DESIGN AND DEVELOPMENT OF LIGHTWEIGHT STABILIZATION PLATFORM FOR MULTICOPTERS ARMAMENT

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Abstract. For the usage of armament that requests precision targeting on multicopters (rotary-wing drones), it is necessary to provide the best possible stabilization with some mechanism that, at the same time, must be lightweight. This paper presents a lightweight stabilization platform based on the Stewart platform mechanism. This parallel mechanism (a mechanism that contains a closed kinematic chain) has six degrees of freedom inside the workspace. The platform must be able to stabilize all disturbances due to the flight of the multicopter and must withstand the recoil of armament if it exists.

Keywords: lightweight stabilization platform, Stewart platform design, armament stabilization, multicopter armament, precision targeting

1. INTRODUCTION

A multicopter is an aircraft with more than two rotors. It is also frequently called a multirotor or rotary-wing drone, and it is most often an unmanned aircraft vehicle (UAV). Today, the most commonly used small unmanned aircraft are multicopters [1].

There are many different categorizations, but in the past, a small UAV was often either a MAV (Micro UAV) with a wingspan no greater than 150 mm) or a MUAV (Mini UAV), which has a mass below 20 kg and an operating range of up to about 30 km [2]. Multicopters advanced from flying cameras, and today, they are used for various missions because they become bigger and more powerful.

As shown in Fig. 1, there are multicopters on the market that can carry payloads of 20 kg and more, like IKA-20 [3]. The multicopter has a maximum width of 2313 mm and a maximum length of 2478 mm while the rotor diameter is 812.8 mm. A much larger payload capacity opened up the possibility of carrying armament on multicopters.

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This type of aircraft most often uses fixed-pitch blades, and in order to control the position and orientation of the aircraft, the rotational speed of each rotor is controlled. This means much simpler rotor mechanics than in the case of helicopters. By changing the rotation speed of the rotor, the thrust and torque are both changed. Flight controllers are in charge of changing the rotor speed to achieve the desired movement of the aircraft. On the other side, rotors are a source of vibration, which can be a problem for some payloads. In case of wind and other flight disturbances, the multicopter needs to change its orientation to keep its position because of rotors and how day produce thrust and torque. Unwanted but unavoidable changes in orientation and additional vibrations are the most important reasons for the usage of the stabilization platform for many payloads, including armament.

Fig. 1. Multicopters IKA-20 that can carry 20 kg of payload [3]

In the case of carrying an assault rifle, the stabilization platform has to be very fast and stable for the assault rifle to have good precision on target. Apart from this, the platform has to withstand recoil and return the assault rifle to the desired position and orientation as soon as possible for the next shot.

2. MECHANISM DESIGN

In order to meet all the previously set requirements, it is chosen to use a parallel mechanism with six degrees of freedom (as shown in Fig. 2) called the Stewart platform [4]. More precisely, a Stewart platform with rotating actuators (6-RUS) is chosen because it is much easier to find suitable actuators (in this case, servo motors) as available products on the market.

This type of mechanism has six pairs of upper and lower levers (together called legs), and the desired movement of the top platform is achieved by rotating the lower lever around an axis going through one end of a lever using a servo motor. This is the revolute joint between the base and a lower lever. The upper and lower levers are connected with universal or spherical joints, and the upper lever and platform are connected by spherical joints. This is the reason why this mechanism is also called 6-RUS, in accordance with the types of joints.

Calculating the required rotations of rotary actuators and lower levers for a given position and orientation of the platform requires solving the inverse kinematics. This is a popular research topic in robotics, with many published research papers about inverse and forward kinematics problems [5, 6], dynamics [5, 7], singularities, and workspace estimation [5, 8].

