iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 Issue: V Month of publication: May 2026

DOI: https://doi.org/10.22214/ijraset.2026.83212

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue V May 2026- Available at www.ijraset.com

Numerical Modeling of Smart Structures Using Finite Element Method

Ullamparthi Navyakanth
Lenora College of Engineering, India

Abstract: Infrastructure Health Assessment has become an important feature of current civil engineering technology due to the increasing need for safety and durability of infrastructure systems. Structural failures can lead to significant economic losses as well as serious threats to human life. Hence, regular monitoring and assessment of important structures are necessary. Although visual inspection is extensively practiced in the industry, the technique is time-consuming, labor-intensive, and highly dependent on skilled personnel. To overcome these limitations, researchers have explored several advanced monitoring techniques over the past few decades. The present study focuses on high-frequency monitoring techniques because low-frequency methods are less effective in detecting minor or early-stage damages. Piezoelectric ceramic (PZT) patches possess unique direct and inverse piezoelectric properties, allowing them to perform simultaneously as sensors and actuators. By the utilizing The sense ability of PZT patches, conductance signatures of the a Structure can be measured and used for evaluating structural health conditions. The conductance response obtained from an undamaged structure is considered the baseline signature, while the response measured after a certain period is referred to as the secondary conductance signature. The Electromechanical Impedance (EMI) technique is particularly effective because it excites higher-frequency vibration modes, which are highly sensitive to local damage. In this investigation, A frame made of reinforced concrete (RC) at laboratory scale model was analyzed. Finite element modeling of the frame was carried out using ANSYS 9 software. The numerical The outcomes were validated using the exploratory findings reported by Soh and Bhalla (2004). Earlier studies mainly concentrated on frequencies below 25 kHz; however, the current work extends the numerical simulation to a higher range of frequencies of 100–150 kHz. The signatures of conductance obtained from both experimental and numerical approaches showed good agreement. Peak conductance values appeared at nearly identical frequencies in both cases, and the correlation in magnitude was better than that reported in earlier studies. Damage conditions in the RC frame were simulated numerically by introducing cracks through reduction of Young's modulus at specific locations. The conductance signatures corresponding to damaged conditions exhibited trends similar to those observed experimentally. The influence of crack formation on the conductance response was clearly identified. In comparison with the studies conducted by Tseng & Wang (2004) and Giurgiutiu and Zagari (2002), the percentage variation between experimental and numerical findings in the present work was found to be comparatively lower.

The outcomes of this research contribute to the advancement of smart structural systems and provide a reliable numerical approach for structural health monitoring applications. The created numerical model can greatly lessen the requirement for comprehensive experimental investigations, saving both time and expense. Additionally, the research offers a foundation due to future research involving Shell piezoelectric coupling and plate formations, as well as analysis of fractures under coupled electromechanical behavior.

I. INTRODUCTION

A. General

Structural Monitoring Health (SHM) refers to The ongoing observation and evaluation of structures under different loading as well as environmental conditions. It involves measuring the responses of structural systems and identifying any abnormalities, degradation or harm that might their performance and security. According to earlier studies, Health surveillance has a vital function in evaluating the condition out of structures before, during, and after severe occurrences like earthquakes, heavy loading, or the surrounding exposure.

B. Need For Health Monitoring

Proper maintenance and continuous monitoring are essential for extending the service life of civil engineering structures and preventing sudden structural failures. Modern infrastructure systems are subjected to higher operational loads, complex design requirements, and longer service periods, making structural monitoring increasingly necessary.

C. The project's goal and scope

The primary objective of this undertaking is to create techniques for the Analysis of smart structures using finite elements used within structural health monitoring applications. The study mainly focuses on comparing experimental observations obtained from a laboratory-scale frame made of reinforced concrete (RC) with numerical simulation results developed using finite elements techniques.

D. Organization Of The Report

There are five chapters in this study, including the present chapter of introduction.

