The Prototype of Gyro-Stabilized UAV Gimbal for Day-Night Surveillance

Karol Jędrasiak, Damian Bereska, and Aleksander Nawrat

Abstract. This paper presents a designed and created prototype of stabilized UAV gimbal for day-night surveillance. There is a need for UAV gimbals capable of stable target detection and tracking, regardless the time of the day. The prototype gimbal is capable of pan and tilt rotations in range of full 360 degrees with 10 bit turning resolution. Full turn takes approximately 1.2s. The gimbal itself and possible future external devices are able to communicate via extended VISCA protocol and RS-232C standard. Performed tests and evaluations have shown promising results regardless the time of the day. The presented gimbal shows a great potential for target detection and tracking using UAVs and developing more sophisticated algorithms for stabilization.

Keywords: surveillance, gimbal, thermal imaging, UAV stabilization.

1 Introduction

Unmanned aerial vehicles (UAVs) are often used for infrastructure and strategic building surveillance. Recently they are not only used for military applications but also for geodesic measurements and mass events surveillance. Due to the requirement of minimal size, weight and energy usage, micro UAVs are equipped only with the most necessary, often simplified, devices. In this paper we present a designed and created working prototype of Gyro-Stabilized Gimbal for day-night surveillance applications.

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Detection and tracking algorithms are sensitive to vibrations caused by propulsion system of the flying objects as well as the influence of the environment e.g. wind. It is important to reduce the impact of those vibrations on the results of object tracking and remote sensing UAV's capabilities. Video stream stabilization regarding the video camera mounting can be achieved by stabilization at the level of the whole aerial vehicle [1], software stabilization level [2] or at gimbal level. Software image stabilization is computationally complex, therefore it is not wise to perform it unnecessary by UAV's CPU. PID or fuzzy controllers are often used for stabilization with the usage of servos. Recently fuzzy PID composite control was introduced [3].

Video cameras and image processing techniques are a basis of visual surveillance. However vision information is used not only for target tracking but also for navigation e.g. estimating the attitude of the UAV or horizon detecting [4]. Typically, there is mounted a single video camera for day applications [5]. The camera can be hard mounted or capable of pan, tilt rotations to follow the object of interest. Acquired aerial images are later often georegistered and used for creation of a detailed map of the area or image mosaic [6].

Designed gimbal, in order to perform tasks regardless of the day/night conditions, is equipped with two video cameras. First is a visible light video camera used for day applications. Second is a thermal imaging camera used for additional information during day and object detection and tracking during night. Thermovision camera can be used for object detection, localization and tracking as presented in [8]. The prototype pan-tilt gimbal can further improve capabilities of object tracking by rotation in adequate direction. In order to improve the speed of computations image processing algorithms can be implemented in FPGA as in [9].

Visible and thermal video fusion can also be used in order to improve detection and tracking quality. Regions of interest found in thermal images are capable of using, as an additional source of information, for e.q. particle filter tracking as presented in [10]. Fusion of both streams can also be presented to a human operator at the ground station. Such fusion can show additional details in a single video stream and therefore aid the task of monitoring especially during twilight.

2 Gimbal Overview

Continuous object tracking, regardless of the UAV movements, is an important task for the gimbal. Our prototype gimbal (fig. 1) is capable of pan and tilt rotations in full 360 degree range. Two servo mechanisms with ten bit resolution are used for turning. Pan and tilt precision is therefore equal to 0,35 degree. Full 360 degree turn is performed in exactly 1.2 s. It was decided that first prototype is to be restricted to single turn only.

To reduce the impact of vibrations and environmental forces on video cameras streams, a 9-DOF (degree of freedom) IMU (inertial measurement unit) was mounted inside the prototype gimbal. There are 3-DOF of gyroscopes of X, Y and Z axes and respectively 3-DOF of linear accelerometers. Additionally, there are also

3-DOF magnetometers for computing reference data. At the current state of development, data from gimbal's IMU is used for hardware gimbal level stabilization. It is based on the difference between current servos position and the position set. Detected difference is minimized in real time. Gyroscopes measurements were tested and would be used in next implementation to minimize using servos at an angle the gimbal was rotated. In next implementations IMU's data could be used for more sophisticated hardware stabilizations algorithms or by ground station for visualizing current gimbal state.

