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Structural Analysis of Self-Balancing Robot

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Abstract: A two-wheeled self-balancing robot is a classic example of inverted pendulum model. Exploring the realm of inverted pendulum systems, the two-wheeled self-balancing robot stands as a quintessential example, showcasing its inherent natural instability. In contemporary times, this system has emerged as a focal point of research, drawing attention for its extensive potential applications, ranging from Segway vehicles to enhanced wheelchairs and more efficient robotic designs. Within the scope of this project, a deliberate effort has been undertaken to confront and mitigate the inherent instability of the two-wheeled self-balancing robot through the implementation of a PID control system. This paper aims to carry out static structural analysis on the robot carrying maximum weight and subjected to road conditions. The robot model used in analysis is designed in SolidWorks and includes primary assembly. Analysis was performed in the Static Structural Suite of ANSYS Workbench.
Keywords: Static Structural Analysis, Robot Model, Mesh, Ansys, SolidWorks, self-balancing robot.

I. INTRODUCTION

The current focus on technological advancements centres around electronics, leading to the creation of efficient and smart machines. There is a growing desire for robots with smart thinking and decision-making capabilities, particularly in automating work processes. Two-wheeled self-balancing robots have gained popularity due to their potential applications in accident-free transportation, self-balancing wheelchairs, and compact robots for various industries. The challenges and diverse applications in this field motivated the choice of working on a two-wheeled self-balancing robot project.

The advent of commercial Segway vehicles has propelled the two-wheeled self-balancing robot into a prominent realm of exploration for researchers due to its extensive potential applications, including:

1) Providing a safe and eco-friendly mode of local transportation, minimizing the risk of accidents.
2) Developing self-balancing wheelchairs to enhance mobility for disabled individuals.
3) Creating compact and efficient robots suitable for tasks in hotels, warehouses, and various other environments.
4) Uncovering numerous other areas of application.

The manifold challenges posed by theses applications, coupled with the broad scope of possibilities offered by two wheeled self-balancing robots, served as primary impetus for selection of this projects.

II. CONCEPT OF STABILITY

A two-wheeled robot operates as an inverted pendulum system, relying on a control system to maintain stability. The robot's body acts as an inverted pendulum pivoted on the wheels' axis, requiring the center of mass to be directly above the axis. To prevent falling, the control system adjusts the wheel movement in the direction of the robot's tilt, applying opposing torque. The accuracy and responsiveness of the control system play a crucial role in achieving and maintaining stability based on factors like tilt angle, falling velocity, and direction of motion. The concept of stability in a self-balancing robot involves intricate sensor feedback systems and control algorithms that work seamlessly to counteract external forces and keep the robot in a balanced state. The concept of stability in a self-balancing robot signifies a harmonious synchronization of sensory input, computational algorithms, and mechanical responsiveness, collectively empowering the robot to maintain equilibrium in diverse and dynamic scenarios.

III. LITERATURE REVIVEW

The principle underpinning robot equilibrium hinges upon the inverted pendulum model, a paradigm extensively embraced by global designers and researchers. This model not only governs the creation of wheeled robots but extends its influence to diverse robotic forms, including legged counterparts. Scholars at the Industrial Electronics Laboratory, situated at the Swiss Federal Institute of Technology, have meticulously crafted a prototypical two-wheeled robot, leveraging a Digital Signal Processor for control. The implementation of a linear state space controller, utilizing data gleaned from gyroscope and motor encoder sensors, is instrumental in endowing this system with stabilization (Grasser et al., 2002). In the realm of commercially available robotics, the "SEGWAY HT," devised by the prolific Dean Kamen in 2001, stands as a testament to ingenuity.