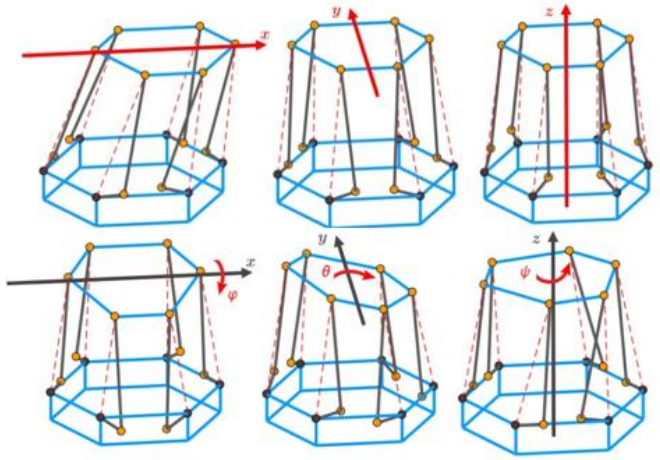

Fig. 2. Translation and rotation axes for Stewart platform

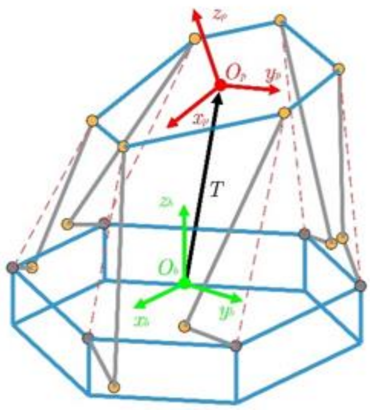

Fig. 3. Reference frames

The most intuitive way of solving inverse kinematics is often referred to as a geometric method. As shown in Fig. 3, the first step is to define two reference frames. A global reference frame ($O_b x_b y_b z_b$) is fixed to the center of the base, and a moving platform reference frame ($O_p x_p y_p z_p$) is fixed to the center of the platform.

Control values are defined by vector $\boldsymbol{q} = [x,\ y,\ z,\ \psi,\ \theta,\ \varphi]^T$ and they represent external coordinates of the moving platform's local reference frame in reference to the global frame fixed to the nonmoving base of the platform. Translation of the platform's frame in reference to the global frame is defined by $\boldsymbol{T} = [x,\ y,\ z]^T$ while orientation is defined using rotation matrix $\boldsymbol{R}$ and Euler angles ($\psi,\ \theta,\ \varphi$), respectively, yaw, pitch, and roll about z, y, and x global axes [9].

This means that the yaw and pitch angles (corresponding to azimuth and elevation) of the platform can be used for stabilization and targeting, while all other control values are used for stabilization.

Based on these control values, it is possible to obtain internal coordinates starting from the following equation, which defines the length between points Pi and Bi (as shown in Fig. 4).

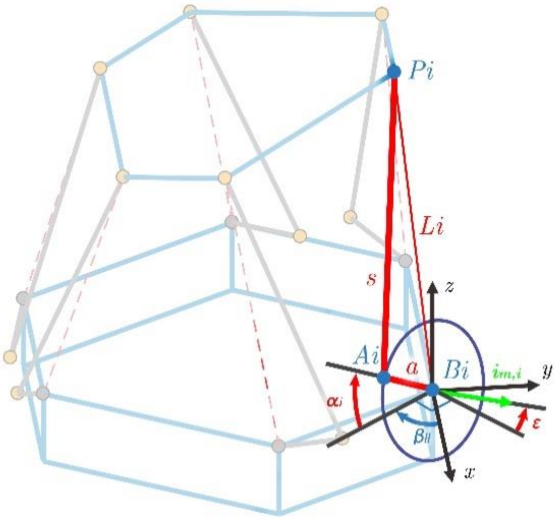

Fig. 4. Geometric parameters

$$L_i = T + Rp_i - b_i \tag{1}$$

Using basic trigonometric relations, it is now easy to determine the required angles for actuators. There are additional geometric parameters that must be defined in order to fully define the geometry of the mechanism. It is possible to optimize the values of these parameters to obtain a tailor-made geometry, as shown in [10].

3. SYSTEM PROTOTYPE

The selected mechanism can be turned upside down and mounted on a multicopter. In that case, the base is fixed to the body of the multicopter, while the armament is fixed to the platform. Armament can be the assault rifle and all necessary equipment, such as targeting lasers and different cameras. Installed servo motors are selected based on the ability to stabilize all disturbances due to the flight of the multicopter, withstand the recoil of an assault rifle, and precisely fire again as soon as possible.

The system prototype is shown in Fig. 5, together with the control application on the tablet, which is an example of how to remotely control the platform.

Fig. 5. Control application on tablet (left) and stabilization platform (right)

Fig. 6. Stabilization platform on IKA-20 multicopter

After mounting the mechanism on the multicopter (as in Fig. 6), it can be used for targeting by changing the desired orientation of the platform in reference to the north-east-down (NED) coordinate system of the multicopter.

The total mass of the stabilization platform with an assault rifle and cartridge is under 20 kilograms. That means that it can be used with multicopter IKA-20, as shown in Fig. 6.

4. CONCLUSION

This paper shows a lightweight stabilization platform for multicopter armament. The developed prototype of the system has proven that it is possible to meet all the set requirements for dynamic response and precision. The designed mechanism has suitable workspace limits for both stabilization and targeting.

The platform shown in this paper is not just for an assault rifle and can be easily adapted to other types of armament.

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