Developing 2 DoF self-stabilizer platform

Emerson Kaneda
Centro de Digitalização de Robótica Inteligente (CeDRI)
Instituto Politécnico de Bragança (IPB)
Bragança, Portugal
a61103@alunos.ipb.pt

Flávio Rossini
Departamento Acadêmico de Engenharia Eletrônica (DAELN)
Universidade Tecnológica Federal do Paraná (UTFPR)
Campo Mourão, Brasil
flrossini@utfpr.edu.br

José Lima
Centro de Digitalização de Robótica Inteligente (CeDRI)
Instituto Politécnico de Bragança (IPB)
Bragança, Portugal
jllima@ipb.pt

***Abstract*—This paper presents the design and implementation of a two degrees of freedom (2 DoF) self-stabilizer platform, intended for integration with mobile robots to support UAV landing operations. The platform leverages an ESP32 microcontroller for its core processing capabilities, interfacing with an ADXL345 IMU sensor via the I2C communication protocol to accurately detect and respond to tilt and orientation changes. The stabilization mechanism is actuated by two Nema17 stepper motors equipped with planetary reduction gearboxes, providing precise and robust control of the platform's movements. Communication between the platform and the control station is facilitated through an HC-12 wireless UART module, ensuring reliable data transmission over extended distances. This setup enables the mobile robot to maintain a stable landing platform for UAVs under various operational conditions, enhancing the overall efficiency and safety of autonomous landing procedures. Experimental results demonstrate the platform's effectiveness in dynamic environments, highlighting its potential for integration into advanced robotic systems.**

***Index Terms*—Self-stabilizer, Control, Sensor, styling, insert**

I. Introduction

Self-stabilizer platforms play a critical role in a variety of technological applications, providing stability and precision in dynamic environments. These platforms are designed to automatically adjust to external disturbances, ensuring that the surface remains level and steady [1]. Bidirectional platforms, which offer two degrees of freedom (DoF) for pitch and roll adjustments, are often used in simpler stabilization tasks due to their straightforward design [2].

In the context of UAV landing operations, a mobile robot can realize this operation in many types of ground able to use in many areas like military, public safety, agriculture [5], [6], [8]. Some methods and algorithm is developing and test to improve landing operations [3], also the take-off operations too [4]. with this operations able the UAV in terrains like farms, that is a economic role that increase more and more implementation of technology [9]. Mobile robots equipped with self-stabilizing platforms can navigate uneven or dynamic terrains while providing a stable surface for UAV landings, significantly improving operational efficiency and versatility [1].

Moreover, self-stabilizer platforms in mobile robots can enhance a wide range of tasks. For instance, in search and rescue operations [7], [8], these robots can traverse rough terrains to deliver supplies or assist in evacuations, providing stable platforms for sensitive equipment. In agricultural settings, they can support precision farming like harvesting task, this is an that use more manipulators with self-stabilizer platform [6], [9], [10]. This technology not only improves task performance but also expands the potential applications of mobile robots, making them more adaptable and capable in various challenging environments.

Focusing on the development and production of a self-stabilizing platform, this paper focuses on a 2 DoF self-stabilizer platform utilizing Nema17 stepper motors for pitch and roll, integrating an ESP32 microcontroller, ADXL345 IMU sensor, and HC-12 wireless UART for robust and reliable operation.

II. Platform Kinematic Analysis

The structure of 2 DoF platform actuate directly in pitch and roll angles, ideally the yaw angle does not change during stabilization, considering the point of the rotation as shown in the Fig 1. It is crucial that the reference point of origin for the pitch and roll angles is aligned with a support point, which should be equipped with a universal joint to allow for mobility in both directions.

To control the both angles, the analysis of each actuators is over the layout of the brackets of the actuator and the length of each bracket, in the Fig 2 illustrates a layout of the positioning of the actuator arms so that the motor has a 180 º of total effective angle, this is due to the fact that the vertical actuation axis of the platform is aligned with the motor rotation axis.

On the other hand, this layout also decides the height of the central support point, standardizing that at 0º the platform is horizontally stabilized on a flat ground, in the first layout of Fig 2 the height of the platform is equal to the length of the second segment of the arm, while in the second layout the