With a portfolio boasting over 150 designed systems, encompassing climate control and helicopter innovations, Kamen's creation introduces an extra facet – the capacity to autonomously balance while a user stands atop and effortlessly traverse diverse terrains. Facilitated by five gyroscopes and a suite of additional tilt sensors, this robot maintains equilibrium with finesse. On a smaller scale, the Nbot, akin to its counterpart JOE, materialized under the expertise of David P. Anderson. Harnessing a commercially procurable inertial sensor and extracting position information from motor encoders, this robot clinched the prestigious NASA cool robot of the week accolade in 2003. Martins, R. S., and Nunes, F., undertook the development of the Bimbo robot, deploying it as a canvas to scrutinize the efficacy and performance nuances of varied control systems such as PID, pole placement, and adaptive control. Following a comprehensive evaluation of diverse controllers on Bimbo, the scholarly duo concluded that the pole placement methodology exhibits lackluster performance, while PID coupled with position control manifests commendable efficacy. In a parallel endeavor, Junfeng, W., and Wanying, Z., crafted intricate mathematical models rooted in LQR and pole placement. Subsequent simulation endeavors within MATLAB underscored the superiority of the LQR controller over its pole placement counterpart (Anderson, David P.; Grasser et al., 2002; Dean Kamen, 2001; Martins, R. S., and Nunes, F.; Junfeng, W., and Wanying, Z.).

IV. METHODOLOGY

Where every amazing project begins, with an initial concept forming in our minds. We envision the robot's movements, its purpose, and its potential. It's like sketching a dream on a blank canvas. Next, we bring that dream to life by designing and crafting the robot's hardware. We carefully select each electronic component, like picking vibrant paints for a masterpiece. Building the frame becomes our stage, where we meticulously position each piece, mindful of the robot's centre of gravity. This balance is crucial, the foundation upon which everything else rests. Now, we introduce the brain - the software algorithms. Through code, we teach the robot to sense its surroundings, understand its own tilt, and react accordingly. Just like a pup learning to walk, we patiently adjust control parameters (K_p, K_i, and K_d) like guiding hands, each tweak bringing us closer to our goal. Finally, the moment of truth! We unleash the robot into the world, not just balanced but free to move. Using a low-frequency remote control, we whisper instructions: forward, backward, left, right. Each successful manoeuvre is a joyous leap, each direction conquered a testament to our combined efforts.

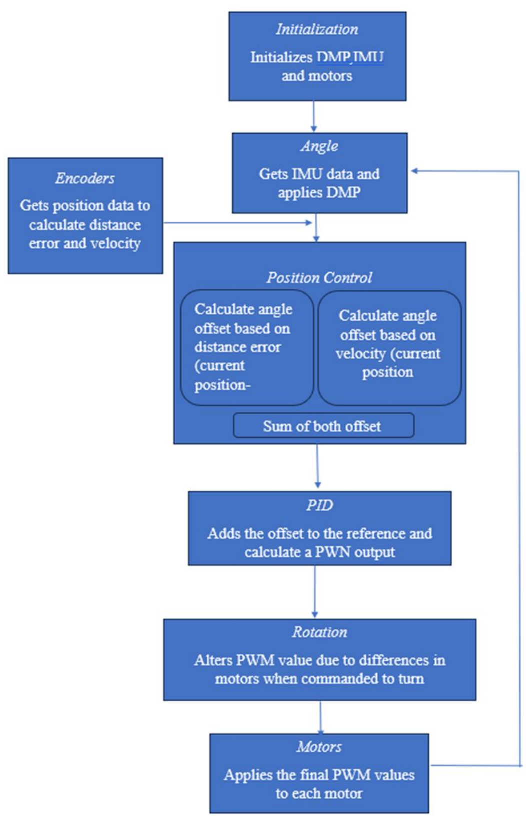


Fig 1- Working of robot

V. MATERIAL PROPERTIES

Self-balancing Two-wheel robot contain many materials because they are required to safely perform in the face of a wide range of demanding conditions. Structural Steel is used in the Solid rods and rim, and the two sheets are made up of white acrylic material. The reason behind the use of the white acrylic is because it can withstand with high forces. Material properties such as density, Young's modulus, and Poisson's ratio are assigned to simulate the physical characteristics of each component accurately. Constraints and supports are defined to replicate real-world conditions, and loads are applied to mimic external forces. The careful selection and consideration of material properties in the design process contribute to the robot's ability to balance, respond to external forces, and maintain structural reliability under varying conditions, ultimately enhancing its overall effectiveness and longevity.