- Chapter 2 gives a comprehensive Assessment of previous investigation related to structural health monitoring techniques and smart structures.
- Chapter 3 discusses the basic principles of piezoelectric materials, PZT patches, and The method of electromechanical impedance (EMI) used for assessing structural health.
- Chapter 4 explains the numerical simulation procedure adopted for the reinforced concrete model frame. The obtained results are presented and discussed in detail.
- Chapter 5 outlines the study's key findings and offers suggestions for further research work in the area of intelligent structural systems and monitoring of health applications.

II. PIEZOELÉCTRICO Y PIEZOELECTRIC INSUMOS

La capacidad de funcionamiento de los materiales piezoeléctricos both como sensores y actuadores makes them highly suitable for structural health monitoring applications.

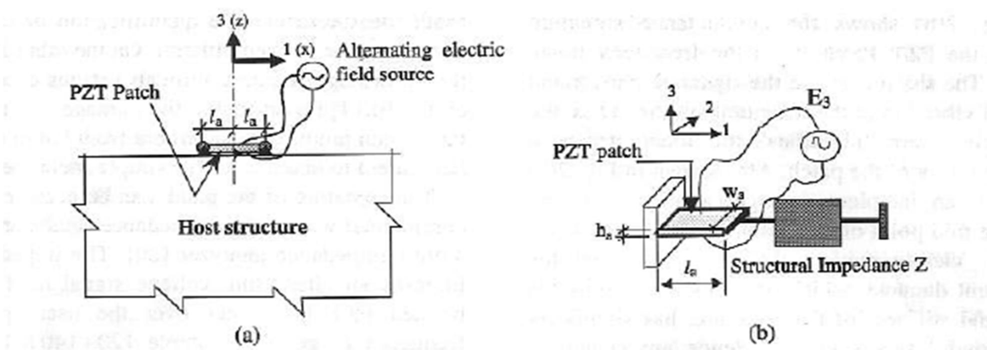
La piezoelectricidad hace referencia a la interacción entre mechanical also electrical sistemas. Algunas anisotrópicas crystalline materials develop electrical charges cuando es sometido a mechanical deformation. Conversely, these materials undergo mechanical deformation when exposed to an eléctrico field. Pierre fue quien descubrió este fenómeno. Curie y Jacques Curie en el año 1880.

This present investigación se centra en the elemento finito modeling de estructuras inteligentes, particularly estructuras integradas con parches piezoeléctricos. Therefore, this behavior and characteristics of piezoelectric materials se analizan a fondo.

This commonly used commercial los materiales piezoeléctricos son:

1) Cerámicas piezoeléctricas, como el titanato de zirconio y plomo (PZT)
2) Por ejemplo, los piezopolímeros Polyvinylidene Flúor (PVDF)

A. Relaciones Piezoeléctricas Fundamentales



Dónde:

- (S) = tensión vector
- (T) = estrés vector
- (s^{E}) = Matriz de cumplimiento con campo eléctrico constante
- (d) = acoplamiento piezoeléctrico coefficient
- (E) = campo eléctrico vector
- (D) = desplazamiento eléctrico vector
- (\varepsilon^{T}) = dielectric permittivity matrix