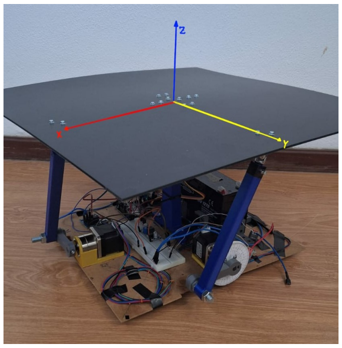

Fig. 1. Referential rotation point

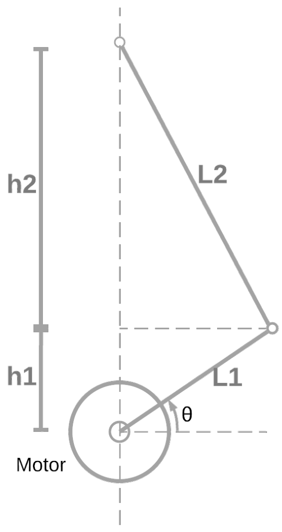

Fig. 2. Layout of the arm

height follows a trigonometric relationship of the arms as it forms a right triangle, thus the height between the motor axis and the platform plate is given by (1)

$$h = \sqrt{L2^2 - L1^2} \tag{1}$$

Another important analysis in this structure is the maximum slope of each angle, this value is given by 2 values, the position of the motors along the pitch and roll axis considering the distance between the central support to the motor shaft, and the maximum and minimum height reached by the brackets. Analysing the Fig 3 the distance between the central support and the motor shaft is static, however, the smaller this value, the greater the inclination angle.

According to the Fig 3 the slope function of roll and pitch angles is given by (2).

$$Slope(\theta) = \arctan \frac{h(\theta) - h_{CentralSupport}}{d} \tag{2}$$

Where $h(\theta)$ is given by (3)

$$h(\theta) = L1 * \sin(\theta) + \sqrt{L2^2 - (L1 * \cos(\theta))^2} \tag{3}$$

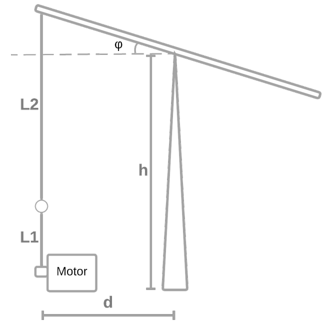

Fig. 3. Slope of the platform

For the platform structure developed in this paper the values of each feature follow the Table I, for both actuators

TABLE I
LENGTH OF THE STRUCTURE

Feature	**Value (mm)**
Central Support Height	187.35
L1 length	70
L2 length	200
Motor shaft to central support distance	200

Based on this values, the cinematic behavior is given by the graphic in Fig 4, the figure shown a non linear system, due the trigonometric behavior of the layout.

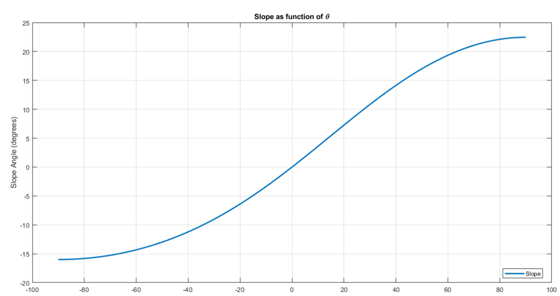

Fig. 4. Slope Kinematic behavior

III. Hardware and Software Implementation

The hardware implementation of the 2 DoF self-stabilizer platform integrates several key components to ensure robust operation. The core processing unit is the ESP32 Wemos board, which interfaces with an ADXL345 IMU sensor via I2C communication to monitor pitch and roll angles. Data transmission is facilitated by an HC-12 wireless serial module, with a step-down buck converter providing regulated at 5V power supply. The motors are driven by DRV8825 step motor drivers with 32 micro-steps configuration, ensuring accurate and reliable control. Power for the entire system is supplied by a battery 12V 7Ah, which provides continuous power to maintain stability and functionality during operation.

All implementation can be resume in the following block diagram in Fig 5

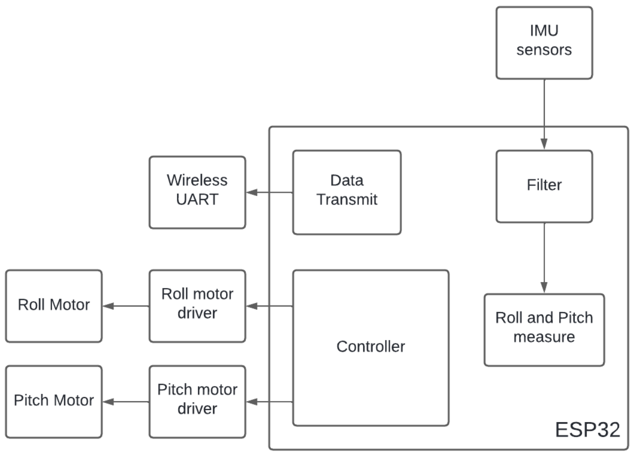

Fig. 5. Block Diagram of implementation

A. Roll and Pitch angles measuring

To measure pitch and roll angles, the ADXL345 accelerometer is utilized for its precision in detecting linear acceleration along three orthogonal axes: X, Y, and Z. The sensor provides raw acceleration data that sum with a high noise, to avoid this a digital filter is used, however the filter must be fast and efficiently, the most commom filters are FIR and IIR, the response of those filters depends the number of coefficients and this number generate the delay response. To save processing and get a fast response, a variation of exponential moving average filter can be used, the output of this filter is given by (4)

$$y[0] = \frac{y[-1] * N + x[0]}{N + 1} \tag{4}$$

After filtering the raw acceleration, the data can be converted into angular measurements. The pitch and roll angles are calculated in (5) (6) respective.

