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Development and Evaluation of a Low-Cost Dynamic Motion Platform for Investigating Inertial Measurement Unit Behavior Using the MPU6050 Sensor

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Abstract: This study is based on the investigation of the dynamic movements and behavior of the MPU6050 IMU sensor under different motion circumstances, with the help of a specially designed test apparatus. The MPU6050 has three axes of gyroscopes and accelerators, which make it significant in most systems related to motion. Yet, because the outcomes of classic techniques are unrefined, they may include noisy data, stray statistics and errors in measurement. The motion platform was designed to use an Arduino, various servo motors, ultrasonic sensors and a system to record effects of impacts. The device can reproduce both straight and curved movements, set to different tilt levels (for instance, 60°), allowing real-time measurement of acceleration and angular displacement. Results from the sensors showed that large discrepancies were found in roll measurements when the aircraft moved and turned, compared to changes in pitch and yaw. In this study, the value of gravity and dynamic motion is highlighted, and it introduces a practical strategy for setting up and correcting the output values from IMU sensors. Results from experiments make it simpler to create and improve motion-sensitive systems in robotics, navigation and stabilization.

Keywords: Inertial Measurement Unit (IMU), MPU6050, Dynamic motion testing device

Introduction

Air and maritime vehicles, various tracking devices, stabilization systems, robotics, biomechanical applications and similar are all important to the attitude estimation done by inertial measurement units (IMUs). Since they rely on MEMS, Inertial Measurement Units (IMUs) are available to many users and useful in numerous industries. Most of these devices include accelerometers and gyroscopes for measuring movement accurately in one direction or in rotation. Most of the time, they are used to observe and detect movements in several navigation and maneuvering setups, including those of aircraft. Number of authors got precise directional and speed data from vehicles and robots (Krishna & Rao, 2016; Malik et al, 2022; Preston et al, 2018). Data measured by an accelerometer is easily contaminated by noise caused by vibrations and by gravity. Drift in gyroscope data results from warming and accumulation of data collected over a duration. Several approaches have been designed to reduce both random and systematic errors in order to get accurate information from measurements.

- Selection and peer-review under responsibility of the Organizing Committee of the Conference

For this job, I used a specially created tool to test the MPU6050 sensor which reports linear and angular velocity. Many techniques to correct these ongoing errors have been analyzed and put to the test, so the system effectively tracks body motion. Various methods have been designed by researchers to resolve both types of errors caused when reading from the MPU6050 (Redhyka et al, 2015; Jouybari et al, 2017). Deterministic errors happen when measurements or biases are not accurate or when the inertial measurement unit (IMU) is not correctly aligned. Some of these errors can be caused by problems in sensor design, with manufacturing or because the unit was not properly aligned when installed on the object. With laboratory calibration, these problems can be resolved.

We have designed a testing device in this paper that lets us measure the performance of an MPU6050 sensor via Arduino technology. Since Arduino uses open-source technology, it is designed for prototypes and makes it simple to move between software and electronic components. Hundreds of thousands of designers, engineers, students, developers and innovators around the world use it in many areas like music, gaming, making smart homes, farming, self-driving vehicles, artificial intelligence and so on.

According to Nadeem (2024), this research introduces a two-doF mobile platform that stabilizes itself on uneven or moving surfaces, thanks to clever design and affordable components. You can use the developed self-stabilizing control system in medical equipment, military systems and devices for logistics, as they need to be stable on uneven ground outdoors. Within two degrees of freedom, its mechanical design makes it stable as it moves. All control is done via an Arduino UNO and the movement in the X and Y directions is managed by servo motors. Using an advanced algorithm, the system examines digital data from the gyroscope to figure out how the system is currently angled. A complementary filter is added after that to improve the signal and decrease noise and then the tilt angle is controlled by a proportional controller. (M. Pokydko,2024) investigated an accurate and convenient method to implement a MEMS gyroscope by using the MPU-6050 triaxial inertial measurement unit together with the ATmega328 microcontroller.