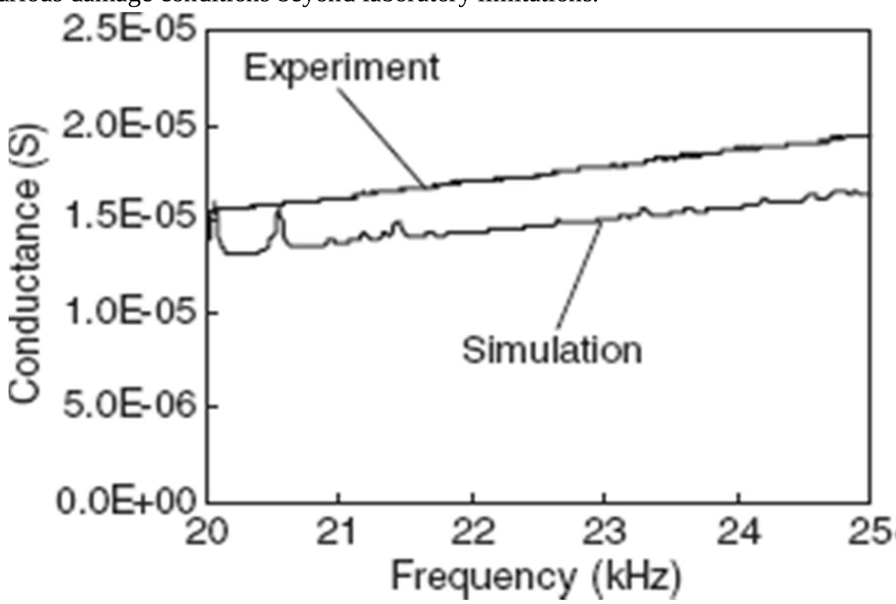
These coupled equations form the basis for analyzing Estructuras inteligentes integrated con sensores y actuadores piezoeléctricos.
Consider as piezoceramic actuator Unido a the estructura de soporte empleando un adhesivo epóxico de alta resistencia, as illustrated en la figura. 3.1. El actuador is electrically entusiasmado through an analizador de impedancia. Se supone que el PZT remiendo undergoes expansion and as contraction only along dirección 1 cuando an El campo eléctrico se aplica en la dirección 3. The parameters (h_a), (l_a), and (w_a) represent el grosor, la longitud y el ancho del parche de PZT, respectively. The stress acting en dirección 1 es denoted by (T_1), while El campo eléctrico aplicado en la dirección 3 es represented by (E_3).
The fundamental constitutive relations governing the behavior del parche de PZT can puede expresarse como follows (Ikeda, 1990):

$$S_1 = \frac{T_1}{Y_{11}^E} + d_{31}E_3$$

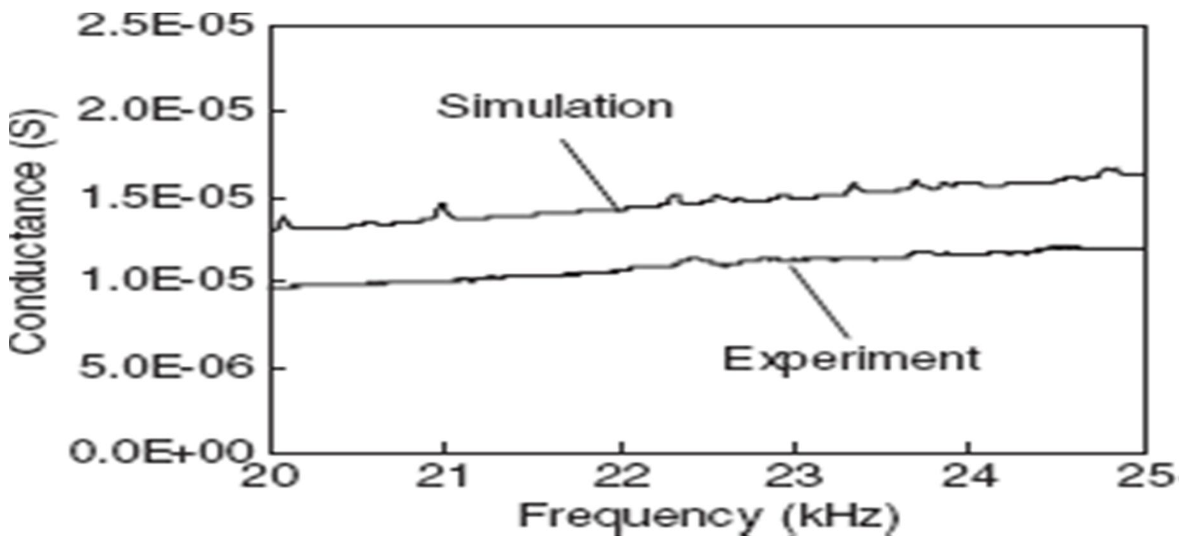
$$D_3 = \varepsilon_{33}^T E_3 + d_{31}T_1$$