$$Pitch = \arctan(\frac{a_y}{\sqrt{a_x^2 + a_z^2}}) \tag{5}$$

$$Roll = \arctan(\frac{-a_x}{a_z}) \tag{6}$$

With this filter the curve of both angles become smooth to keep de controller stable, on the other hand, this filter is still susceptible to noise from vibrations on the platform. The following grapich in Fig 6 shown the curve of pitch and roll measured during a step response of the controller, it is possible to see a small mechanical vibration circled in the graphic.

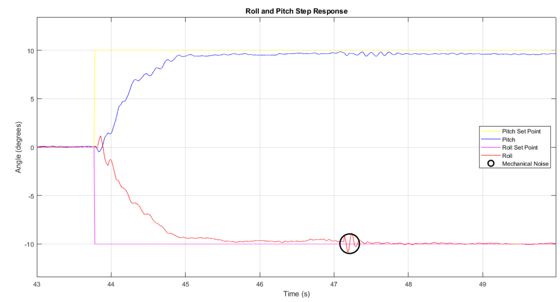

Fig. 6. Step response of the platform

B. Controller

In this platform, the controller must be actuate on the angular position, and this made by input a number of steps in driver motor, so the number of steps is calculated by converting directly the value of the error, that means a simple P controller can be enough to this problem, the Fig 7 shown the control diagram of the system

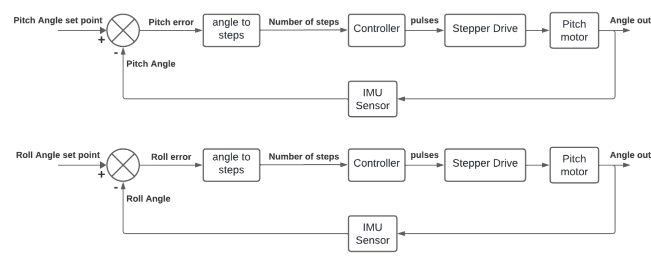

Fig. 7. Control diagram

An important consideration for this controller is the maximum pulse frequency of 250 kHz for the DRV8825 stepper driver, as specified in the datasheet. However, the motor does not respond effectively at this step frequency. Therefore, the controller adjusts the motor speed by calculating the step period based on the error during each controller cycle.

Furthermore, it is essential for the digital controller to respond promptly. However, taking into account the motor's lower response rate, a period of 10 ms has been established between controller cycles. This period is also utilized as the sampling interval for the sensors. In the Fig 6 the controller got a good response without a overshoot, characterizing a overdamped controller in that test. In other test with more step responses is visible the controller have small overshoots and noise in during the rise time, the Fig 8 is visible the cited behavior

IV. Conclusion and Future Works

The prototype of this platform demonstrated good stability with a relatively quick response time, achieving stabilization in just over 1 second. Its simple structure directly influences pitch and roll angles using stepper motors controlled by pulse counts, which facilitated development by allowing direct

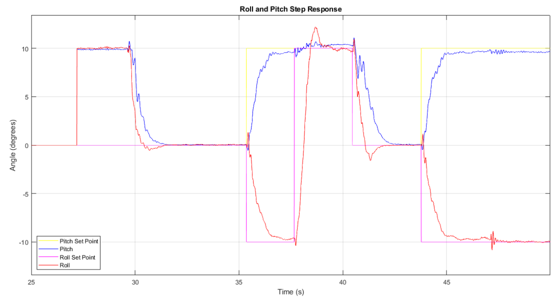

Fig. 8. Sequentially Step responses

angle control through the controller. However, the bidirectional structure imposes torque demands on the motors, necessitating investment in more powerful motor options. Therefore, exploring alternative structure models such as delta or Stewart platforms could optimize motor utilization, despite the increased system complexity.

Another critical consideration lies in the measurement of both angles using accelerometers only, where the influence of vibrations was noticeable. To mitigate this noise, integrating additional sensors and employing sensor fusion techniques could effectively eliminate external influences. Alternatively, implementing a damping system could attenuate mechanical vibrations, further enhancing measurement accuracy and stability.

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