Towards modelling an atmospheric pseudo-satellite imaging system

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Abstract. Although atmospheric satellite research has a long history, in the past few years it gained a new momentum due to the development of the solar panel technology and material design. The so-called high-altitude platforms (HAPs) have a great advantage over satellites at imaging resolution and telecommunication in a lower cost. In this paper we present a hardware configuration for modelling aeroelastic vibrations of the wing of an atmospheric Unmanned Aerial System (UAS) with imaging and inertial sensors. The cameras have multiple purposes in our setup, we intend to use them for super-resolution imaging and to reduce the inertial measurement drift by image registration through time intervals.

1 Introduction

In recent years lots of industrial researches have targeted the atmospheric UAS or HAP e.g. Facebook's Aquila, Google's Solara and Airbus's Zephyr project [1]. This type of aircraft flies above the troposphere at an altitude of about $20[km]$. This flight altitude is between earth observation satellites $500 - 600[km]$ and aerial geospatial imagery planes $240 - 460[m]$, which has several advantages. Atmospheric UASs can fly for months regardless of weather conditions [1]. They have lower cost, it is easier to navigate and repair them than satellites. As a consequence of the lower altitude they can provide better geospatial resolution and serve as mobile telecommunication stations [2].

2 System overview and design principles

Towards modeling an atmospheric satellite imaging system and inspecting it under laboratory conditions a simulation platform was planned, which is shown in Figure 1. Concerning imaging, we chose two wing-mounted cameras (colored green) and one wing observation camera (colored yellow). Since we were not

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[1] https://www.airbus.com/en/products-services/defence/uas/uas-solutions/zephyr

planning to model airflow directly, we only need to simulate wing vibrations. Therefore as it turned out the optimal solution should use an aluminium profile vibrated by a direct drive (colored red) setup with masses. We also designed a changeable mass configuration (colored blue) along the profile to model multiple wing characteristics.

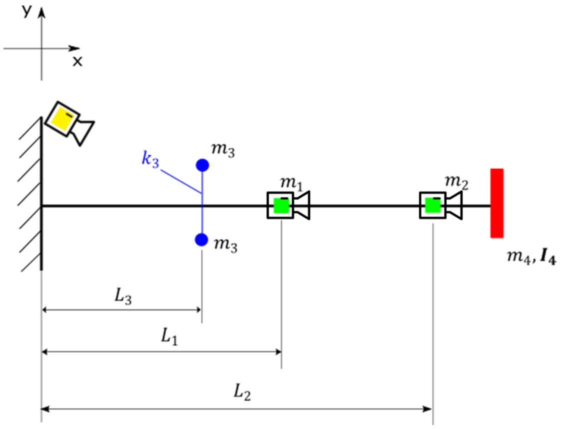

Fig. 1. Schematic of the planned system

2.1 Digital modelling

To find the optimal location and length of the wing, as well as the cameras, a digital twin was made from MPLAB's MIMO Arena [3]. The purpose of fitting the simulation platform in this room is that later on, we will be able to measure precisely the vibrations. The MIMO Arena is equipped with an *Optitrack*[2] system with ten *Prime 13* infrared cameras. The cameras are tracking retroreflective markers with sub-millimeter precision up to $240[Hz]$. With this setup, it is possible to track the modeled wing vibrations along the profile in 6DoF.

For the virtual twin model, the room was scanned by a FARO Focus$^{\mathrm{S}}$ 350 [3] 3D laser scanner, and the result is shown in Figure 2. The 3D scan of the Arena was imported to Blender[4]. We simulated the possible profile locations with multiple camera configurations (sensors and lenses), some cases are shown in Figure 2 (b). We determined the wing's location and length, with the latter being $6[m]$ ($5[m]$ swing length plus $1[m]$ for locking). After this, an iterative development process started:

1. An aluminium profile was chosen for the wing model.

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[2] https://optitrack.com
[3] https://knowledge.faro.com/Hardware/3D_Scanners/Focus
[4] https://www.blender.org/

2. Swing simulations were carried out in MATLAB Simulink.
3. Vibration data was imported to Blender to simulate camera measurements.
4. Camera and lens configuration was chosen.
5. The changed masses were fed back to the Simulink simulation and then if it was necessary a new profile was chosen.

(a) Top view with measures (b) Simulated camera configurations

Fig. 2. MIMO Arena digital twin

As a result of this process we chose Blackfly S [5] cameras with $50[mm]$ lenses [6] as the wing mounted cameras. For the wing observation a Grasshopper3 [7] camera with a $25[mm]$ lens [8] was chosen. For this configuration the theoretical minimal detectable displacement and rotation approximation with the assumption that the overall mean pixel error is $0.3[px]$ between matching two images:

$$d_{min} = \frac{1.3 \cdot d \cdot ps}{f} = \frac{1.3 \cdot 7.84[m] \cdot 3.45[\mu m]}{50[mm]} = 0.704[mm] \tag{1}$$

$$i_{min} = \frac{1.3 \cdot ps}{f} = \frac{1.3 \cdot 7.84[m] \cdot 3.45[\mu m]}{50[mm]} = 18.5[''] \tag{2}$$

Where d is the camera - wall (target) distance, ps is the sensor's pixel size and f is the lens's focal length.

Using a the digital model we carried out camera calibrations with less than $0.2[px]$ overall pixel error and tested some super-resolution algorithms with varying but promising results.

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[5] FLIR BFS-U3-89S6C-C: 8.9 MP, 42 FPS, Sony IMX255, Color

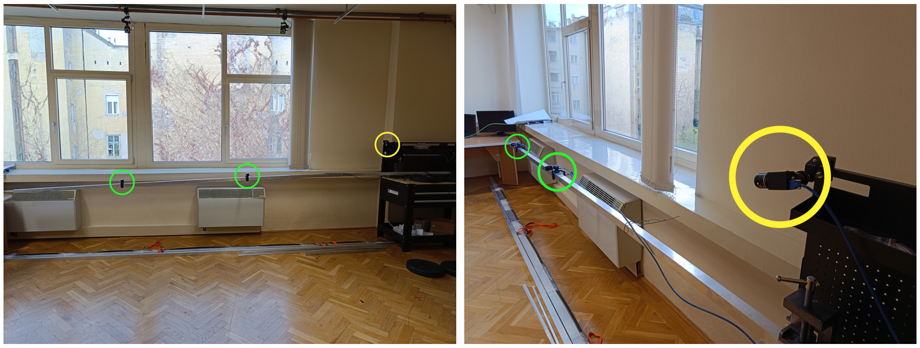
[6] Computar V5028 50mm, 1.1", C mount lens

[7] FLIR GS3-U3-23S6C-C: 2.3 MP, 163 FPS, Sony IMX174, Color

[8] Computar V2528 25mm, 1.1", C mount lens

2.2 Hardware configuration

As shown in Figure 3 the hardware setup was built with the specified cameras according to our plans. The wing cameras are highlighted with green circles, while the wing observation camera with yellow circle. The wing cameras can be moved freely, allowing different measurement setups.



(a) Front view (b) Side view - wing observation camera

Fig. 3. Actual hardware setup

With the current state of the hardware configuration we carried out vibration tests using the Optitrack system to validate our previous simulations. The results were slightly different, which is due to the not completely vibration free fixation.

3 Conclusions

A unique measuring system was designed to model atmospheric UAS imaging beside aeroelastic vibrations of the wing. To choose the proper sensors and profiles the hardware configuration was tested with a digital twin in Blender. In the virtual environment the vibrations and the imaging were also tested. As an accomplished milestone in the long term research project, the real hardware setup was created, making further research opportunities available.

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