14] proposed machine learning techniques for intrusion detection in computer networks. Mazunga et al. [15] proposed a low-cost unique and effective manhole intrusion detection system. Sukhwinder Singh Et al. [16] presented smart border surveillance system using wireless sensor networks with open CV and TensorFlow.

Great efforts have been taken so far to discriminate human footstep frequency ranges from other moving objects. The researchers have accurately detected the movements in crowded and less crowded areas. The challenges in system development for border surveillance systems are very well discussed. Open CV and Deep Neural Networks (DNN) are taken into consideration for designing of border surveillance and intrusion detection systems. Despite the scrupulous efforts to develop border surveillance and intrusion detection systems, it has limited success as far as system deployment in Indian Army is concerned.

The objectives of the proposed research are to identify various moving object's frequencies and to distinguish the human footsteps from other moving objects. To design and develop the system for the defence and other security personnel to detect illegal movements in restricted area.

Table 1: Range of frequency

Objects	Detection Range (Frequency) in Hz
Human footsteps	1-4
Vehicles	10-40

Table 1 depicts the frequency range for human footsteps and vehicles.

The rest of the paper is organized as follows: Section 2 describes the material and methods used for system design and development. Section 3 focuses on results of the experimentation and performance evaluation. Section 4 concludes the paper.

II. MATERIAL AND METHODS

The material and methods section are divided into three sub sections as follows: Initially the detailed block diagram with components is discussed. Further sections details about sensors and hardware design respectively.

A. Block Diagram And Components

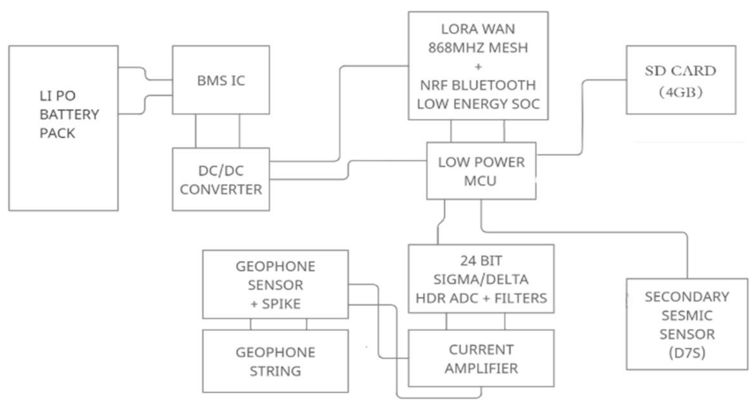

Fig 1: working of system

The system uses D7S seismic sensor to sense the ground vibrations. The output signals from seismic sensors are given to current amplifier STEVAL. The Amplified output is further converted into digital form using ADS1256. The digital signal is then processed using ESP32 Pico-D4. The processed is stored on the SD-Card for further reference. The system also consists of a battery management system MCP73831/2 to provide the necessary power to the components. The processed data in digital form is communicated to control stations using LORA-WAN (Long Range Wide Area Network) communication. As LORA WAN consumes more power, signals are sent to control station in certain intervals of time. Figure 1 depicts the interfacing of all the blocks.

The system component details are explained in further sections.

1) *D7S Seismic Sensor:* The basic idea of a geophone is to convert the ground movement or vibrations into the voltage. Geophone is enclosed in a small case where in the down side is a small rod type structure which is buried under the ground and above that is a geophone casing. The upper casing consist of a moving magnet and a coil is wrapped around it. The moving magnet is attached by springs on its four corners. When the magnet inside the spring moves, it generates small voltage in range of 5µV - 10µV.