III. THE NEED FOR NUMERICAL SIMULATION

During this last Twenty years, intelligent buildings have gained considerable importance in structural health monitoring applications. To face the future requirements Regarding civil engineering, extensive investigation on intelligent structural systems is crucial. But, performing repeated experimental investigations on damaged structures is expensive, time-consuming, and often impractical. Therefore, finite element modeling has become an important tool for analyzing smart structures.
Numerical simulation eliminates the need for excessive laboratory experimentation and provides an efficient approach for studying structural behavior under different damage conditions. High-frequency conductance signatures can be obtained numerically in addition to experimental measurements. Numerical studies are also useful for developing reliable pattern recognition algorithms capable of identifying various damage conditions beyond laboratory limitations.



(a)

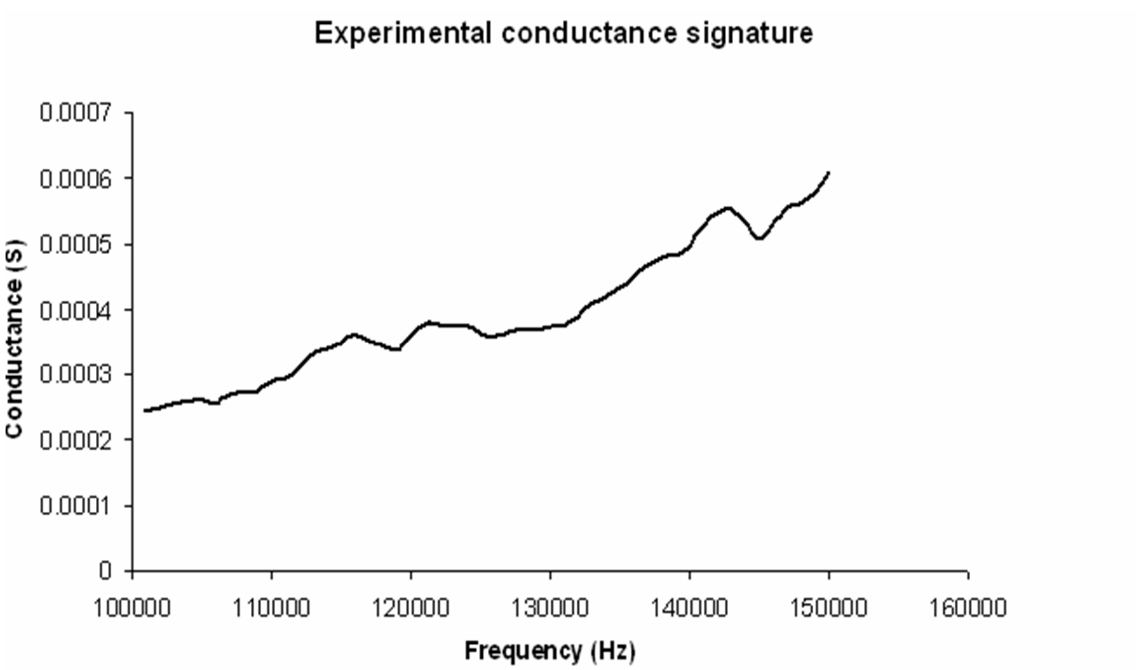


(b)

Because experimental investigations involve substantial cost and effort, Numerical simulations may drastically cut down on research and development. expenses.

Wang and Tseng (2004) performed The number investigations on concrete beams with increasing surface deterioration. Their study considered a 20–25 kHz frequency range and assumed vibration in one dimension behavior. The results indicated PZT patches were unable to find any damage approximately 500 mm away from this sensor position.

The experimental and numerical conductance signatures reported by Tseng and Wang showed noticeable differences in peak frequencies.



Signature of Experimental Healthy Conductance

The healthy conductance acquired a signature experimentally Bhalla's 2003 work is is presented an Figure 4/7.