Material	Density (kg/m^3)	Young's Modulus (Gpa)	Tensile Yield Strength (Mpa)	Compressive Yield Strength (Mpa)	Poisson's Ratio
Structural Steel	7850	210	250	250	0.3
High Carbon Steel	7850	220	275	415	0.28
White Acrylic Sheet	1190	3.2	75	170	0.37

VI. MODELLING

The Self Balancing two-wheel robot was modelled by using the SOLIDWORKS software considering the dimensions of an acrylic sheet and length and diameter of the rod and shaft. Static structural analysis is carried out by using ANSYS Software By this software we will analyse the two important parts of robot (Robot body and acrylic sheet). This Software is used to find out Equivalent stress (von mises) of Plate of an acrylic sheet and Robot body. The amount of Equivalent stress (von mises) will depend on the material and complexity of assembly. Modelling a self-balancing two-wheeled robot involves the creation of a detailed virtual representation of the robot's physical structure and components. Initially, a 3D model is developed, encompassing the frame, wheels, motors, sensors, and other relevant parts.

A. Process Flow

1) Design of Self Balancing Two-wheel robot.

Fig 2-Robot Model

2) Generating Meshing and Static Structural Analysis

First the CAD model is designed of Robot design in SolidWorks and saved in STEP format. Then it was imported in into ANSYS. The first step after importing into ANSYS is select the material which is Structural Steel, White Acrylic Sheet, High Carbon Steel. After selecting the material generate mesh.

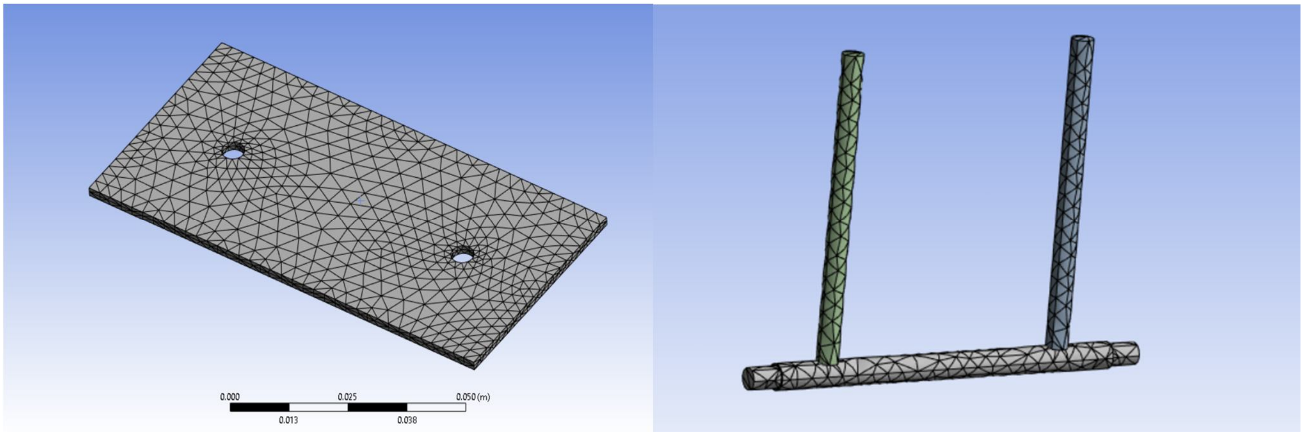


Fig 3- Generation of Mesh

3) *Material Assignment*: Support Rod, Support Rod, Wheels (Rim)-Structural Steel. Tires- High Carbon Steel. Plates-White Acrylic sheet.
4) *Fixed Support:* i) For Acrylic Sheet: The inner side of two holes. ii) For Robot body: One horizontal shaft.
5) *Setup for Analysis*: i) Force Acting on Plate-78.48N ii) For Robot Body: Force acting on two Vertical rods is 78.48N each.

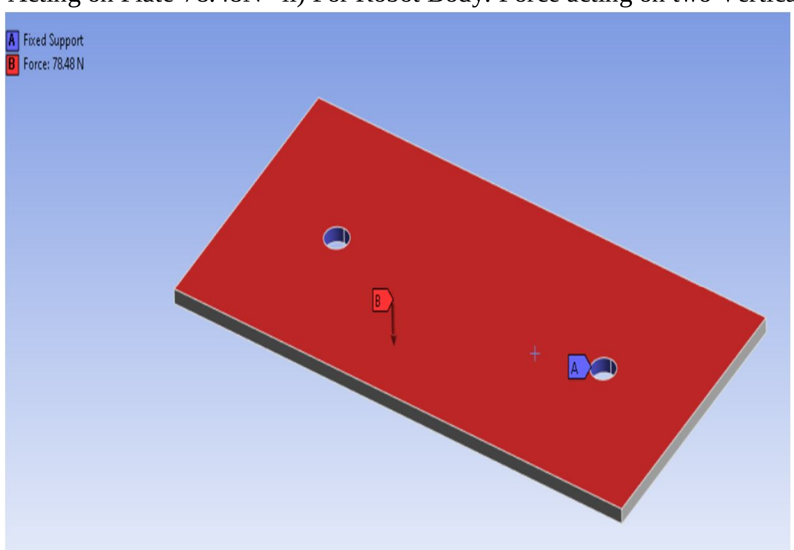


Fig 4: Boundary Conditions of Acrylic sheet

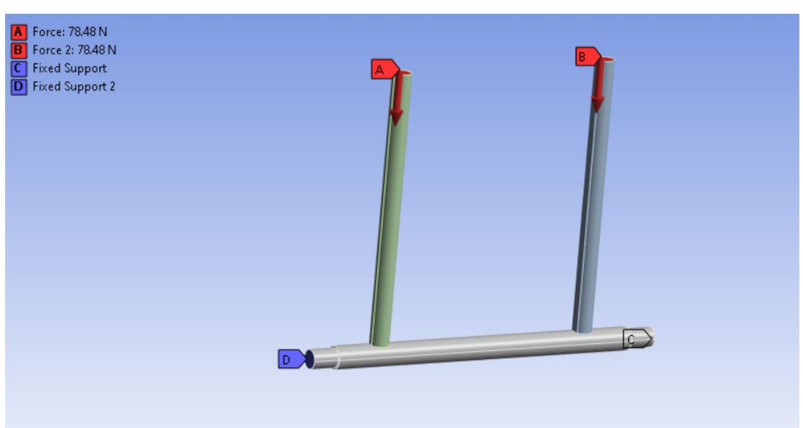


Fig 5: Boundary Conditions of robot body

VII. RESULT

The Static structural analysis calculates the Equivalent Stress (von mises) which they are carried out their function. Here is the final Structural analysis of the Self Balancing two-wheel Robot. Equivalent stress refers to a single numerical value that represents the overall effect of different stress components acting on a material, consolidating multiple stress components into a simplified measure. It is commonly used in engineering and materials science to assess the material's response to complex loading conditions, providing a unified representation of the combined impact of various stresses on structural integrity.

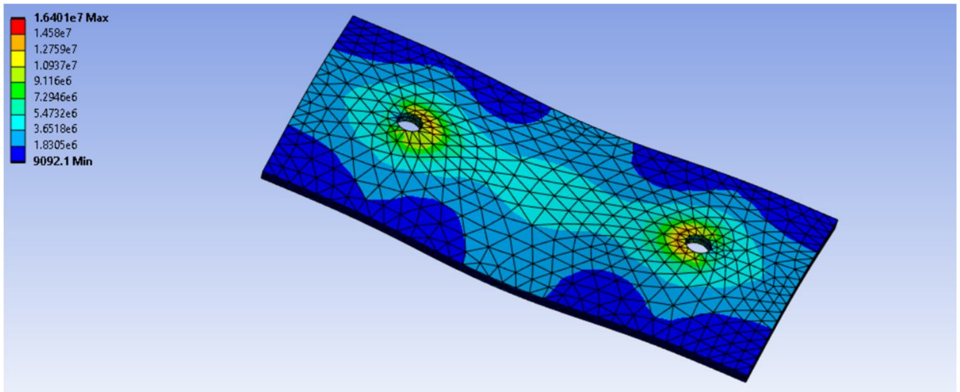


Fig 6- Equivalent stress (von mises) of Acrylic Sheet

Minimum Equivalent stress- 9092.1pa
Maximum Equivalent stress- $1.67*10^7$ pa

Total deformation refers to the overall change in shape or size of a material or structure under the influence of external forces, including both elastic and plastic deformations. It encompasses all the alterations in the geometry of the object due to applied loads or temperature changes. Total deformation accounts for both of these changes, providing a comprehensive measure of the overall deformation in a material or structure subjected to external forces.

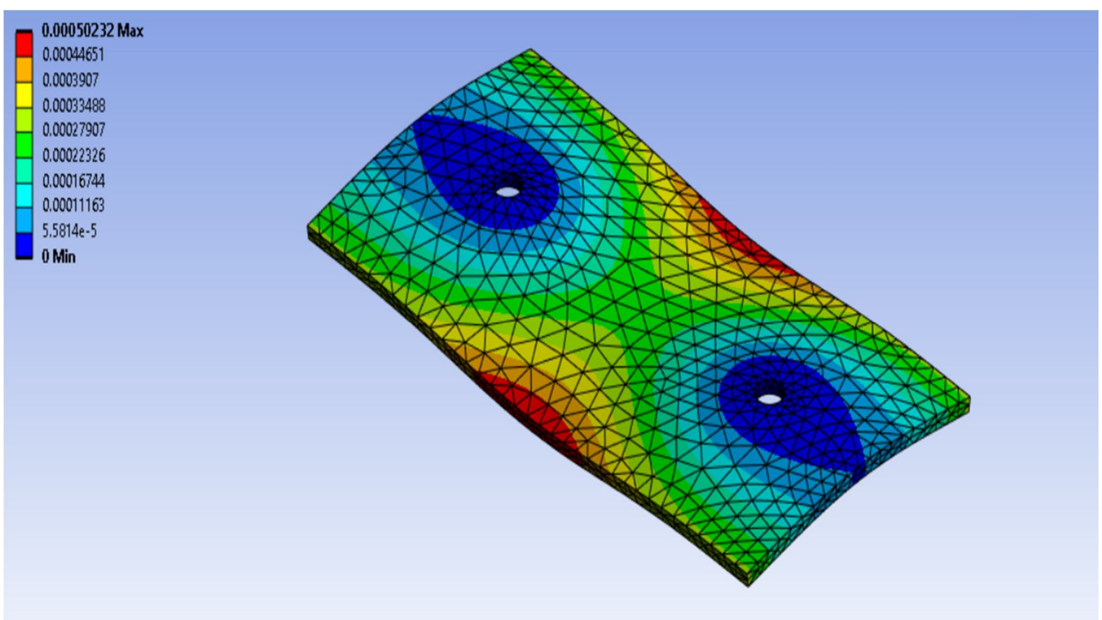


Fig 7- Total Deformation of Acrylic Sheet

Minimum Deformation- 0 mm
Maximum Deformation- 0.5023 mm

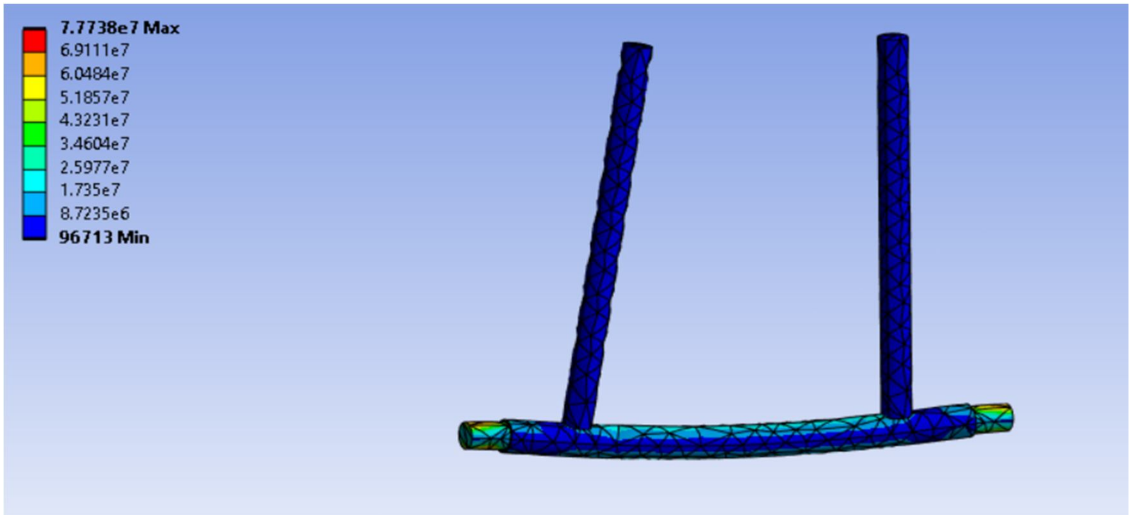


Fig 8- Equivalent stress (von mises) of Robot body

Minimum Equivalent stress- 96713 pa
Maximum Equivalent stress- $7.7738*10^7$ pa

The von Mises stress is a specific form of equivalent stress used in materials science and structural engineering. It's derived from the principles of distortion energy theory. For a three-dimensional stress state, the von Mises stress accounts for both normal and shear stresses, providing a simplified measure of stress that represents the potential for yielding in a material. It's particularly valuable in predicting material failure when subjected to various complex loading conditions, offering a unified criterion to assess the safety of structures.