This research aims to connect the functional blocks over I2C, so the calibration of the gyroscope sensors works well and the zero offset has been fixed in all orthogonal axes, lowering measurement errors. An examination of the electromechanics of gyroscopes revealed that how vibrating systems respond can differ. Besides, improving how the sensors were treated and developing an error model considering sensor nonlinearity led to lifting the accuracy of measurement to less than 1%. The new advancement leads to a better performance of the gyroscope which helps ensure accurate measurements in sensitive uses. Describe the design of a self-stabilizing platform that makes use of the MPU-6050 as an Inertial Measurement Unit (IMU). The use of an ARM processor and two high torque motors enable us to keep the platform horizontally steady when the orientation of the structure shifts. An IMU is used to measure how a body changes position and angle. Here, we use the MPU-6050 as the IMU, which has a built-in accelerometer and gyroscope to provide six degrees of freedom. The logic behind the software part is the conversion of digital data obtained from the MPU-6050 into positional acceleration and angular velocities, followed by filtering the data and calculating the platform's orientation (in the form of angles) using some predefined mathematical functions. Then, the orientation is converted into angular rotation and finally into PWM signals to control the motion of the servo motors (Tripathi,2019).

In this study, MPU 6050 sensors are employed to read and process data and implement it as a tilt sensor in one axis balancing model which is a combination of an accelerator and a gyroscope sensor. The sensor was meant to be read by a Kalman filter, which helps to refine the accuracy of the sensor read, thereby decreasing drift (and other effects that can affect the accuracy of measurements) like small signal variations due to motion. The ATMega328P chip, which is mounted on Arduino Uno control board, was used to implement the filter. This research is important in minimizing errors created by drift and tilt in motion sensors thereby enhancing precision in mechatronics especially in small systems like humanoid robots and drones. The results obtained after experimentation were compared with the reference data obtained by using the exact calibration instruments, and the results were in good agreement with the reference data. The findings show that the system is capable of giving credible data that is characterized by a low response time which can be useful in the real world in the future.

The design and implementation of a low-cost Inertial Measurement Unit (IMU) by the Arduino environment to compute the roll, pitch and yaw angles of drones. This unit is dependent on in-built MEMS sensors, which are an accelerator and a three-axis gyroscope to present six degrees of freedom of movement(Pham,2021). The paper has shown that incorporating these sensors through an open software platform like Arduino offers the possibility of developing a cost-effective and efficient sensing platform that can be applicable in aerospace and aviation applications due to the presence of embedded computing in the microcontroller (Kumar, 2023). The researchers had to use MPU-9250 sensor, an MPU-6050 sensor on it, which includes an accelerator and three-axis gyroscopes, because of the lack and inadequate distribution of seismic monitoring stations, particularly in the regions around volcanoes. Simulated seismic signal calibration showed that the sensor can detect the movement of particles with a similar magnitude as those of natural earthquakes, which means that the sensor could be an effective and inexpensive component in seismic monitoring systems in developing countries (Palevi, 2024). One of the latest research works concerns the design and development of wearable inertial measurement unit (IMU) that can be used in various fields (healthcare, sports and motor rehabilitation).

This research is aimed at addressing the short-term motion analysis needs, including the high frequency signal sensing and the long term, low-frequency needs, by a low-cost, flexible motion monitoring device. The outcomes of the evaluation prove the significance of the deviation, noise, and accuracy analysis to secure a good performance, along with the requirements to improve the performance and provide a smart design that will be able to track human movement in general, with energy and storage efficiency. The study is a step in the creation of versatile sensors, although the literature on this topic is limited and does not cover an evaluation of performance to such a great extent (Valdés Tirado, 2024). The study has created an inertial sensor-based anemometer to measure the wind speed in northeastern Brazil that supports the technologies of renewable energy generation.

The experiment involved a sequence of experiments to adjust the machine, the sensor noise, and to process the data recorded by the sensors in the process of observations. Calibration was performed in three steps, namely noise analysis, inertial data analysis and calibration curve extraction, with sampling rate of 10 Hz. The findings indicated that the inertial sensors used in determining the speed of the wind can be applicable in the application of the wind system, although there are quite a considerable variation in the prototype measurements. In order to minimize these variations, a three-value moving average filter was used. The K-NN algorithm was subjected to defining an accurate relation among the measured information and the reference data, indicating that is remarkably proficient in enhancing the quality of the estimates (Americo, 2025).