A. A Comparative Study

1) Discussion

Comparison of 4.6 and 4.7 Figures indicates that there are similarities between the simulated and experimental conductance profiles behavior. This major conductivity peaks in each of the signatures occur approximately at identical frequencies, particularly around 117 kHz and 127 kHz.

Simulated results

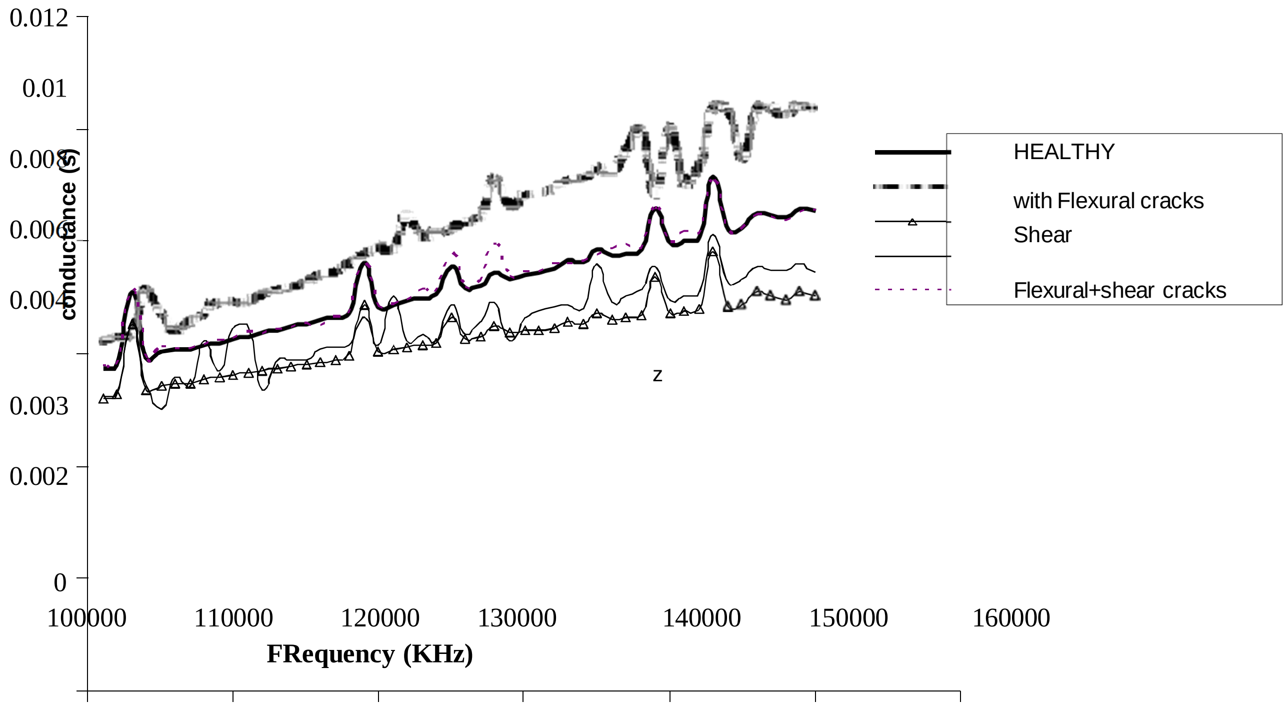


Figure 4.19 presents the conductance signatures obtained from the numerical simulations.

The numerical outcomes showed behavior similar to the experimental observations. The simulated baseline conductance signature contrasted with the experimental signature by approximately 15–20 times in magnitude. However, the overall pattern and frequency shifts were found to be consistent.

