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Stability Control Investigation of a Self-Balancing Platform on the Robot Smart Car Using Navigation Parameters

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Stability Control Investigation of a Self-Balancing Platform on the Robot Smart Car Using Navigation Parameters

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Abstract. A self-balancing platform is constructed on a robot smart car, and its navigation parameters are investigated by running the car outdoors on a straight surface with structured bumps of 3and 5 mm in height. A ball-and-socket joint are supported at the centre of the platform, which is to be freely rotated with the lateral and longitudinal movement of the platform and in each axis, is controlled by three servomotors. Which move according to the recorded data movements from a gyro-accelerometer sensor which controlled by an Arduino UNO. The SimMechanics Matlab simulation helps to give the initial values of all parameters and the additional unexpected signals due to the influence of bumps on the vibration signals, with the proportional-integral-derivative (PID) controller, used to control the relationship of the rapid simulation of the robot smart car and mathematical model between platform and car shock absorber system with respect to the servomotor's rotation angle. These bump is more effective on the pitch and roll angle values when compared to other parameters, with more than 815 degrees and error up to 35 degrees due to vibration signals, and the time required for stabilization increases due to the bump height and the navigation parameters, roll angle from 2 to 6 in mean change value 2 , yaw angle from 43 to 59 in mean change value 8 and pitch angle from 1 to 2 in mean change value 0.5, which indicates that yaw, roll and pitch angle have variation changing in Mission Planner software

Keywords— Stability control, PID controller, Arduino UNO, Self-balancing platform, SimMechanics Matlab .

1. Introduction

Kalman Filter and fitting the mixture of Gaussians is introduced, to decrease the impact of IMU noise are based in one an algorithm, and the results achieve a high accuracy with error is not more 1%, and is immune to electromagnetic interference. The powerful of the low-cost embedded IMU, and GPS could be an Intelligent Vehicles and tracker software which supported by information given from accelerometer and gyroscope [1].

Two-wheel self-balancing robot is constructed using a low-cost components, and controlled with a pair of DC-motor, an Arduino microcontroller board, a single-axis gyroscope, and a 2 axis accelerometer added to determinate the attitude. kinematic parameters is determined experimentally; PID -control is designed to satisfy the requirements of study [2], a new model is built with an addition of two long arms in the center of a four-wheel drive robot, these arms allow it to stand-up for balancing and navigate stairs. The experimental data on the real robot is shown with a single extra degree of freedom increases the field capabilities of self-balancing robots [3].

This Self balancing car robot unit runs with a PID control loop which improves the stability of the system. On different surfaces, car robot was tested and analyze the stability of the system in a real-time data plot is done in MATLAB and filtered angle versus time by using PID controller, the results show that surfaces like soft rubber is enough and the most suitable surface to be slightly compressed by the weight of the car robot [4] and with F450 Flame Wheel frame kit is assembled mainly with an AurdoPilot type Mega APM 2.6 controller and the Mission Planner as a ground station software. The GPS coordinates accuracy in comparing with the actual measurements has been investigated with Google Satellite coordinates, than the Google earth images with error within the range (0.1 - 5) meters , However, controlling is not so easy to put it into wide scale civilian applications [5].

These model of the robot some time is constructed based on the Lagrangian function, relies upon dynamic balancing systems for balancing and maneuvering for balancing robots , which based on inverted pendulum configuration. DC motor attached to the base frame of the robot which helps for maneuvering , tilt and accelerometer Sensors are used for balancing [6]. Advanced development in the field of robotics is studied with a self-balancing robot which is based on Inverted pendulum theory. An efficient micro controllers and sensors for control system is used to stabilize an unstable system [7] and for local path planning, the Jump Point Search (JPS) algorithm is adopted, and an Information System map is used with consideration of including Global Positioning System position. The optimal safety path is done successfully, and it has a lower time complexity compared with the Vector Field Histogram [8].

The signal processing aspects of position and orientation estimation are studied and used microelectromechanical system with inertial sensors are used and have become widely available, due to their small size and low cost as 3D accelerometers and 3D gyroscopes, inertial sensors are combined with models and additional sensors [9], which very important in design of an autonomous underwater vehicle, which is designed to move quickly without collision and cooperate with the other AUVs, to find the target with the self-organizing map (SOM) neural network is used to build dynamic alliances in real time for getting a good tracking short way cooperated with navigation parameters [10].

The increasing of mass structure weight should be given decreased in eigenvalues and increasing in stresses concentration in the mass positions on the truss structure, which effect on the vibration parameters during the motion of the mass. Therefore the study should not be taken high velocity of mass in the model and if will take a long period of time, there can be a loss of precision solutions [11].