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2) *STEVAL-AETkt1V2:* This is a current amplifier. The system needs current amplifier because the output given by d7s sensors is very small and an amplifier is required for proposed system to use it. To get the required accuracy from the proposed system this amplifier is used, so that no data is missed. Wide common mode voltage range: -20 to 70 V Offset voltage: ±200 µV *max. 2.7 to 5.5 V supply voltage Quiescent current: 20 µA in Shutdown mode Temperature range: -40 to 125°C*
3) *Analogue to Digital Converter ADS1256:* The ADS1256 is a 24-bit analog-to-digital (A/D) converter with extremely low noise. ADS1256 consists of a 4th-order delta-sigma modulator which is followed by a programmable digital filter in the converter. A multiplexer is a device that can handle differential or single-ended signals with circuitry to check the integrity of the external sensor linked to the inputs.
4) *ESP32 PICOD4.1:* The ESP32-PICO-D4 is a System-in-Package (SIP) module based on ESP32 that has full Wi-Fi and Bluetooth functionality. The module is only 7.0000.100 mm 7.0000.100 mm 0.9400.100 mm in size, needing very little PCB space. a4-MBSPIflash is integrated within the module. This equipment analyses all of the data and determines whether the vibrations are caused by humans or animals. The data is then communicated to the user through the LORA communication system via the LORA SX1276 after the operation is completed.
5) *MCP73831/2:* The MCP73831/2 devices are highly advanced linear charge management controllers designed for use in applications with limited space and low cost. The MCP73831/2 are appropriate for portable applications due to their small physical size and minimal number of external components required.
6) *AP7312-1533W6-7:* AP7312-1533W6-7 is a dc/dc converter which is used to power up the LORA-WAN and ESP32 Pico D4. The converter is 150mA, fixed output voltage, low dropout direct controller. The AP7312 include the pass element, error amplifier band- gap, current limit and thermal shutdown circuitry which secure the IC from damage in fault conditions. The AP7312 has two enable pins (EN1 and EN2) to single handed-ly turn the individual channel on when a logic high level is applied. The characteristics of low dropout voltageand low quiescent current make it suitable for low power operations. The typical quiescent current is approximately 60µA.
7) *LORASX1276:* The LoRa® long-range modem in the SX1276 transceivers delivers ultra-long-range spread spectrum communication and high interference immunity while consuming minimal current. Its range varies from 2.1km to 21 km depending on the surrounding area.

B. *Seismic Sensors*

Seismic sensors are used to sense the vibrations of earth by using velocity sensors and accelerometer. Originally developed in the 1860s to detect earthquakes, these sensors are now also used for the purpose of vibration detection and security surveillance. For security purposes, seismic sensors collect vibration signals is happening in designated area. It also detects ground (surface and underground) vibrations. Human actions on the ground cause vibrations from the point of contact. Rayleigh waves are responsible for 70% of those earthquake tremors, which spread across the earth's surface. What's left is Body waves, which travel in direction perpendicular to the Rayleigh waves. To be able to catch the vibrations of the human and vehicles, Rayleigh waves can be very convenient way. The major challenge in measuring the vibrations is the noise generated due to underground metro, sewage systems etc. To solve the problem of noise precise and proper calibration of seismic sensor is required to solve the problem of noise.
The proposed system uses D7s (geophone sensor) [2]. It converts the ground movement or vibrations into the voltage. Figure 2 depicts the constructional details of D7s sensor. D7s consists of Micro Electromechanical System (MEMS).

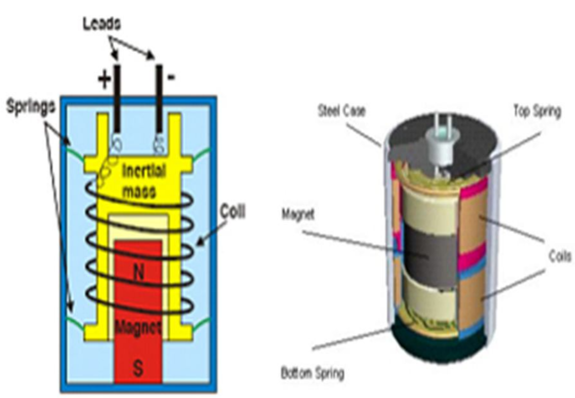

Fig 2: Parts of geophone

Geophone has a small case in which the down side is small rod type structure which is buried under the ground. Geophone casing has a magnet inside it. Moving weight and a coil is wrapped around it. The moving weight is attached by springs on its four corners. The reaction of a coil/magnet geophone is proportional to ground velocity. MEMS often respond proportionally to acceleration. MEMS has a substantially greater noise cancellation level than geophones (50 dB velocity difference) and can only be used in active seismic or severe motion applications.