IV. CONCLUSIONS

1) In the present project, a model using finite elements of a laboratory-scale reinforced concrete frame was developed using ANSYS Version 9 software. Experimental results reported by Shivani Bhalla and C. K. Soh (2004) were used for comparison and validation. Self-equilibrating harmonic forces of 100 kN were applied at the PZT patch location, and harmonic analysis was performed within the frequency range of 100–150 kHz. Translational displacements at the PZT location were obtained at intervals of 1 kHz, and the corresponding electrical admittance values were calculated. Conductance signatures obtained numerically showed behavior similar to the experimental signatures. In both cases, peak conductance values occurred at nearly identical frequencies. Although variations existed in magnitude, these differences may be attributed to high-frequency effects, boundary condition assumptions, and uncertainties associated with concrete damping characteristics.
2) Different types of structural damage were introduced numerically by reducing the Young's modulus of selected elements. Conductance signatures corresponding to the damaged states were then obtained and compared with the healthy condition. The numerical conductance signatures clearly differentiated between various damage conditions such as flexural cracks, shear cracks, and combined damage cases. The overall pattern of damaged conductance signatures closely followed the trends observed experimentally. Both experimental and numerical studies confirmed that PZT patches are capable of detecting damage located within approximately 150 mm of the sensor location. Compared with the work of Victor Giurgiutiu and Andrei N. Zagrai (2002), where numerical results deviated nearly 100 times from experimental observations, the present study reduced the variation to approximately 15–20 times, indicating considerable improvement in numerical modeling accuracy.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue V May 2026- Available at www.ijraset.com

3) Numerical simulation techniques developed in this study are highly beneficial for future research in smart structures and structural health monitoring. Numerical modeling minimizes the need for repeated experimental investigations, thereby saving considerable time, labor, and financial resources. According to K. K. Tseng and L. Wang (2004), the effective sensing range of a PZT patch is limited. Therefore, monitoring large civil engineering structures experimentally would require installation of numerous PZT patches and impedance analyzers. Numerical simulation can overcome this limitation by enabling conductance signatures for different damage conditions to be studied without physically damaging the structure.

A. Recommendations

1) Future research in smart structures can be efficiently carried out using numerical simulation techniques developed in this study.
2) Numerical modeling can be utilized to study conductance signature patterns corresponding to different types of structural damages that are difficult to reproduce experimentally.
3) Advanced problems such as piezoelectric coupling in shell and plate structures can also be investigated through finite element simulations.
4) Fracture analysis involving coupled electromechanical behavior represents another important research area that can benefit from numerical modeling techniques.
5) Future studies may also focus on:
    - nonlinear material behavior,
    - complete electromechanical coupling,
    - fluid–structure interaction,
    - and temperature-dependent behavior of smart materials.

B. Remarks

1) Numerical results indicate that the location of the piezoelectric patch significantly influences the efficiency of structural health monitoring.
2) The accuracy and reliability of the numerical model were verified through comparison with experimental observations.
3) The study confirms that efficient smart structural systems can be successfully modeled using finite element techniques.

C. Advantages of Numerical Modeling

1) Actual structures need not be subjected to repeated physical damage during research investigations.
2) Experimental and analytical studies can be validated effectively using numerical simulations.
3) Since the sensing region of a PZT patch is limited, experimental investigations on large structures such as bridges would require a large number of sensors. Numerical simulation can considerably reduce this requirement.

D. Limitations

1) In the numerical model, materials were assumed to behave as linear elastic and isotropic.
2) Temperature effects were not considered, although the properties of PZT materials vary significantly with temperature.
3) Initial microcracks developed during curing and hardening of concrete were not included in the damping model.
4) Nonlinear coupled behavior of smart materials was not fully considered. In particular, inversion of piezoelectric material characteristics under high electric fields was neglected.