2. Mathematical Modeling Simulation using SimMechanics

The IMU sensors are fixed by the physical orientation of the sensors, and the IMU sensors axes are called a IMU-Fixed frame and all the sensor outputs are referenced to this frame. for the position measurement (x, y, z), the Earth-Fixed frame and utilizing a moving non-inertial frame (u, v, w), IMU Fixed frame with its axes parallel to the IMU sensors axes. A gyroscopes outputs and the accelerometers and magnetometers outputs can combine the advantage of the short-term precision of the gyroscopes and the long-term stability of accelerometers.

The mathematical modeling relationship between platform and servomotor rotation angle is formulated, and the length of the links (L1, L2 and central linkL3) are joining the platform with a motor links (Sr1 and Sr2), which are connected with servomotor shafts are of dimension 12 cm and 3 cm respectively. Servomotor is positioned with an offset length (L3) of 12 cm from center of cart in both the axes [10, 12]. Every time step we are able to know the Euler angles α,φ,θ can keep the order of rotation and follow it every time step as follows:

$$\Delta\theta\left(n+1\right)=\Delta t\times\left[\frac{\dot{\theta}}{2}\left(n+1\right)+\frac{\dot{\theta}}{2}\left(n\right)\right]\ldots\ldots\ldots\ Yaw\ angle \tag{1}$$

$$\Delta\varphi\left(n+1\right)=\Delta t\times\left[\frac{\dot{\varphi}}{2}\left(n+1\right)+\frac{\dot{\varphi}}{2}\left(n\right)\right]\ldots\ldots\ldots\ Pich\ angle \tag{2}$$

$$\Delta\alpha\left(n+1\right)=\Delta t\times\left[\frac{\dot{\alpha}}{2}\left(n+1\right)+\frac{\dot{\alpha}}{2}\left(n\right)\right]\ldots\ldots\ldots\ \mathrm{Roll}\ \ angle \tag{3}$$

Where:

$\Delta\theta$: denotes the incremental angle around the W-axis.

$\Delta\varphi$: denotes the incremental angle around the V-axis.

$\Delta\alpha$: denotes the incremental angle around the U-axis.

Δt: denotes the time step, and n is the time index.

Note that the trapezium rule has been used in equations as numerical integration method. The rotations matrix denoted as M around each particular axis as:

$$M(W,\theta,n+1) = \begin{bmatrix} cos\Delta\theta(n+1) & -sin\Delta\theta(n+1) & 0 \\ sin\Delta\theta(n+1) & cos\Delta\theta(n+1) & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{4}$$

$$M(V,\varphi,n+1) = \begin{bmatrix} cos\Delta\varphi(n+1) & 0 & sin\Delta\varphi(n+1) \\ 0 & 1 & 0 \\ -sin\Delta\varphi(n+1) & 0 & cos\Delta\varphi(n+1) \end{bmatrix} \tag{5}$$

$$M(U,\alpha,n+1) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos\Delta\alpha(n+1) & -sin\Delta\alpha(n+1) \\ 0 & sin\Delta\alpha(n+1) & cos\Delta\alpha(n+1) \end{bmatrix} \tag{6}$$

The general rotation matrix:

$$Rotation(n+1) = M(W,\theta,n+1) \times M(V,\varphi,n+1) \times M(U,\alpha,n+1) \tag{7}$$

The following formulas are used

$$\begin{aligned} pitch = atan2(-m20, sqrt(m21*m21+m22*m22)) \\ yaw = atan2(m10, m00) \\ roll = atan2(m21, m22) \end{aligned} \tag{8}$$

The proportional, integral, and derivative terms are summed to calculate the output of the PID controller. Defining u(t) as the controller output, the final form of the PID algorithm is:

$$u\,(t) = k_p \times e\,(t) + k_i \int_0^t e\,(t)dt + \; k_d \frac{de}{dt} \tag{9}$$

Where:
K_p: Proportional gain, a tuning parameter.
K_i: Integral gain, a tuning parameter.
K_d: Derivative gain, a tuning parameter.
e_t:Error function corrected with navigation parameters.
t : Time or instantaneous time.

The PID controller is used and tuned by varying these constants K_p ,K_d and K_i and optimizing them. In simulation analysis the SimMechanics is used Figure 1, and the mass and the inertia tensor elements are increased by the same rate when the increment unit mass is up to 15 g, and the inertia tensor is normalized according to this mass unit. so this increment unit and a normalized inertia tensor are to be used in the analysis, and the actuators should be not saturate due to their position and velocity limits, and the input signal of platform motion in terms of accelerations, all of these because to the inverse kinematics function of the system, in order to put the specification verified kinematically, since the motors may saturate due to their position and velocity limits, Variation in angle K_p= 0.85, K_i= 3.2, K_d= 0.1(Balancing Condition).