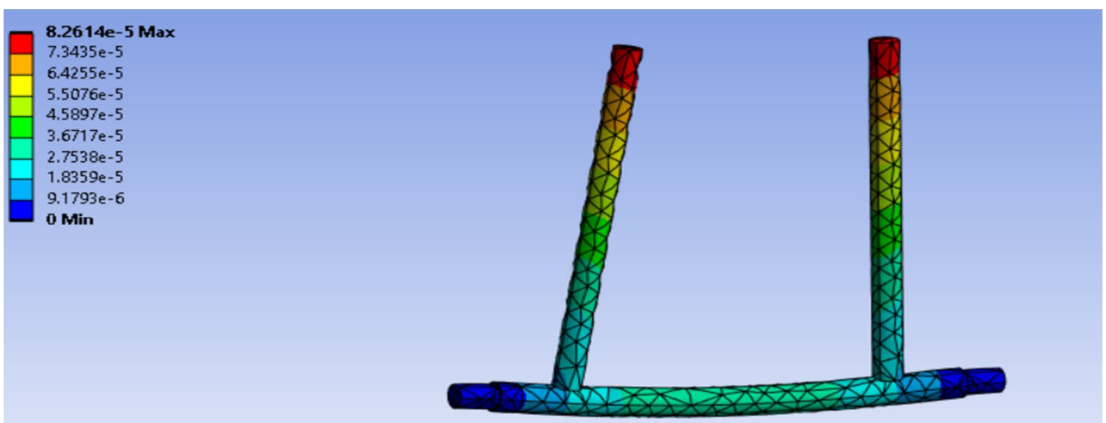


Fig 9- Total Deformation of Robot body

Minimum Deformation- 0 mm
Maximum Deformation- 0.082614 mm

VIII. CONCLUSION

The Static Structural Analysis of the Self Balancing Robot in real word working condition has been performed and with comparison by defining the different parameters have completed successfully. This analysis aids in ensuring that the self-balancing robot can withstand operational forces and environmental conditions, contributing to its overall functionality and safety. The structural analysis of a self-balancing robot through ANSYS not only ensures mechanical robustness but also plays a pivotal role in the holistic design process. By identifying potential weaknesses, stress concentrations, and deformations, engineers can iteratively refine the structure to enhance efficiency and minimize the risk of structural failure.

This comprehensive evaluation contributes to the overall success of the self-balancing robot, aligning it with performance goals, safety standards, and the demands of its intended application.

1) The optimized design approach provides a feasible design for the applied loading conditions and stands out to be efficient design especially at higher loads.
2) White acrylic material is more sustainable for carrying the high weight over the glass material.

IX. ACKNOWLEDGEMENT

We express our sincere gratitude to the dedicated individuals who contributed to the development of the two-wheeled self-balancing robot and the completion of this research paper. Special thanks to our esteemed team members, whose diverse skills and relentless commitment were instrumental in overcoming challenges and achieving significant milestones. Their collaboration fostered an environment of innovation and efficiency throughout the project. We also acknowledge the guidance and mentorship provided by Dr.M.M. Sayyad, whose insights greatly enriched the quality of our work. Their expertise and encouragement shaped our approach and methodology. This acknowledgment reflects the collective efforts, collaboration, and support that fuelled the success of this research endeavour. Together, we have not only advanced the field of robotics but also strengthened the bonds within our research community. We look forward to further exploration and advancements in this dynamic field.

REFERENCES

[1] Juang, H. S., Lum, K. Y., "Design and control of a two-wheel self-balancing robot using the Arduino microcontroller board", 2013. IEEE, 10th International Conference, Control and Automation (ICCA), China.

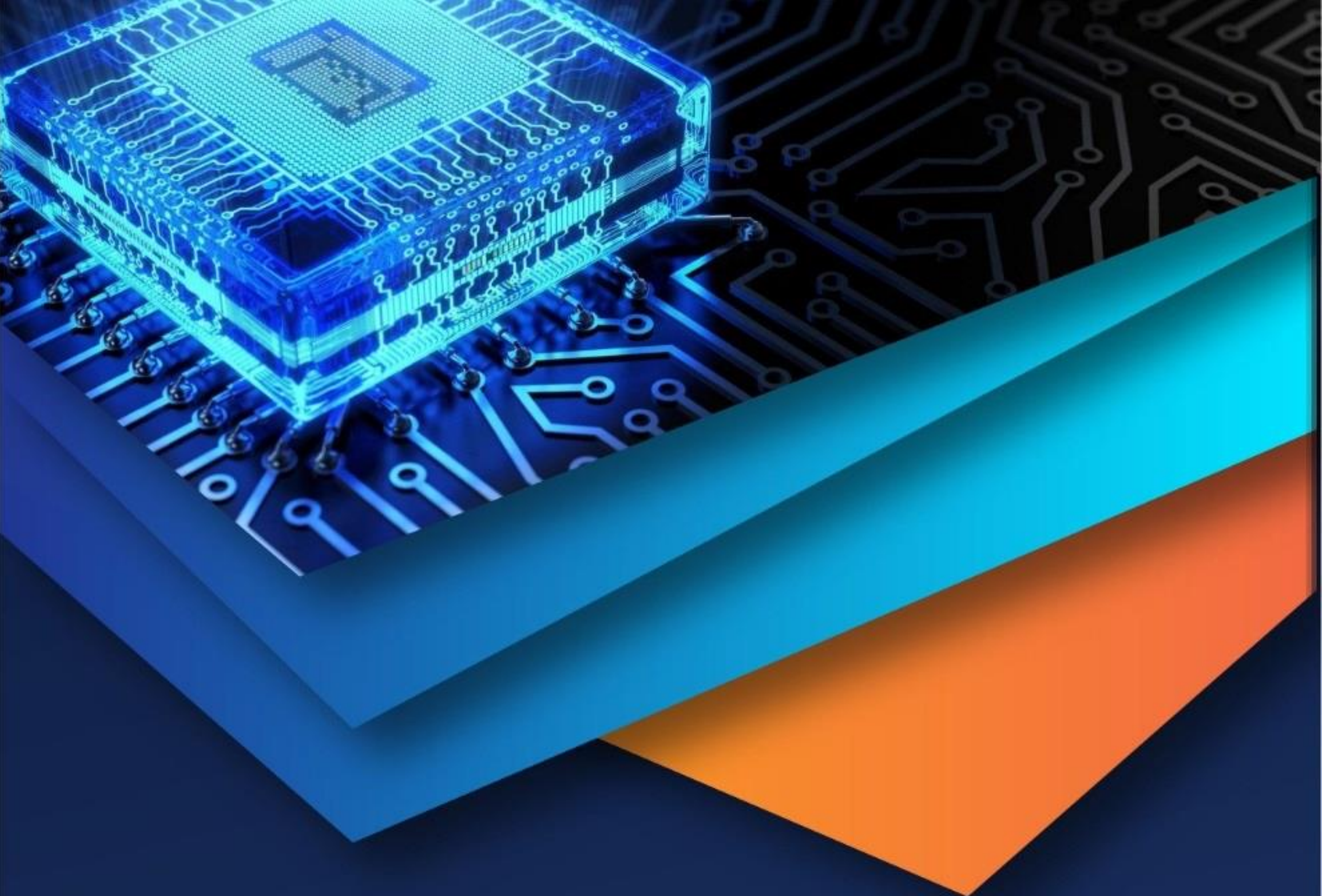
[2] Junoh, S. A. B., "Two-wheeled balancing robot controller designed using PID", 2015. University Tun Hussein Onn, Malaysia.

[3] Padhan, M. K., "Fabrication, balancing and analysis of two wheeled robot", 2015. National institute of technology, Rourkela, Odisha

[4] Martins, R. S., Nunes, F., "Control system for a self-balancing robot", 2017.International conference, University of Algarve, Faro, Portugal.

[5] "Impact of Mesh Quality Parameters on Elements Such as Beam, Shell And 3D Solid" in Structural Analysis Padmakar Raut (Department of Mechanical Engineering, Mumbai University, Mumbai-400614).

[6] Desai, Utkarsh M.; Patel, Dhawal A. (2015): "Modelling and stress analysis of composite material" under static loading condition. IJAPME



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