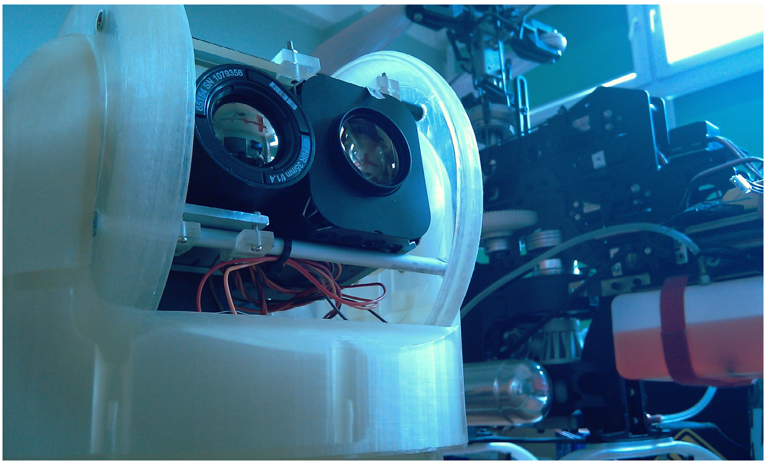

Fig. 1 The prototype gimbal

Except the autonomous hardware stabilization, additionally, the gimbal can be remote controlled by a PC computer. This feature can be used for tracking detected target using pan-tilt gimbal's capabilities without the need to change the trajectory of the whole UAV.

3 Gimbal Construction

The created and tested prototype of the stabilized optical gimbal is shown in fig. 2. The gimbal is a result of the first stage of design and construction universal stabilized platform for UAV. Aim of the work was to produce a stabilized platform that was capable of installing visible light and IR camera. Priority was to enable rotations around axes x and z.

Size of the empty space was designed for installing a various type of additional sensors and video cameras. It was optimized for easy installing most of the visible light and IR camera models. Gimbal's cylindrical shape is large enough for: two video cameras, propulsion system of the axis x, IMU and a required electronic chips

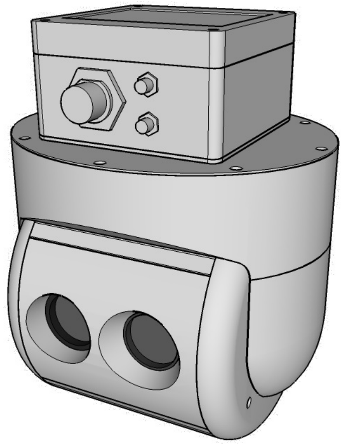

Fig. 2 The gimbal visualization

for control and communication. An additional space for possible future sensors was also designed at the mounting part of the gimbal.

Applied propulsion system enables rotation in the range from 0 to 360 degrees in both axes. It was decided to limit the range to the single full rotation and avoid using rotor connector in order to simplify the communication with the installed sensors and video cameras. Designed range is assumed to be sufficient since target UAV type is a rotorcraft which can easily change vertical orientation. Capability of full rotation around x axis was designed in order to allow hiding cameras in a safe zone of the gimbal. Such an approach significantly reduces the risk of any damage and allows installing video cameras lenses pneumatic cleaning system.

4 Communication with External Devices

The prototype gimbal is communicating with external devices through RS 232 standard and extended VISCA protocol developed by Sony Corporation. Parameters of the RS-232C communication are as follows [11]:

- communication speed: 9600 bps,
- 8 data bits,
- 1 start bit,
- 1 stop bit,
- no parity,
- no flow control.

There can be multiple (up to 7) external devices in VISCA. Each device is identified by its number starting from 1. PC computer is a controller with id equal to 0. Sending

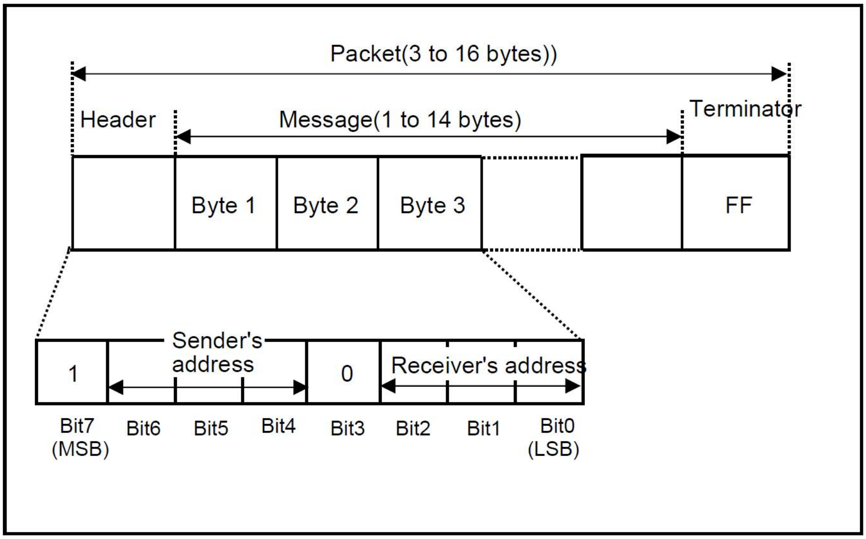

Fig. 3 VISCA packet structure

a command with an id of 8 is interpreted by VISCA as the broadcast command to all devices. Commands are send in data packets (fig. 3) consisting of 1 byte header, up to 14 bytes of command data and an end of packet, byte 0xFF.

Before communication a controller has to be initialized by sending an init command. After initialization, gimbal's servo manager is available. Each of servos is controlled with a command consisting of bytes: 0x81, 0x01, A, B, C, D, S, 0xFF.

S is the servo mechanism speed. It is a value in range between 0x00 and 0x80. A and B, C and D are respectively lower and upper bytes of the number in range from 0 to 1023. A and B are used to control pan servo while C and D values are used for tilt servo mechanism. Lower and upper bytes are computed using the equations (1-2):

$$U_b = value\, div\, 32, \quad (1)$$

$$L_b = value\, mod\, 32, \quad (2)$$

where:

U_b, upper byte value,

L_b, lower byte value.

Video streams from the cameras mounted in the gimbal can be accessed using identical standards as the original ones e.g. PAL or 384x288 pixels resolution.

5 Tests during Day and Night

Experiments were designed in order to test gimbal's surveillance capabilities. Test goal was to detect and track object of interest. Object with temperature that significantly varies (parameter alpha) from the background temperature was assumed as an object of interest. All tests were performed during day and night on a low class PC computer equipped with a 1,8 MHz and 2GB of RAM.

In the scene observed during experiments there are three physical objects. The object of interest is a bottle of hot water. It is placed on top of the table in the room temperature. In the background a wall is visible. During experiments gimbal was moved or rotated and its capabilities to track the object were recorded.

At first, try standard motion detection using background modeling was used to detect object of interest. Image frame was divided into segments and each segment was continuously updated using equation (3):

$$B_{t+1} = \alpha I_t + (1-\alpha)B_t, \tag{3}$$

where: B_{t+1}, segment background value,

I, segment median intensity,

α, speed of background update.

However, due to thermal camera internal image equalization, the algorithm was instable. It was decided to use image global average as a reference value for thresholding. Each pixel with intensity value different then average background value by beta parameter was assumed as a foreground pixel. Beta parameter was experimentally set as 0.3.

All detected pixels were grouped into blobs and the blob characterized by the largest area was chosen as the successfully detected object. Object tracking was implemented as follows: first, blob is detected in the frame, next, in the second frame, blobs are detected and compared against the list of blobs found in the previous frame. If Euclidean distance of the blobs's center of mass is smaller than DELTA parameter, then it is assumed that the two virtual objects represent the same physical object.

Detected object's distance from the center of the image frame was used as a control signal for servo mechanisms. If the distance along x and y axes is larger than gamma parameter, then servo mechanisms are turning in the direction with the speed proportional to the blob's distance from the image's center.

Acquired results during tests are presented in the following section.

6 Experiments Results

During the first test, the object of the interest was placed in the scene. The test was performed during the day as all the following tests. In laboratory conditions there was no difference between thermal camera video streams from day and night. Therefore, only day results are presented. Successfully detected object is bound with a yellow rectangle. The green line connects the center of mass of the object and the center of the image frame. The line represents distance of the object from the center. In fig. 4A it can be seen that the object is in a distance of about quarter of the image center. Measured distance is used to control servos in order to rotate the gimbal that the detected object is in the middle of the thermal camera image frame. Screenshot images from the turning process are visible in fig. 4B and fig. 4C.

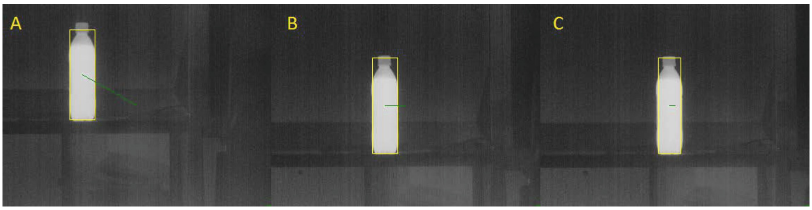

Fig. 4 Images acquired during first experiment

During the second test, gimbal was rotated by a yaw angle and translated to the left. Test's goal was to check whether gimbal was able to detect and track object during simulated UAV movement. As shown in fig. 5 the prototype gimbal fulfilled the test.

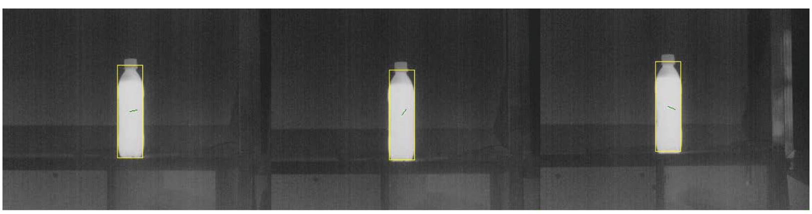

Fig. 5 Images acquired during the second experiment

The last, third test's goal was to track object during gimbal rotation by a roll angle. In fig. 6. it can be seen that gimbal successfully tracked object during rotation however, a lack of degree of freedom for roll angle resulted in a rotated image.

During UAV operation usually there is no need for 3-DOF because observed objects are relatively small in comparison to the whole image frame, therefore objects rotations do not affect the tracking process.

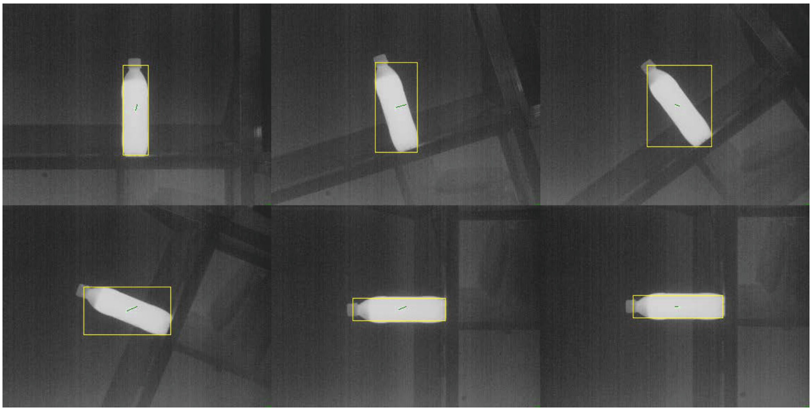

Fig. 6 Images acquired from thermal imaging camera during rotation by a roll angle

7 Conclusions

In this paper the prototype of stabilized UAV gimbal for day-night surveillance was presented. Firstly, the problem of detection and tracking during night was introduced. Next, the stabilization problem and possible solutions were mentioned. The designed and created gimbal is capable of pan and tilt rotations in range of full 360 degrees with 10 bit turning resolution. Full turn takes approximately 1.2s. The gimbal itself and possible future external devices are able to communicate via extended VISCA protocol and RS-232C standard. Performed tests and evaluations have shown promising results regardless the time of the day. The presented gimbal shows a great potential for target detection and tracking using UAVs and developing more sophisticated algorithms for stabilization.

In the future work, we will include multiple objects tracking and implement visible light and thermal cameras fusion in order to develop more accurate detection algorithms. Next versions of the gimbal will also utilize the mounted IMU unit for better stabilization and gimbal state visualization. Building upon acquired experience in laboratory ,we will test next implementations during test flights. There is also possibility of implementation of parallel processing algorithms in order to improve overall performance.

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