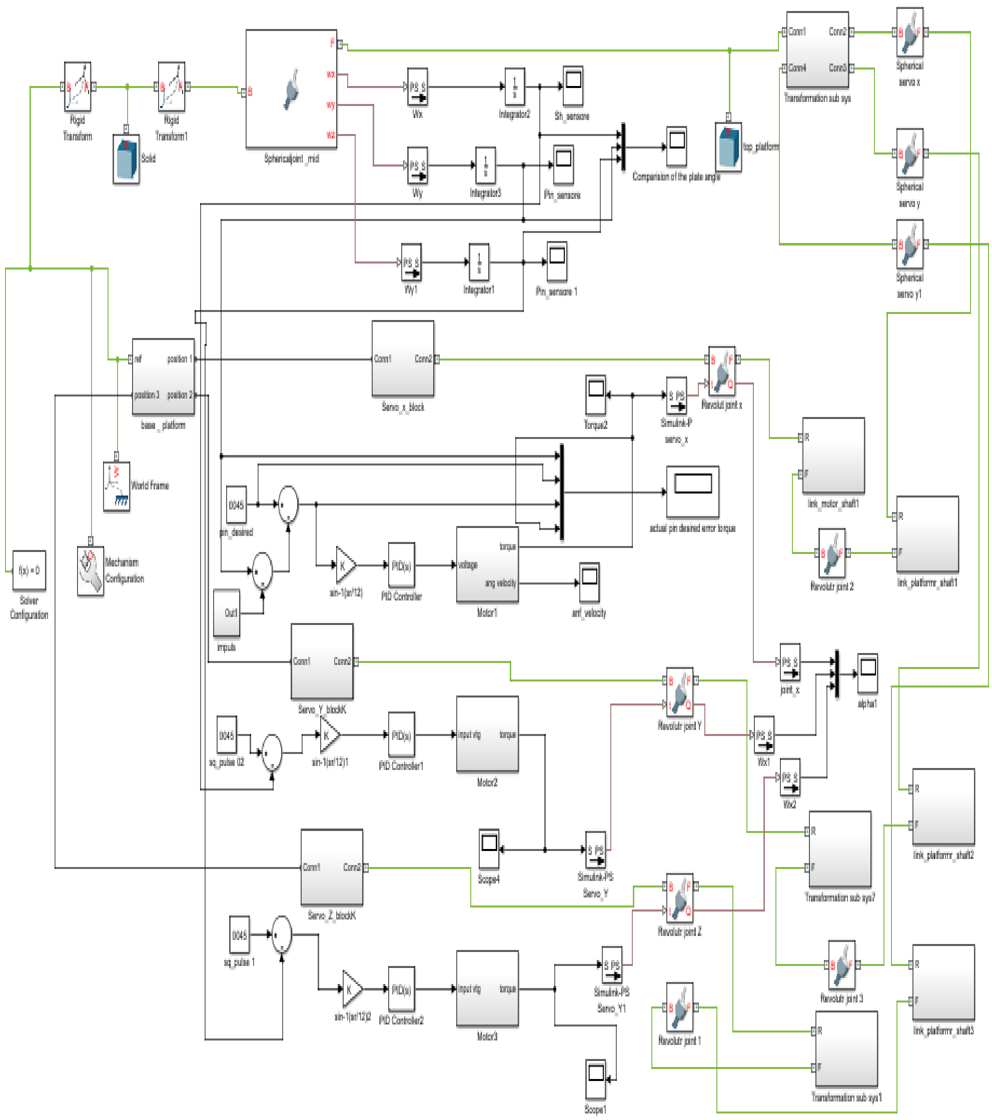

Figure 1. Self-Balancing System Control Model simulation by SimMechanics.

3. Experiment of Physical Modeling of Robot Smart Car

The platform is constructed above the Robot Smart Car and connect the controlling practical parts with it and programming them together to make the system as shown in Figure 2, the platform that works with the movement of the Robot Smart Car which is vibrated because of the unstable movements, these vibration parameters with navigations of location are measured and controlled for a platform self-balancing and comfortable movements. Arduino Uno is a microcontroller board based on the ATmega328P is used Figure 3, the GY-521 MPU6050, 6 DOF 3-Axis Gyroscope and Accelerometer, carrier board based on the MPU-6050 sensor, this sensor contains a MEMS accelerometer and a MEMS gyro in a single chip, at the same time the Micro Electro-Mechanical Systems (MEMS) captures x, y, and z channel. This helps to measure acceleration, velocity, orientation, displacement, and other motion parameters of the system. The schematic of GY 521 connection with Arduino UNO and the electronic circuit of GY 521 as shown in Figure 4.

The sensors are exactly in the same as APM flight controller, for measurements the navigation parameters, however this has an option to be used for built in the compass, with accelerometer, gyroscope sensor which used to detect the attitude of the vehicle (pitch , roll , yaw) by using gyroscope and the

Figure 2. Robot Smart Car with a Constructed Platform.

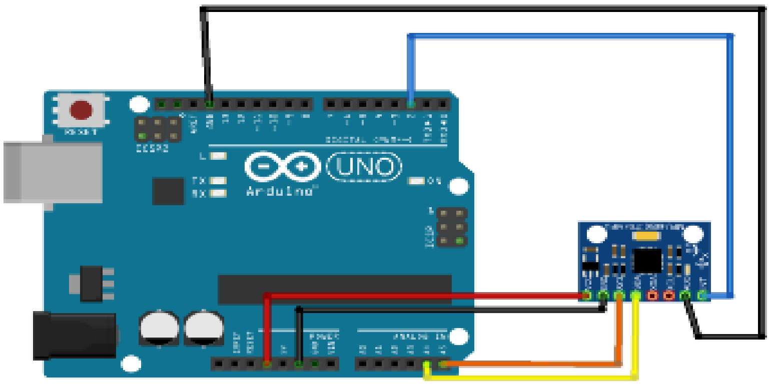

Figure 3. The Connection Gyroscope with Arduino UNO Pins.

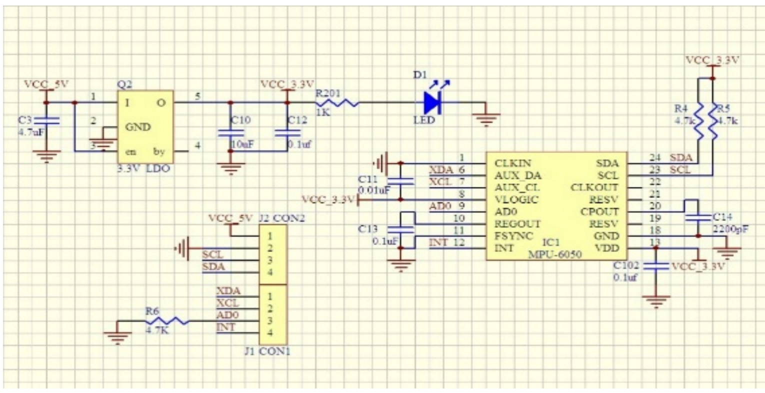

Figure 4. The Electronic Circuit of GY 521.

vibration in x, y and z axis by using accelerometer, which are used to calculate the least vibration happening on the body of car and handle the error and minimize it . An collection navigation system is used in a small car sample designed for self-balancing and self-guidance control under previously prepared programming. The APM 2.8 is a complete open source for autopilot system, and it is connected with others parts in this system as shown in Figure 5 as an unmanned aerial vehicle system competition, which allows the user to turn any fixed, rotary wing or multi rotor cars and boats, into a fully autonomous vehicle and capable of performing programmed missions with waypoints by GPS , the Mission Planner software is used and very powerful measuring the navigation parameters, and more flexibility in positioning location, so that GPS/Compass unit can be mounted further from the noise sources than APM itself. All the Measurement is taken and recording from the sensors, creating platform motion demand for self-balancing, inverse kinematics solution, generating and delivering control output signals to the drivers are done by Arduino UNO in real-time connected with servomotor expects a coded signal with every few seconds for required balancing displacements. The servo motor that we have selected has a torque of 15kg/cm, operating voltage of 4.8 V to 6 V, speed of 60 degree/0.20 sec, dimensions: length 49.3 mm, width-25.4mm, height-42.9 mm and weight about 80g.

The study of the navigation parameters under the vibration and control is apply the principles of navigation parameters, vibration and control navigation parameters, which coming from gyro-accelerometers and locations by GPS during the motion between different points, and understanding the control system programming using sensors for a suitable signal according to the direction guidance using navigation parameters by correction with a Mission Planner software, records navigation parameters in order to reach the stability control for x, y, and z axis with roll, yaw, and pitch angles with effect of vibrations. as shown in Figure 6, Which include the calibration of accelerometer, Radio Control, Electronic Speed Controller (ESC), Compass Calibration.

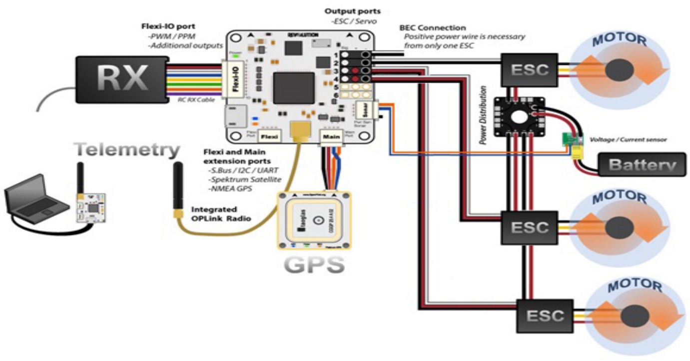

Figure 5. System Parts Connected with APM.

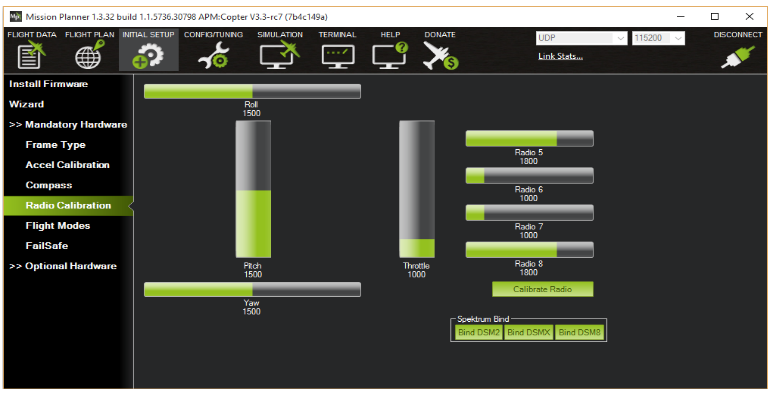

Figure 6. Mission Planner Radio Calibration Screen.

Among these problems, the vibration effect which arises for several reasons, and made imbalance state with defect in the mechanical equipment for guidance of the installation of parts in the not correct axes direction .These mechanical system vibrations cause an error in navigating parameters values during the motion of these vehicles, especially in the gyroscope and accelerometer sensor, these problems and their causes increase the cost of maintenance and repair damage if the accidents has been accrued because of the wrong resulted reading values of these devices. To solve the problem, it must to take into account the errors effected coming from the vibration and the around noises on the signals during the motion with self-balancing to re-correct the values of all navigation parameters used.

4. Results and Discussions

Table 1. PID Simulation Values.

	Roll angle	Yaw angle	Pitch angle
P	0.0832	0.0101	0.0902
I	0.0311	0.0011	0.0421
D	0.0021	0.0001	0.0022

Regarding the simulation test of Figure 7 for more than 5 mm, the system needs nearly 1.6 sec to get back to the stability state. Besides, Figure 8 shows that the pitch angle more sensitive and more effective on the system stability during the motion. The motion of robot smart car with speed bump 3 mm and 5mm height is experimented.

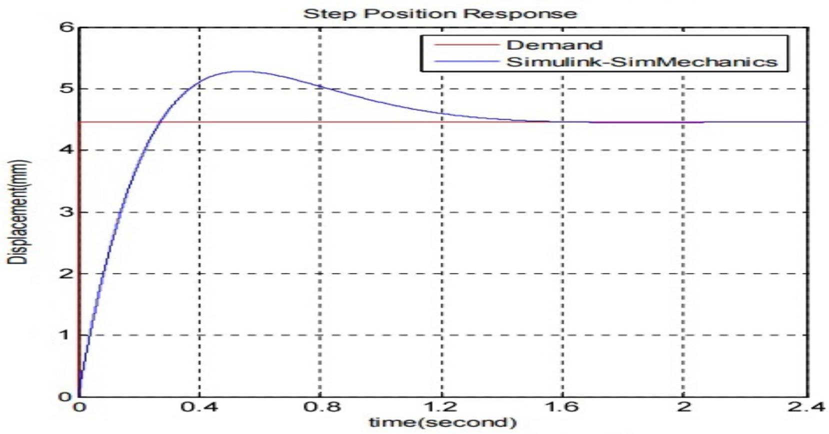

Figure 7. Servomotor Signal Simulation from Simmechanical.

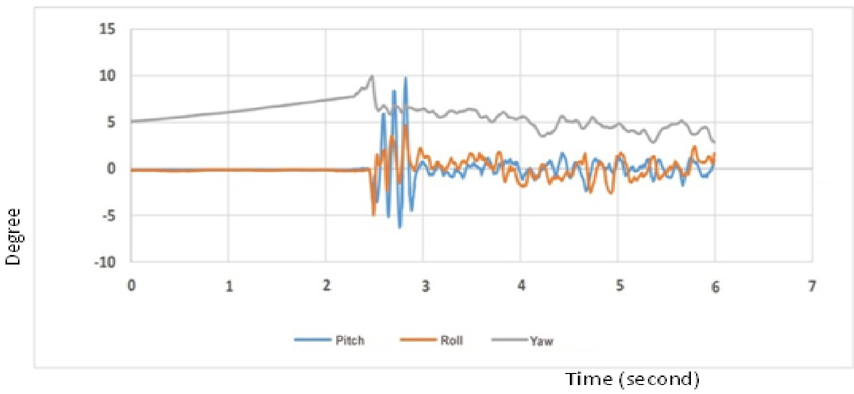

Figure 8. Gyro-Accelerometer Measurements During Random Motion with Vibration Effect.

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According to the pitch angle as shown in Figures 9 and 10, almost the angle changes as roll angle but only stable after first point to end point on the bump surface. The unbalance initializing of the platform make the angle needs to get its stabilization within 1.4 seconds. While, with bump 5 mm it takes more time for balancing and stabilizing. Therefore, it has more sensitive for any changing in the stability of the system during the motion.

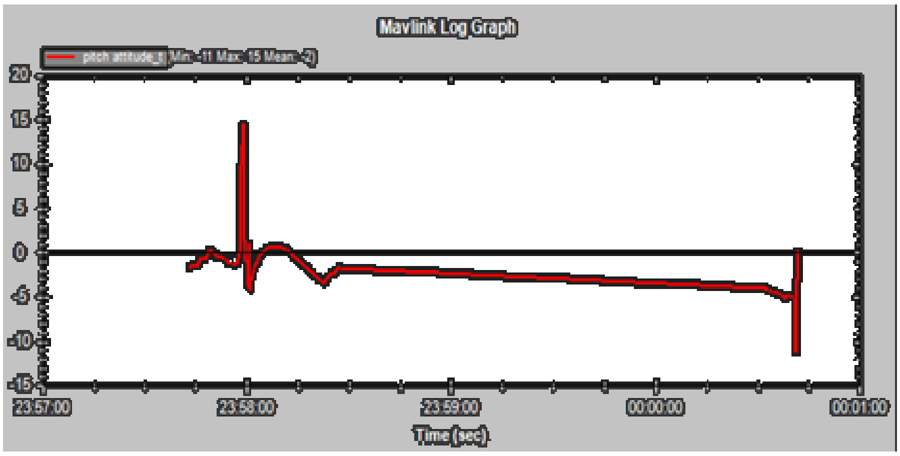

Figure 9. The Pitch Angle, pump 3 mm (Angle between the Longitudinal Axis.)

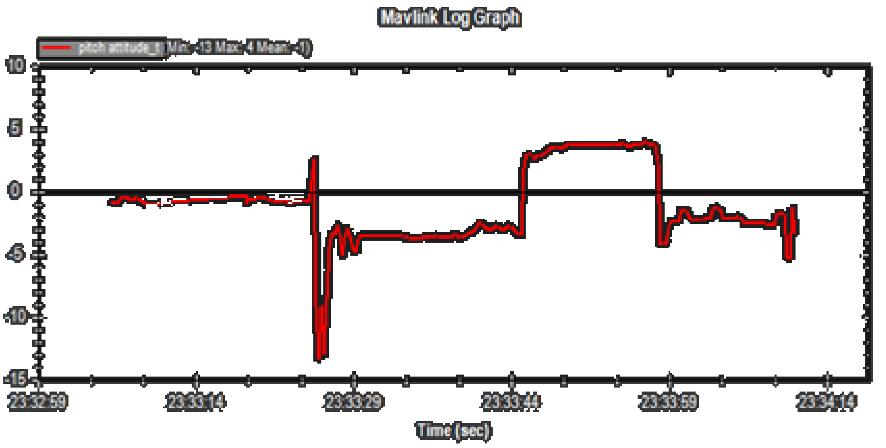

Figure 10. The Pitch Angle, pump 5 mm (Angle between the Longitudinal Axis)

Figures 11 and 12 show that the yaw angle is almost stable. The unbalance initializing of the platform make the angle needs to get its stabilization within 1.2 seconds. While, with bump 5 mm it is more stabilized because of the shape of bump.

According to the simulation results which is specified by the roll angle as shown in Figures 13 and 14, the angle changes between the three angles due to the moving of the vehicle with 3 and 5 mm steps. But, it has not more effect on the stabilization of the system, which starts from initialization state, then start moving, unbalancing of the platform and back to the stability initial value, This process occurs because of the vibration effect had suppled on the surface of motion and the roll angle needs to get its stabilization within 2.1 seconds. Moreover, in case of the bump 5 mm, it has nearly the same time for balancing and stabilizing with bump 3 mm.

The correct values have got from Micro Electro-Mechanical Systems which has been indicated in Figure 15 taking into consideration the vibration and noise signals effect. It has noticed that the sequences pitch,

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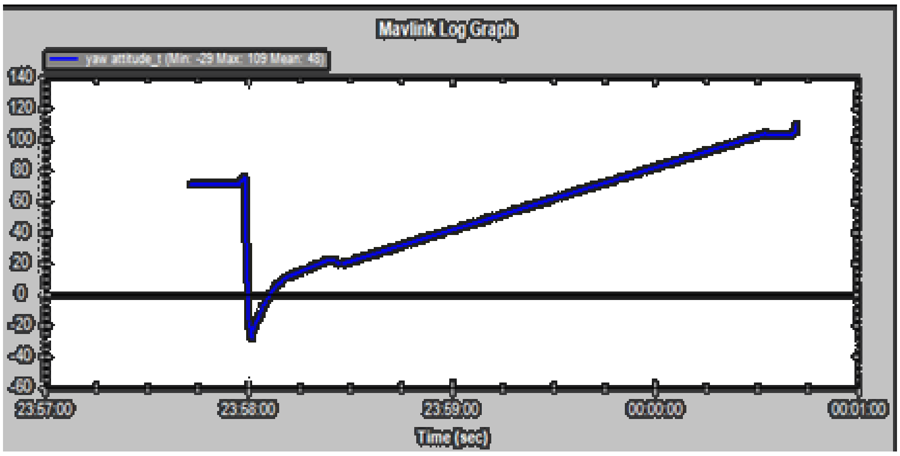

Figure 11. The Yaw Angle, pump 3 mm (Angle between the Vertical Axis).

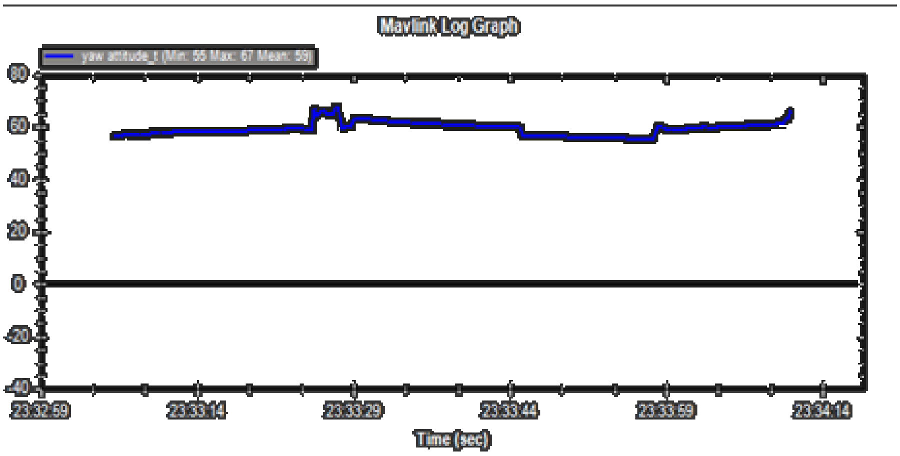

Figure 12. The Yaw Angle, pump 5 mm (Angle between the Vertical Axis).

Figure 13. The Roll Angle, pump 3 mm (Angle between the Lateral Axis).

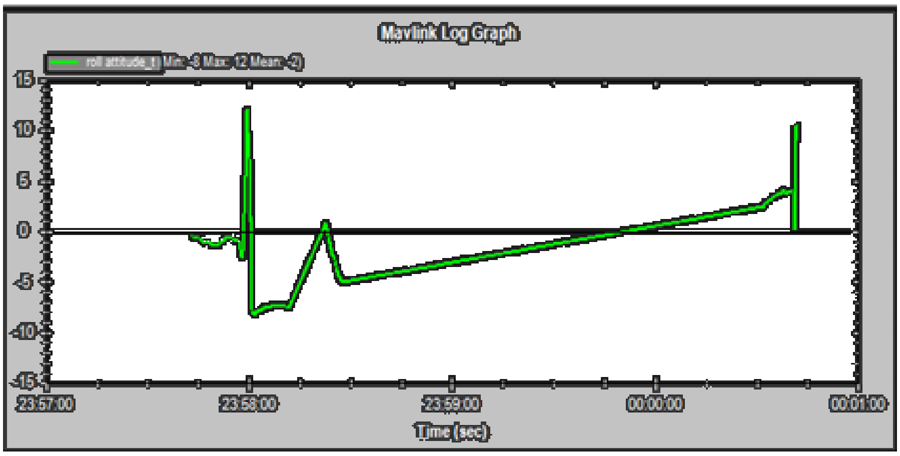

Figure 14. The Roll Angle, pump 5 mm (Angle between the Vertical Axis).

roll and yaw angle have variation change, which should be taken by PID controller for correction stability of the platform.

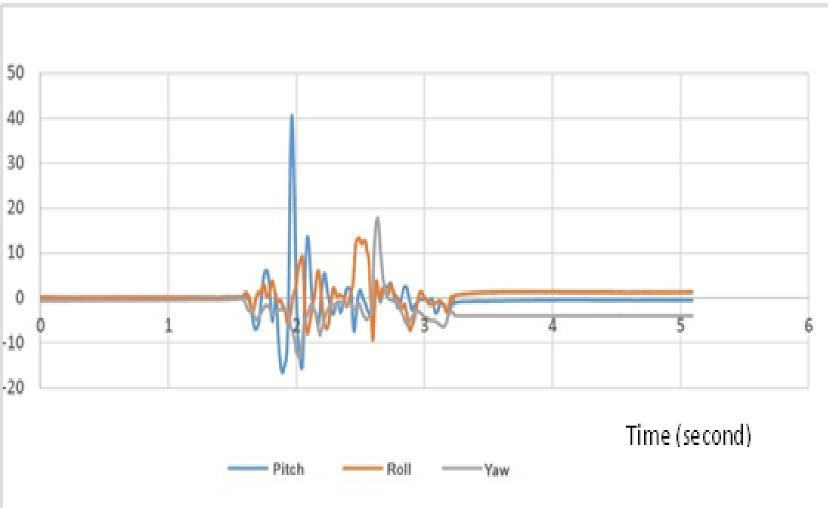

Figure 15. Gyroscope Measurements During Random Motion with Anti-Vibration System Effect.

5. Conclusion

The most critical frequency is the lowest frequency because of the input signal of platform motion in terms of accelerations in that frequency. The PID controller is suitable than PI or PD according to this application which selected before choosing the type of controller based on previous works with an initial acceleration for 3-axis directions as X $= 0.1$ m/s^2 , Y $= 0.1$ m/s^2 and Z $= 0.1$ m/s^2 . The roll and pitch angles are limited to 45 degrees and the yaw angle is limited to 180 degrees. It was able to balance the car smoothly with a maximum roll and pitch angle error of 3-5 degrees. The balancing was also determined with some limitations. Keeping in mind, without a significant movement its unable to get the balancing by car itself after bump step position within a range of -1 mm and +1 mm around the balancing spot in order to balance itself on the flat surfaces. Among these problems, the vibration effect which made imbalance state with defect in the mechanical equipment for guidance of the installation of parts in the not correct axes direction.

References

[1] Almazan J, Bergasa LM, Yebes JJ, Barea R, Arroyo R. Full auto-calibration of a smartphone on board a vehicle using IMU and GPS embedded sensors. 2013 IEEE Intelligent Vehicles Symposium (IV) [Internet]. IEEE; 2013 Jun; Available from: http://dx.doi.org/10.1109/ivs.2013.6629658.

[2] Juang H-S, Lurrr K-Y. Design and control of a two-wheel self-balancing robot using the arduino microcontroller board. 2013 10th IEEE International Conference on Control and Automation (ICCA) [Internet]. IEEE; 2013 Jun; Available from: http://dx.doi.org/10.1109/icca.2013.6565146.

[3] ROBILLARD, Dominic; LANTEIGNE, Eric. Development of Compact Self-Balancing Robot with Self-Standing and Stair-Climbing Capability.2013.CCToMM Mechanisms, Machines, and Mechatronics (M3) Symposium.

[4] Jisha Kuruvilla , Jithin Abraham, Midhun S , Ranjini Kunnath , Rohin Reji Paul.Two Wheeled Self Balancing Robot For Autonomous Navigation.2014. INTERNATIONAL JOURNAL OF ELECTRICAL ENGINEERING and TECHNOLOGY (IJEET), Volume 5, Issue 8, pp. 13-20.

[5] ABDULMAJEED, Wael R., ATHAB, Omar A., SATTAM, Ihab A. Implementation And Evaluation Of Apm 2.6 - Controlled Quadcopter With Aerial Imagery As A Case Study.2016.Journal of Engineering and Applied Sciences, Vol. 11, No. 19, October 2016.

[6] Srinath. G, V. P. Haridasan. Two-wheeled self-balancing autonomous robot. 2016. Journal of Chemical and Pharmaceutical Sciences, Department of Mechanical Engineering, SRM UNIVERSITY Kattankulathur Chennai -603203, JCPS Volume 9 Issue 4, 2016.

[7] SHAON, AKM Asfaque Shakil, et al. Design And Implementation Of A Self-Balancing Robot.2017. Proceedings of the International Conference on Mechanical Engineering and Renewable Energy 2017 (ICMERE2017) 18 20 December, Chittagong, Bangladesh, 2017.

[8] Zhou K, Yu L, Long Z, Mo S. Local Path Planning of Driverless Car Navigation Based on Jump Point Search Method Under Urban Environment. Future Internet [Internet]. MDPI AG; 2017 Sep 12;9(3):51. Available from: http://dx.doi.org/10.3390/fi9030051.

[9] Kok M, Hol JD, Schn TB. Using Inertial Sensors for Position and Orientation Estimation. Foundations and Trends in Signal Processing [Internet]. Now Publishers; 2017;11(1-2):1153. Available from: http://dx.doi.org/10.1561/2000000094.

[10] Ni J, Yang L, Shi P, Luo C. An Improved DSA-Based Approach for Multi-AUV Cooperative Search. Computational Intelligence and Neuroscience [Internet]. Hindawi Limited; 2018 Dec 2;2018:113. Available from: http://dx.doi.org/10.1155/2018/2186574.

[11] ABRAHEM, Hussain Abdulaziz; HASSOUN, Enaam Obeid. A Variation Method In Simulation Of The Slow Moving Concentrated Mass On Truss Structure.2015.Iraqi journal of mechanical and material engineering. 15(1): 1-11.

[12] Skrobek D, Cekus D, Zajc T. Control of the mobile robot using controllers of types P, PI, PID. Journal of Applied Mathematics and Computational Mechanics [Internet]. Czestochowa University of Technology; 2018 Mar;17(1):6978. Available from: http://dx.doi.org/10.17512/jamcm.2018.1.07.