C. Hardware Design

Fig 3 Vibershield Design

The proposed system is named as Vibershield. Vibershield consists of two polymer boxes. The polymer isolates the circuitry from the surrounding. Lower box has the D7s sensor which detects the vibrations. The upper polymer box consists of battery, LORA, ADC and other circuitry. The proposed design of Vibershield is basically a geophone sensor buried 2 meters under the ground. The part on the surface will have a battery that can be replaced or charged. The Upper Polymer enclosed circuitry can communicate to the similar devices deployed in the radius of 50m range each. Vibershield network is formed by deploying many more Vibershields. All Vibershields can communicate with each other provided it is within the 50m range. If one Vibershield detects the vibrations, it will communicate to all the Vibershield devices in the network. The Vibershield will detect the vibrations will communicate it to end device (Vibershield with antenna). The end device will communicate the detected vibrations to the base station. Both the boxes of Vibershield are connected to each other through a wire. It will be an easy plug and play device so that anyone without the technical background can handle it. Figure 3 depicts the design of Vibershield.

Every moving object generates unique frequency and frequency of each moving object is to be recorded. As per the Ji, Tianjian et al. [4] human footsteps frequency is 1-4 Hz, and vehicle generates frequencies in the range of 10-40 Hz.

Vehicles of different types have different frequency. A motorcycle will generate less frequency in the range of 10-15 Hz. But a heavy vehicle like trucks will have a higher frequency in the range. 50-100 Hz. The upper polymer box will remain near the surface, so that it will be easy for maintenance and repair.

III. RESULTS

Vibershield is used to detect and differentiate vibrations of moving objects including humans, animals and vehicles. Figure 4 depicts the frequencies obtained from human movement. Vibershield is also tested for Light Motor Vehicle (LMV) and Heavy Motor Vehicles (HMV). Figure 5 depicts the frequency range obtained from the vibrations of LMVs. Considerable amount of frequency range difference can be observed in the vibrations generated from LMVs and HMVs. Light motor vehicles which include like two wheelers like bikes and scooter have frequency range of 15-25Hz. Heavy motor vehicles include vehicles like trucks and heavy armoured vehicles. These types of vehicles have their frequency range in 30 to 40Hz. Figure 6 presents the comparison of frequencies of LMVs and HMVs.

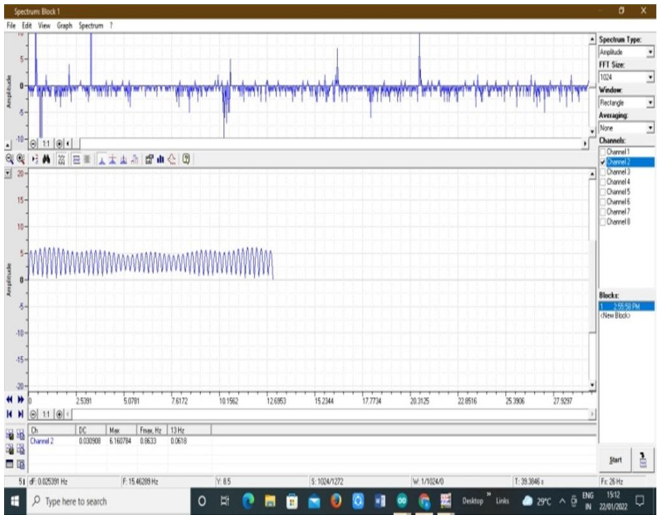

Fig 4 Human movement frequency graph

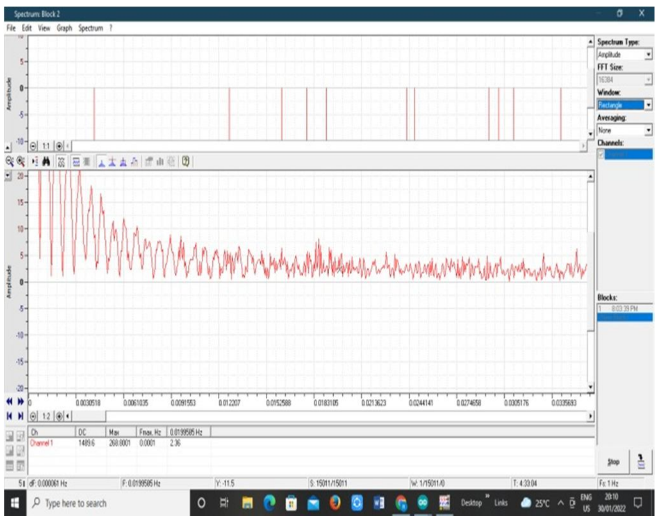

Fig 5 LMV vehicle graph

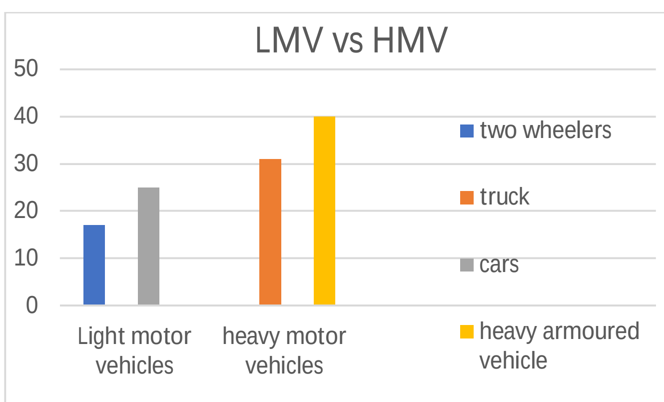

Fig 6 Comparison of frequencies obtained from LMV and HMV

Natural walk and suspected walk can be analysed and differentiated by finding the time duration between two consecutive tapping of footsteps on ground. Time duration between the two consecutive footsteps is calculated for normal and suspected walk.

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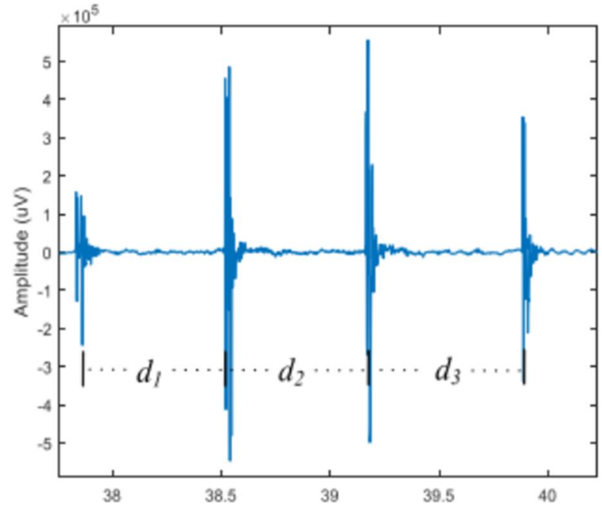

Fig 7 Waveform analysis

Four seismic pulses induced by a walking man in the field is depicted in Figure 7. These footstep seismic signals are acquired by a geophone. The frequency sensed by the geophone is in the range of 0-4 Hz for human walk. Time intervals between four footsteps are named as d1, d2 and d3. Approximately 0.7s time duration and 5 µV amplitude is observed between 2 consecutive footstep tapping for normal walk. For suspected walk the time interval of duration observed is 1.1s and 3 µV amplitude is observed.

IV. CONCLUSION

This paper presents the design and development of unique Vibershield for the border surveillance and intrusion detection. Vibershield detect and differentiate Human footsteps from animals and vehicles. It can further identify the difference between LMVs and HMVs which ultimately helped in identifying the tanks and armed vehicles. Human Footsteps vibration Ranges from 1-4Hz and that of vehicle vibrations ranges from 10-40Hz in which LMVs generate 15-25Hz frequency and the HMVs generate 30-40Hz frequency. The Vibershield data is further sent to the base station by using LORA communication. Our further research aims to use the artificial intelligence and machine learning technology for identification of Moving objects without human intervention. The successful design and development of the system is done in LVL Alpha Pvt Ltd.

V. CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

VI. ACKNOWLEDGEMENT

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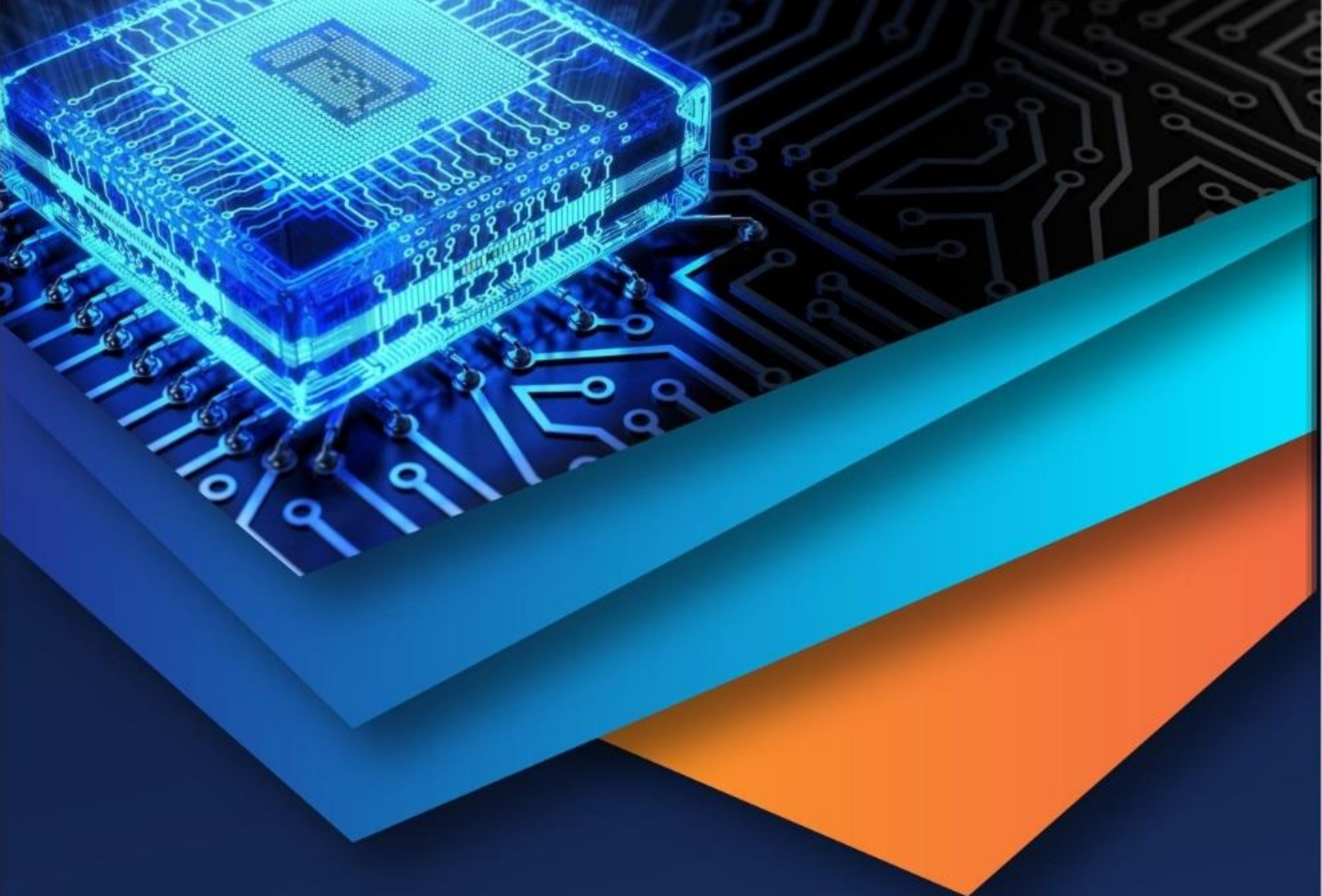

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