Method

Experimental Framework

Dynamic motion devices are built around the Arduino-Uno, which represents the central processing unit (CPU), as shown in Figure 1. MPU6050 sensor is used to measure the acceleration and angular orientation of the object that is attached to it (platform). The ultrasonic sensor is used to measure distances of lift and down of the platform by emitting sound waves to detect obstacles and calculate distance (0-10cm). To rotate and adjust the position of the platform at different angles (40, 60, 90, 180) we used a two-servo motor controlled by two potentiometers. 16x12 LCD screen used to display the reading of the MPU6050 gyroscope. Also, an SD card module is used to store sensor readings (acceleration, distance, and angles of the servo motors).

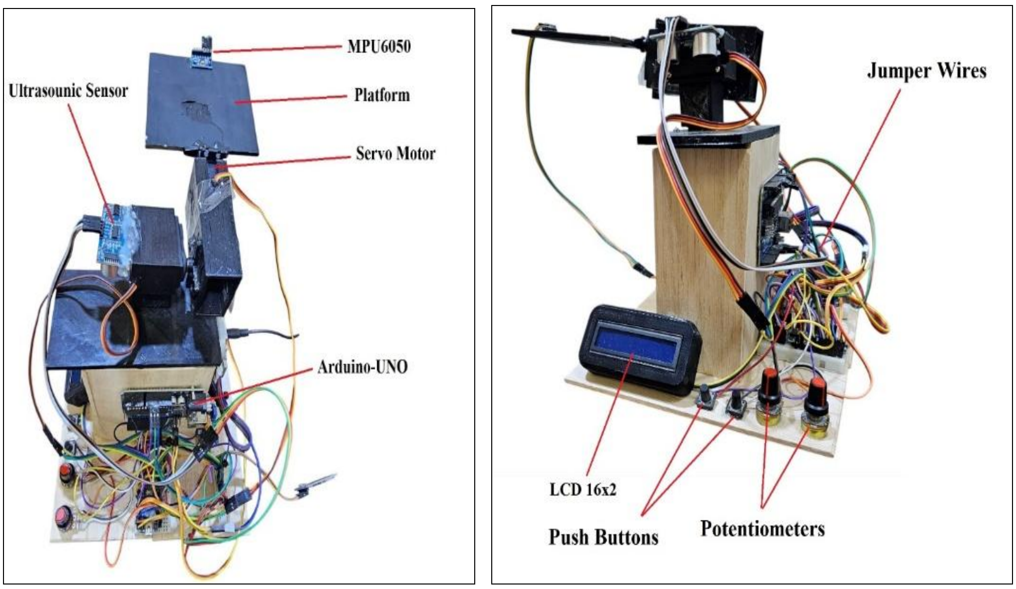

Figure 1. Dynamic motion testing device

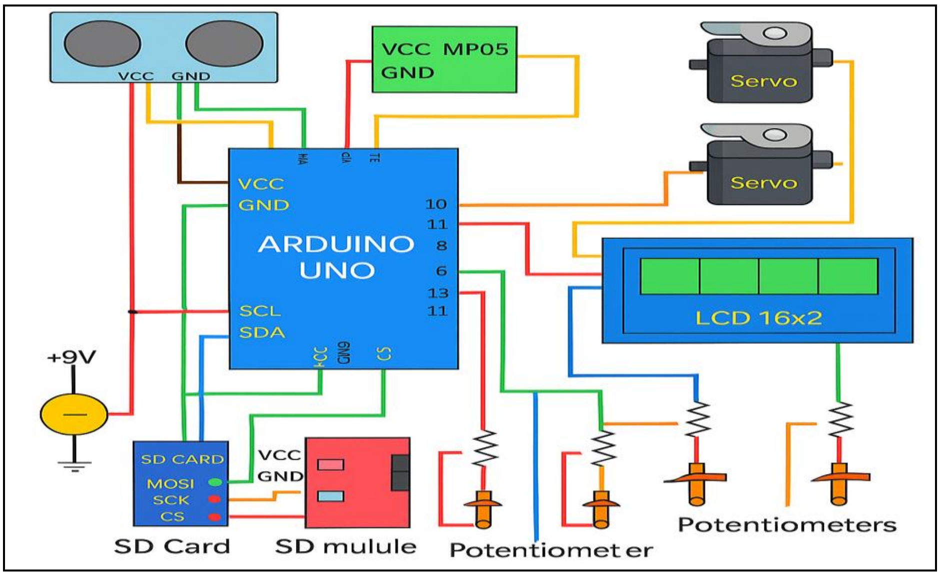

Figure 2. Schematic diagram of the dynamic motion testing device

Tools

Dynamic motion testing device integrates a combination of multi-Arduino components which mentioned above, all working together to facilitate controlled motion testing. The test dynamic motion device is a crucial tool in modern engineering, such as:

a. Arduino-Uno

In a test motion device, the Arduino-Uno processes the signals from the actuators (servo motors and stepper motors). It is based on the ATmega328P process and contains 14 digital pins and 6 analog pins used as output and input to the Arduino board.

b. MPU6050

Both the gyroscope and accelerometer offer unique advantages, but when combined, they provide highly accurate data on an object's orientation. This is where the MPU6050 comes into play. Both a gyroscope and an accelerometer are included, so information about how it moves and how much gravity pulls it down are captured. There is a need to know what accelerometers and gyroscopes entail prior to the integration of MPU6050 into an Arduino project. Our Test Motion Device mounts the MPU6050 on a moving platform and drives it with the help of servo motors. Due to such motors, the sensor can be shifted and turned, and thus we can examine what positioning changes lead to. Consequently, this system is suitable to researche the motion processes and to develop more realistic systems in the practical issues.

c. Servo Motor

A servo motor largely determines the motion of the platform equipped with MPU6050 sensor. It has a 1.5 to 2.5 kg.cm torque and angles of 0º to 180º (or 360º to continuous models). The servo rotates based on PWM and at 4.8V -6 V finishes the 60 degrees rotation in an approximate of 0.1 seconds at 6 V. This control is an important device in the study of motion dynamics with MPU6050 due to the specific movements that it allows.

d. Ultrasonic sensor

The Test Motion Device requires the ultrasonic sensor to calculate the distance between a moving platform and the reference point. Using 5 V, and with a distance capable of between 2cm and 400cm, the sensor can achieve a precision of 3mm and utilizes 40 kHz ultrasonic waves reflected back in order to calculate the time taken by the sound to travel. The outcome is accurate in-the-moment platform tracking that assists in equating motion alterations to information of the MPU6050 sensor and enhance the examination of motions.

Results and Discussion

The platform (60º degree angle in the first dataset) induced evident variations in the manner in which the sensor was tracking angular displacements and accelerations on its axes. Based on the pitch curve, the platform remained nearly at 2 degrees with slight variations as it was running forward and back. The roll tilt however increased to over 98 degrees during part of the datasets which is an indication that the platform was tilted sideways due to the activity that occurred in it perhaps as a result of unforeseen movement or instability. This was the turning point of the aircraft at -8.63 degrees of the yaw angle that indicated that the aircraft was turning gradually but not a lot. In terms of acceleration, the X-axis registered an approximation of 9.31 m/s 2, i.e., the effect of gravity was majorly concentrated in this direction as the platform was inclined.

The Y-axis showed a value of -2.08 m/s², indicating some lateral influence of movement. The Z axis, on the other hand, registered 5.44 m/s², which is lower than the expected gravitational acceleration (9.81 m/s²). Since gravity isn't even now, the movement along each axis is also uneven because of the included platform. As a result of the rocket's 60-degree tilt, gravity appeared differently on each axis, so its acceleration was not the same in all three directions. A comparison of this dataset to one with a platform angle of 90 degrees should show greater differences in pitch, roll and yaw, as well as a shift in the way the forces of gravity affect the three axes. When the body changes its orientation, the output from the sensors shows how motion and sensor data are affected by platform inclination.

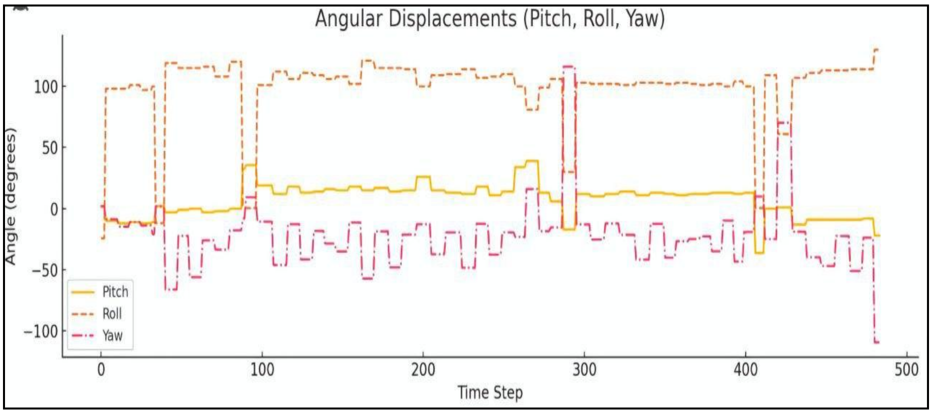

Figure 3. Angular displacements (pitch, roll, and yaw) at platform angle 60º

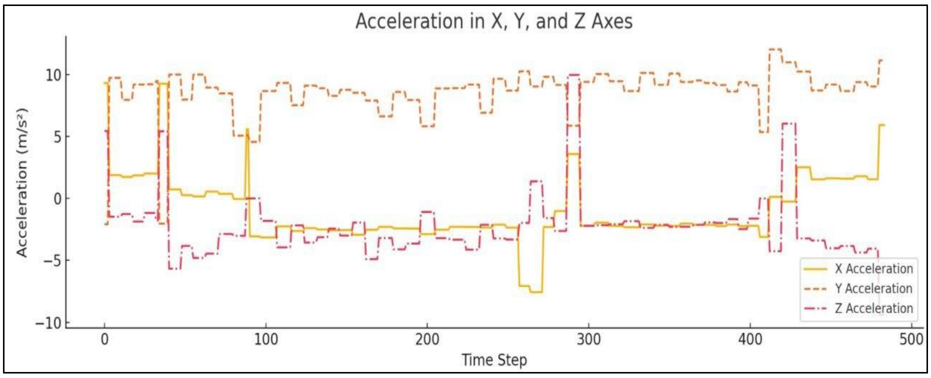

Figure 4. Acceleration (x, y, and z) at platform angle 60º

Experimental Setup

A dynamic motion testing apparatus was created to assess the motion sensitivity and performance attributes of the MPU6050 inertial measurement unit (IMU). As a result, the model involves several factors to reproduce and examine regulated linear and angular motions, helping obtain comprehensive data from many movement situations.

The main processing happens using an Arduino Uno microcontroller at the center of the circuit. An MPU6050 sensor module, combining a 3-axis gyroscope and a 3-axis accelerometer, is attached to a mobile platform that can be moved into any position. The sensor has been calculated to access real-time acceleration and angular velocity information on the three spatial axes. Two servo motors produce platform mobility, and each motor produces a rotational action at a specific axis (X and Y), enabling the platform to tilt at specified angles (40º, 60º, 90º and 180º degrees). The advantage is that the positions of the servo motor are adjusted manually by using potentiometers, which is helpful to adjust the tilt of the platform. These servo motors offer sufficient motion and torque(approximately 1.5 -2.5 kg cm) to offer consistent tilts of dynamic nature, significant to gauge sensor responsiveness in a variety of mechanical conditions.

A sensor that is ultrasonic in nature is monitored to measure the vertical movement of the platform relative to a reference surface. It works in the 2-400 cm range, with a standard error of ±3mm and its principle is that it generates the high-frequency sound waves, and the time-of-flight (TOF) is calculated by using the reflection. This sensor will assist in correlating the elevation of platforms with the sensor outputs that were taken and in cases where there are vertical motion components.

Outputs of a sensor and real-time feedback including angular orientation (pitch, roll, and yaw) and acceleration are presented on a 16×2 liquid crystal display (LCD). A safe digital (SD) card module is used to store the raw sensor data to be analyzed and verified at a later date following the experiment. With the composite system, it becomes possible to separate and examine how gravity and motion affect the performance of the IMU. The method allows for purposeful rotation of the platform and observation of the results the sensor provides. This structure supports the correction and alignment of IMU data used in robotics, navigation and systems for keeping objects steady.

Conclusion

The study effectively demonstrated the development, testing and measurement of the MPU6050 IMU using a flexible motion testing device in different motion scenarios. An approach was used to construct a platform for this research by merging an Arduino Uno, servo motors, an ultrasonic sensor and a data recording system to simulate and measure the motion of robotic systems at the required tilt angles.

It was shown during the experiment that changes in platform tilt have a strong effect on the sensor measurements of angular displacement (pitch, roll and yaw) and acceleration. The data shows that IMU measurements are sensitive to gravity and the platform's orientation, especially in roll and Z-axis components during a 60° tilt. It was proved that motion context and appropriate calibration play major roles in correctly interpreting data from an IMU.

The findings provide guidance for making IMU-based systems better in real-world applications for robots, autonomous cars, navigation and stabilizers. The analysis shows that advanced filtration and compensation are important steps to reduce drift, noise and gravity issues in MEMS sensors, including the MPU6050. Researchers could explore calibration processes in real time, combining various sensors and using machine learning to improve the accuracy of measurements when things are changing rapidly.

Recommendations

Expand the present experimentation to examine simultaneous multi-axis movements (pitch, roll and yaw) to assess the performance of MPU6050 in a more natural and complex movement condition. Look at what it does in terms of temperature, vibration, and how it performs in an electromagnetic area, especially if you're in an outdoor or industrial environment. Drone orientation correction. Biomedical human motion capturing

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

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References

Jouybari, A., Ardalana, A. A., & Rezvani, M.-H. (2017). Experimental comparison between Mahony and complementary sensor fusion algorithm for attitude determination by raw sensor data of XSENS IMU on buoy. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLII-4/W4*.

Krishna, B. S. B. V., & Rao, P. M. (2016). Implementation of two-wheeled self-balancing platform. *International Research Journal of Engineering and Technology (IRJET)*, *3*, 1237–1241.

Kumar, S. S. G., Gudipalli, A., Phang, S. K., & Pandian, B. J. (2023, December). Design and Development of an Inexpensive Inertial Measurement Unit in the Arduino Environment. In *2023 Innovations in Power and Advanced Computing Technologies (i-PACT)* (pp. 1-5). IEEE.

Lupitha, M., & Haryono. (2022). Prototype of movement monitoring objects using Arduino Nano and SMS notifications. *Jurnal dan Penelitian Teknik Informatika, 2022,* 601–610

Malik, N. N., Hyder, M. J., & Shah, A. experımental ınvestıgatıon on technıques to ımprove the accuracy of mpu 6050 for tılt measurement. *Journal of Harbın Instıtute of tTchnology, 54*(9), 2022

Nadeem, M. M., Khan, S. U., & Mazhar, D. (2019). Dynamic self stabilizing mobile platform. *International Electrical Engineering Conference (IEEC 2019),*1-5.

Palevi, B. R., Praswanto, D. H., Andinisari, R., Megawati, C. D., & Setiawan, R. (2024, July). Low-cost high-performance MEMS inertia measurement unit (IMU) for seismic activity monitoring. In *AIP Conference Proceedings* (Vol. 3077, No. 1). AIP Publishing.

Pham, D. A., & Pham, T. N. (2021, November). Determination of a tilt angle for the automatic balancing system with the inertial measurement unit mpu6050. In *International Conference on Advanced Mechanical Engineering, Automation and Sustainable Development* (pp. 349-354). Cham: Springer International Publishing.

Pokydko, M., Oliinyk, O., & Tymchenko, V. (2024, September). MEMS Gyroscope Based on MPU-6050 Sensor and ATmega328 Microcontroller. In *2024 IEEE 7th International Conference on Smart Technologies in Power Engineering and Electronics (STEE)* (pp. TT3-39). IEEE.

Preston, V., Salume, T., & Ruusmaa, M. (2018). Underwater confined space mapping by resource-constrained autonomous vehicle. *Journal of Field Robotics*, *35*, 1122–1149.

Redhyka, G. G., Setiawan, D., & Soetraprawata, D. (2015, October). Embedded sensor fusion and moving-average filter for Inertial Measurement Unit (IMU) on the microcontroller-based stabilized platform. In *2015 international conference on automation, cognitive science, optics, micro electro-mechanical system, and information technology (ICACOMIT)* (pp. 72-77). IEEE.

Tirado, D. V., Carro, G. G., Alvarez, J. C., López, A. M., & Álvarez, D. (2024). Design and characterization of a wearable inertial measurement unit. *Sensors*, *24*(16), 5388.

Tripathi, V., Bansal, A., & Gupta, R. (2019). Development of self-stabilizing platform using MPU-6050 as IMU. In *Advances in Signal Processing and Communication: Select Proceedings of ICSC 2018* (pp. 373-382). Springer Singapore.

Rocha, Á. B., Fernandes, E. D. M., Souto, J. I., Gomez, R. S., Delgado, J. M., Lima, F. S., ... & Lima, A. G. (2024). Development of Anemometer Based on Inertial Sensor. *Micromachines*, *15*(10), 1186.

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