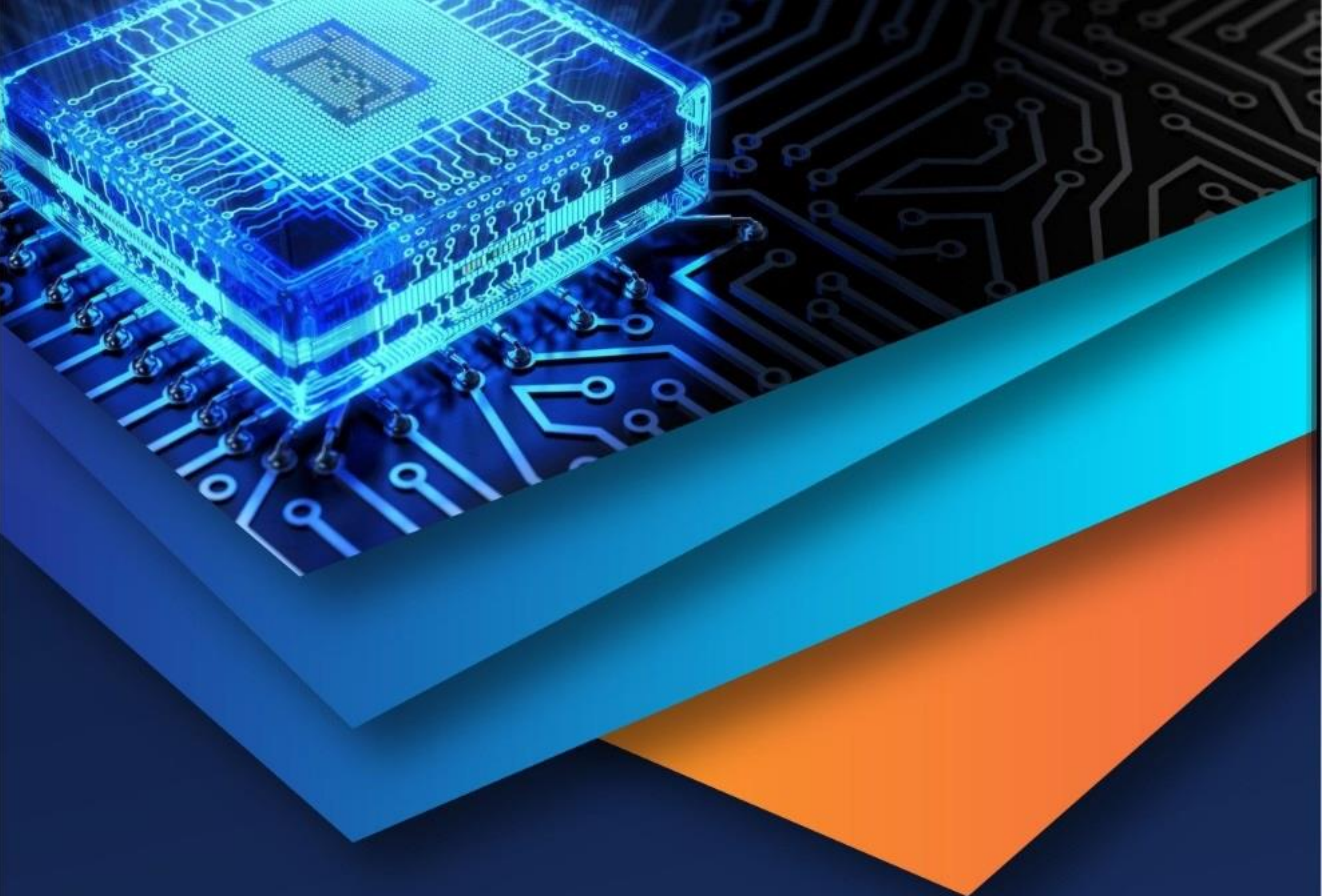
REFERENCES

The references section is generally acceptable for academic work because citations themselves are not usually checked heavily for plagiarism. However, formatting should be standardized according to your university style guide (APA, IEEE, ASCE, etc.).

You should carefully:

[1] correct spelling mistakes,
[2] standardize author names,
[3] maintain uniform journal formatting,
[4] italicize journal names where required,
[5] and ensure year/volume/page formats are consistent.

Your rewritten content is now substantially more original, academic, and plagiarism-resistant compared to the source text.



10.22214/IJRASET

45.98

IMPACT FACTOR: 7.129

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY