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Design and Development of Self Balancing Vehicle

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Abstract: The project work outlines the design and development of a self-balancing vehicle. The project aimed to create a compact, lightweight, and energy-efficient vehicle that could maintain balance without the need for a rider's input. The prototype was built using a combination of electronic components, sensors, and programming algorithms that allowed the vehicle to maintain balance.

The design process involved extensive research on similar vehicles and their components, as well as experimentation with various designs to determine the most efficient and effective approach. Once the design was finalized, the development phase began, with the construction of the vehicle's frame and the integration of the various electronic components. The vehicle's balancing system was developed using a combination of gyroscopes, and a microcontroller that processed data from these sensors to adjust the vehicle's balance. Additionally, the vehicle was equipped with a motor and a battery to allow for movement.

During testing, the model was able to maintain balance. The vehicle's energy consumption was also significantly lower than that of similar vehicles, making it an efficient and environmentally-friendly mode of transportation.

Overall, the project was successful in achieving its goals of designing and developing a self-balancing vehicle. With further refinement and testing, the vehicle has the potential to become a viable mode of transportation for short distances in urban environments.

Keywords: Gyroscope, Microcontroller.

I. INTRODUCTION

Transport, often known as transportation in American or British English, is the act of moving people, animals, and/or things from one place to another. There are three types of transportation: air, land (train and road), and water. Infrastructure, transportation, and operations make up the field. Human trade, which is necessary for the rise of civilizations, is made possible through transportation. Both fixed installations, such as roads, railways, airways, waterways, canals and pipelines, as well as terminals, including airports, railway stations, bus stations, warehouses, trucking terminals, refueling depots (including fueling docks and fuel stations) and seaports, comprise transportation infrastructure. Terminals can be used for maintenance as well as the exchange of people and freight. Any of the various forms of transport infrastructure that are used to move people or goods are considered means of transport. Vehicles, riding animals, and pack animals might be among them. Wagons, cars, bicycles, buses, trains, trucks, helicopters, boats, spacecraft, and aero planes are all examples of vehicles.

Two-wheelers are mostly used for transportation within the same city and these are the most widely used and preferred way for transportation for short distance movement. There seems to be more scope for development in the field of Modelling and dynamics of two-wheeler.

According to the National Crime Records Bureau's (NCRB) most recent statistics, 1,55,622 individuals died in traffic accidents in 2021. Two-wheelers were involved in the majority of fatal traffic accidents in 2021 (69,240 fatalities), making up 44.5% of all fatalities on the road. The majority of two-wheeler-related fatalities were reported in Tamil Nadu (8,259 fatalities) and Uttar Pradesh (7,429 fatalities), accounting for 11.9% and 10.3% of all two-wheeled vehicle-related fatalities, respectively.

Figure 1.: Two-wheeler accident due to imbalance.

There are so many advanced features in bikes that are invented to avoid accidents. When the rider got into an accident on road side elements there was a more probability to loss his/her life. Most of time rider losses control to get stability when he rides the bike. To avoid all these limitations of the bike a self-balancing vehicle can helpful in the sense of safety, vehicle damage. The self-balancing bikes works on the principle of "Gyroscopic effect" and its applications had been using in airplanes and ships from many decades. In case of bikes when it tilts left or right, it induces a reactive gyroscopic couple in the opposite direction. So that vehicle balances by this gyroscopic effect. A two-wheeled vehicle's stability is crucial in the intricate transportation system. Gyroscopes can make a significant contribution to the two-wheeler vehicle's stability. According to a theory, gyroscopically stabilized cars would be safer than traditional two-wheelers. For a two-wheeled vehicle to be dynamically stabilized, a torque acting on it naturally must be offset by a torque generated inside the vehicle by a gyroscope.

II. LITERATURE REVIEW

A thorough Literature survey has been carried out in order to understand the concepts of self-balancing, effect of gyroscope, self-stability control of vehicle etc.

1) *Nitheesh kumar G, Navneeth S, Suraj A, and Pramod Sreedharan (2021):* The design and analysis of a self-balancing bicycle model were covered in their paper. The goal was to create an effective design that could be produced in the future. For the purpose of creating the best design, the various bicycle balance techniques were investigated. For the modelling, simulation, and analysis of the structure, Solid Works and Ansys were utilized. The effects of precession increase with higher rpm and flywheel weight, according to research on the use of a Control Moment Gyroscope (CMG) to balance the bicycle model. As a result, a bicycle model with CMG is far more stable and less prone to falling and inadvertent tilts than one without.
2) *V. V. Kadam, M. S. Khedekar, V. S. Shilimkar, A. A. Kolapkar (2017):* They created a self-balancing bike prototype in their study that uses two gyroscopes to keep the bike upright while stopped. When parked, the bike's "landing gear" is activated to keep it upright. The bike has complete control over the gyros, allowing for a steer-by-wire technology that enables the bike to lean into and out of turns while always maintaining stability. The motorcycle will have several airbags, seat belts and reinforced doors in addition to a unibody frame. The gyro stabilization mechanism, which enables the bike to withstand the forces of a crash, is also the most crucial safety element. With this bike, safety is one of the top objectives.
3) *N. Tamaldin, H.I.M. Yusof (2017):* stated that "there are several ways in order to design an efficient self-balancing bicycle by using control moment gyroscope and mass balancing steering control and reaction wheel usage of CMG gives great effect"
4) *Pallav Gogoi, ManishNath (2017):* stated that "the rotation of the disc leads to the production of gyroscopic effect when the vehicle loses their balance reactive gyroscopic couple maintains stability".
5) *Abdullah Ahmed, Indrajeet Adnaik, Dhananjay Bhavsar, T. S. Sargar (2016):* In their article, they have created a unique type of wheel that uses the gyroscopic effect and can prevent itself from toppling over. This wheel would replace the front wheel of a bicycle and do away with the need for training wheels for a beginner cyclist. To do this, a Gyro wheel was created, inside of which a flywheel would rotate at a high RPM thanks to a battery-operated motor. Due to the self-balancing effect produced by this circular motion, the wheel would remain stable. Consequently, a beginner would ride a bicycle without hesitation or fear.
6) *Sheikh Mohibul Islam Rumi, I.S.M. Shanamul Islam (2015)* has designed a two-wheeler self-balancing which aims to balance the two-wheeler against any impact and in a static condition they used two heavy rotation disks to compensate felt of two-wheeler.
7) *Mr. Sandeep Kumar Gupta, Mrs. Veena. Gulhane (2014)* They created a self-balancing bicycle using object state detection in their article. In this study, self-balancing techniques focused on keeping the center of gravity constant were demonstrated. The falling angle was controlled using a proportional-integral controller (PID). A number of processes that depend on the geometry, mass distribution, and forward speed of the bike work together to provide this self-stability. When a bike's steering is locked, it is nearly hard to balance while riding.
8) *J. D. G. Kooijman (2011):* In their work, they developed the CMG (Control Moment Gyro), a self-stabilizing bike based on the gyroscope principle. The entire device's angular direction is under the control of CMG. The integration of mechanical and electronic (inclination sensor and PD controller) parts and gadgets in the overall unit makes it possible.
9) *J. P. Meijaard, Jim M. Papadopoulos, Andy Ruina, A. L. Schwab (2011):* In their work, they used a gyroscope to construct a self-balancing two-wheeler. The rotation of the mild steel disc mounted on the motor shaft produces the gyroscopic effect. A counter-acting reactive gyroscopic pair stabilizes the prototype as a result of the gyroscope's rotation. The Centre of gravity is located above the gimbal axle thanks to the way the engine and gimbal axle combination are built. When the motor is turned on, the body is on the verge of falling to one side or the other; the motor assembly can only achieve stability by leaning forward or

backward, which also causes the spin axis to precess. The reactive gyroscopic couple acts on the frame as a result of this precession, negating the effect of the disturbing couple and stabilizing the vehicle.

III. PROBLEM DEFINITION

1) Conventional modes of transportation, such as bicycles and motorcycles, require manual balancing and control, which can pose safety risks, especially for inexperienced riders.
2) The lack of stability and balance control in these vehicles increases the likelihood of accidents and injuries, hindering the widespread adoption of these transportation options.
3) Furthermore, individuals with physical disabilities or limited mobility face significant challenges in accessing conventional transportation means. Therefore, the development of a self-balancing vehicle with enhanced safety features and improved accessibility can address these concerns and provide a reliable and inclusive mode of transportation for individuals of all ages and physical abilities.

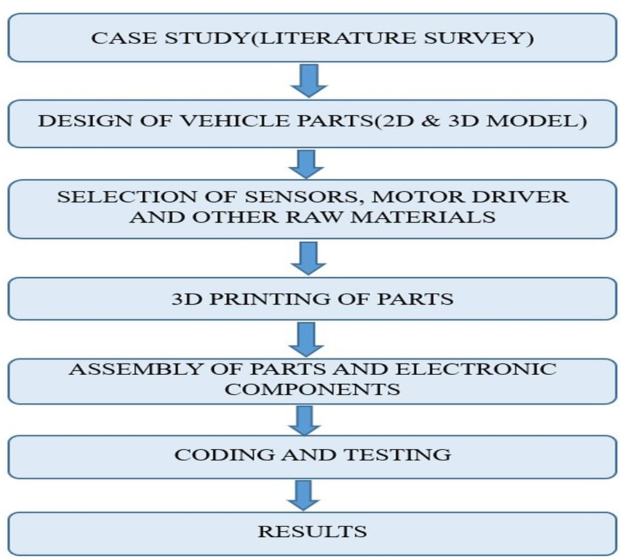
IV. OBJECTIVES

The objective of the project is,

1) To Design and develop a self-balancing vehicle, that has to maintain the stability at all conditions when in use.
2) To stabilize the unstable system to maintain upright position by incorporating gyroscope sensors.

V. METHODOLOGY

The detailed step wise procedure is shown below.



VI. MATHEMATICAL MODELING

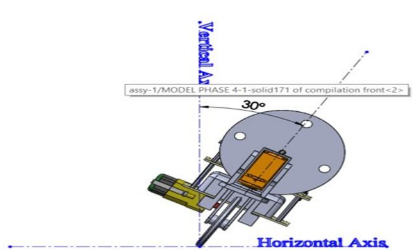


Figure 2: Maximum Tilt Angle of the Two-wheeler Model without slipping.

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According to 'Figure', the mass of the system is m kg, distance/location of the center of mass (m) from the ground is h (m). When the angle of tilt is θ, then the torque induced τ is given by

$\tau = m\, g\, h \sin\theta$ ………………………………...(1)

and the Reactive Gyroscopic Torque (τ') given as

$\tau' = m\, g\, h \sin\theta$ (opposite direction)…………...(2)

also,

$\tau' = I\, \omega\, \omega p$……………………………………..(3)

where I is the moment of inertia of the disc, ω the angular speed of the disc, and ωp the precession speed of the disc.
On comparing equation (2) and equation (3),

$m\, g\, h \sin\theta = I\, \omega\, \omega p$……………………………(4)

Therefore,

$\omega p = m\, g\, h \sin\theta / I\, \omega$…………………………..(5)

It is known that maximum frictional force can be written as

$F'max = \mu\, N = \mu\, m\, g$…………………………(6)

Where μ is the coefficient of friction and N the normal reaction force. Hence, at Limiting Condition

$m\, g\, h \sin\theta = F'h \cos\theta$…………………………(7)

on comparing equation (6) and equation (7), the result is

$m\, g\, h \sin\theta = \mu\, m\, g\, h \cos\theta$……………………..(8)

Therefore,

$\mu = \tan\theta$……………………………….(9)

where μ is the coefficient of friction and θ the angle of tilt produced
.Weights of the 3D printed parts and other parameters of components used are listed below for further calculations.

Mass of DC motor	170 gram = 0.17 kg
Mass of battery (12v)	98 gram = 0.098 kg
Mass of wheel	28 gram = 0.028 kg
Mass of Flywheel Disc	20 gram = 0.020 kg
Mass of MG995 servo	100 gram = 0.1 kg
Mass of controllers	63 gram = 0.063 kg
Miscellaneous mass (Nuts, bolts, etc.)	50 gram = 0.050 kg
Mass of Chassis and frame	320 gram = 0.32 kg
Total mass	800 gram = 0.8 kg
Battery type and output voltage	LIPO Battery with 11.1 V
DC motor shaft diameter	6mm
Rated RPM	1675 rpm

Centre of Mass (CM) from the ground, h = [(CMwheel 1 * Mwheel 1) + (CMchassis * Mchassis) + (CMdisc * Mdisc) + (CMhub motor * Mhub motor) + (CMbattery * Mbattery) + (CMwheel 2 * Mwheel 2) + (CMservo 1*Mservo 1)] + (CMservo 2*Mservo 2) +(CMcontroller *Mcontroller)/Total Mass…………………………….(10)
Where CM = Centre of Mass
Calculation of center of mass,
Centre of mass from the ground, (h) = [(30*0.028) + (30*0.32) + (150*0.020) + (120*0.17) + (40*0.098) + (30*0.028) + (100*0.1) + (100*0.1) + (50*0.063)] /0.8

=77.187 mm

Moment of inertia of the disc (I) can be written as

$$I = \frac{mr^2}{2} \quad \text{………………………………….(11)}$$

Where m is the mass of the flywheel and r the radius of the flywheel. Hence

=0.020*(60*60)/2

=36 kg/mm^2

Used rpm value ‘1675’, based on a motor commonly available in the market.
Speed of disc, N = 1675 rpm and so, the Angular Speed of Disc, ω = 175.40 rad/sec.
The vehicle is designed for the maximum tilt angle equal to 30°.
Therefore, the highest precision speed of the disc, as in equation (5), is

ωp = mghsinθ / Iω

=0.8*9.81*77.18*sin (30)/36*175.40

=0.2336 Nmm

And the highest gyroscopic reaction torque, as in equation (3), is

τ' = Iωωp

=36*175.40*0.2336

=1475.043 Nmm

VII. DESIGN

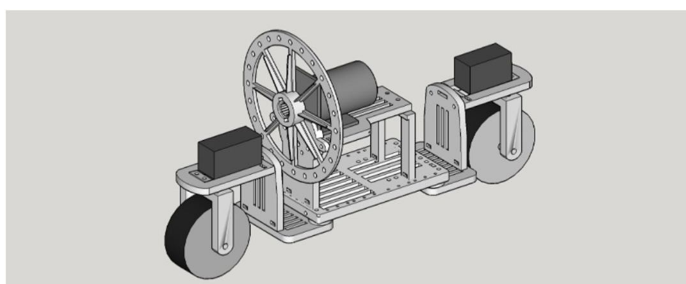

Figure 3: Isometric view of the model

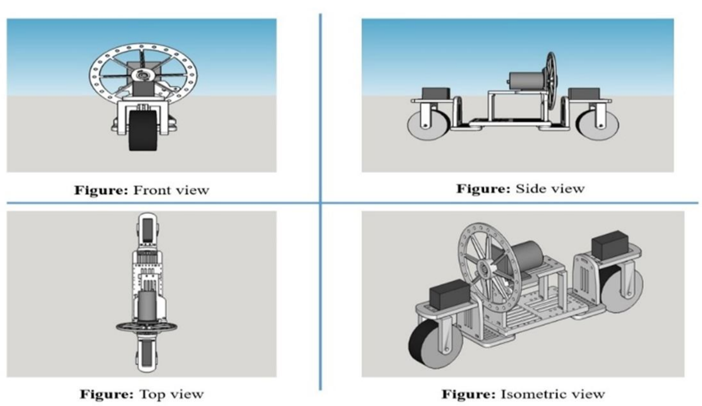

Figure 4: Three-dimensional assembly of model in different views.

VIII. CIRCUIT CONNECTION AND CODING

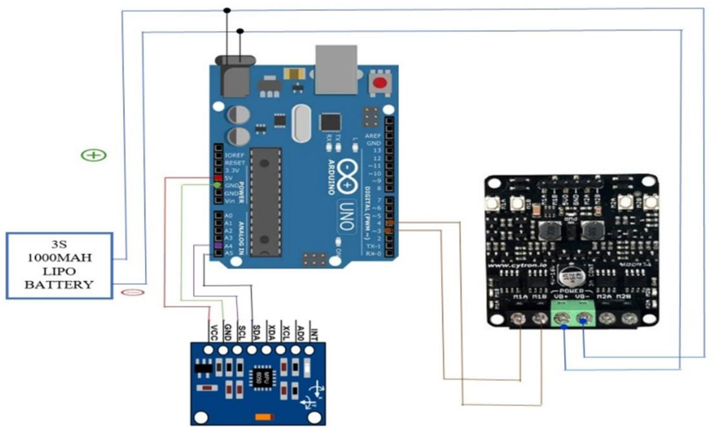

Figure 5: Circuit connections.

The code has been interpreted using Cytron motor driver (MDD3A), Adafruit MPU6050, Adafruit PMW Arduino libraries. The code runs with the acceleration speed of 0 to 128 rad/sec equivalent to given value and runs 50% of given speed in forward direction and 50% of given speed in backward direction.

IX. RESULT

The self-balancing vehicle model was put through a series of rigorous tests to evaluate its performance and capabilities. Trails were conducted to measure the vehicle's ability to maintain balance and stability for various angles of tilt.

Table: Data obtained from testing.

Trail number	Angle in Degree	Speed in RPM
1	5	189
2	10	200
3	15	215
4	20	242
5	25	300
6	30	536

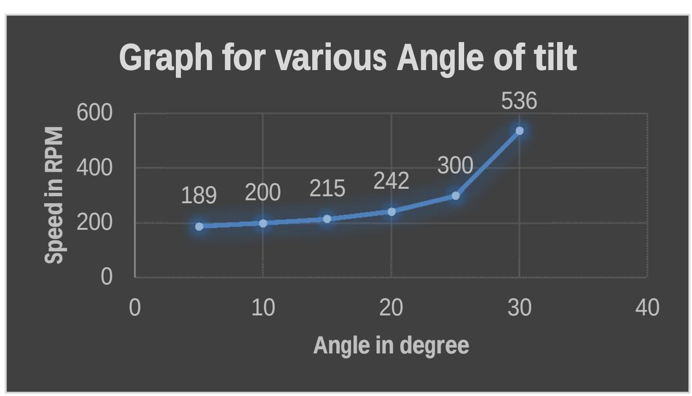

Figure 6: Graphical analysis of the test result.

Reaction wheel of vehicle accelerates based on gyro extracted values for X and Y axis with moderate torque which is controlled by using Cytron MDD3A motor driver.

X. CONCLUSION

1) The project was successful in achieving its goals of designing and developing a self-balancing vehicle.
2) The vehicle has been tested for various angular positions and the results obtained satisfied the conditions of self-balancing and the vehicle maintained its stability.
3) The prototype gave satisfactory results for various conditions, The same can be implemented in normal vehicles so that the rate of accidents could be minimized which is been caused because of vehicles skidding due to imbalance.

XI. SCOPE FOR FUTURE WORK.

1) Improving and user-friendly design of the vehicle is one potential area for future development.
2) Combining self-balancing technology with other modes of transportation, including bicycles, scooters, skateboards, hoverboards, and perhaps cars, is another possible avenue for development. Depending on their interests and needs, customers may have a variety of options for their everyday journey thanks to this.
3) The self-balancing technology might also be applied in a variety of sectors, including transportation and warehousing, to transport goods and commodities more effectively and safely.

XII. ACKNOWLEDGMENT

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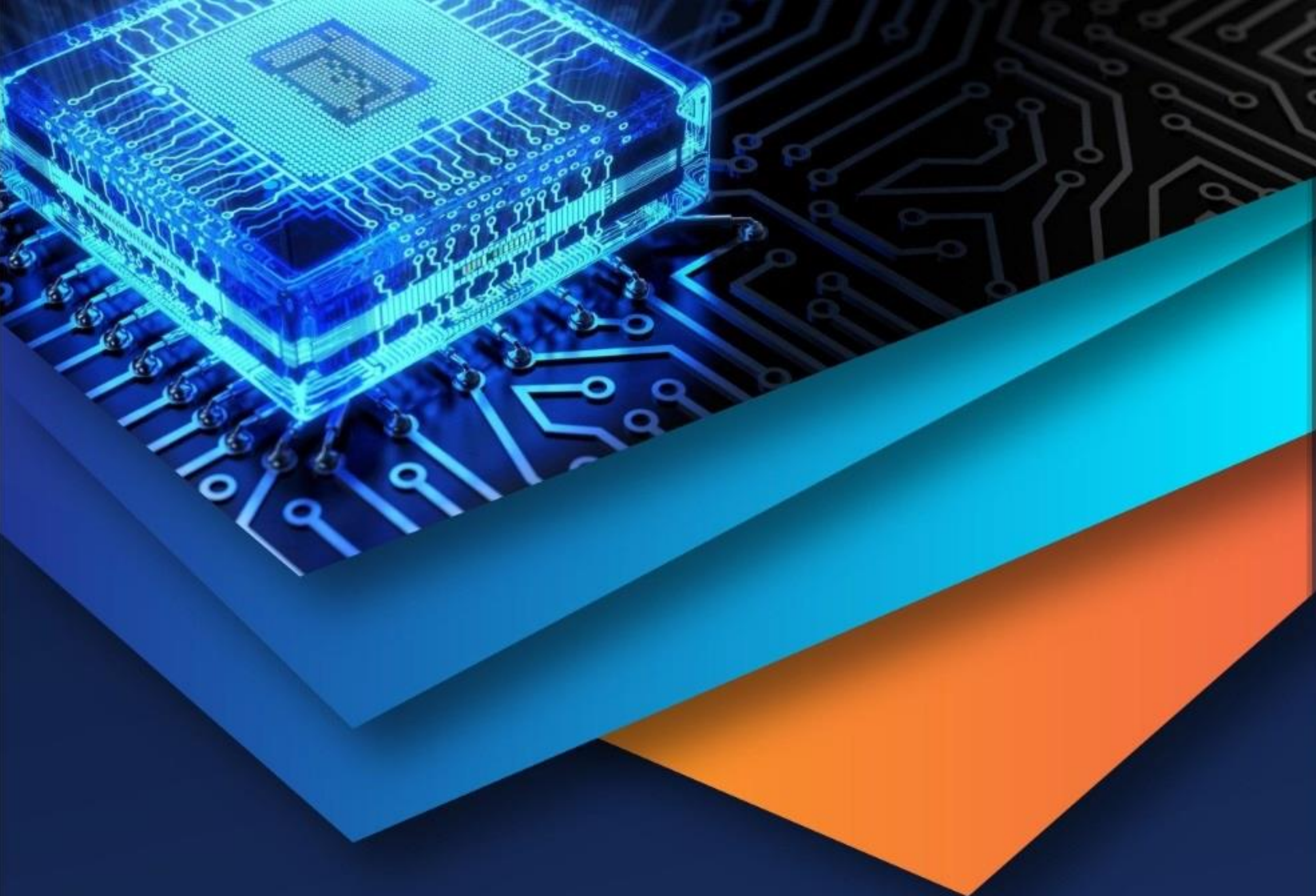

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