Reliability of visual inertial odometry on an unmanned aerial vehicle

Tiro Setati[1], *Thabisa* Maweni[1], and *Natasha* Botha[1]

[1]Centre for Robotics and Future Production, Manufacturing Cluster, Council for Scientific and Industrial Research, South Africa

Abstract. There is a need to ensure that an Unmanned Aerial Vehicle (UAV) can fly safely in indoor environments. In this paper, the visual-inertial odometry (VIO) implemented in a commercial UAV is tested to determine its reliability to keep its position in confined indoor spaces. The experimental results indicated that the UAV was able to track the subject from an average distance of 3915.23 mm in the y-direction, with $RMSE_x$ and $RMSE_y$ of 452.47 mm and 332.66 mm, respectively. This shows that the UAV can track objects in confined environments, such as the aisles of an indoor warehouse.

1 Introduction

Unmanned aerial vehicles (UAVs), also known as drones, have been growing in popularity over the past few years. They have become vehicles of choice for several industries because they can be built to scale according to their application. From large-scale agricultural UAVs carrying large payloads for farming applications [1, 2], to smaller, more agile UAVs used in indoor applications [3].

For outdoor applications, UAVs commonly make use of a Global Positioning System (GPS). Unfortunately, other positioning systems need to be used when flying UAVs indoors because of the limited communication available to the UAVs from the orbital satellites that provide GPS information to the UAV.

For this paper, the reliability of a vision-based tracking system on a UAV flying indoors will be tested. Depending on the application area, there may be space constraints imposed on the area in which indoor UAV are required to fly to protect the environment or equipment in the vicinity. Therefore, a reliable vision-based tracking system is one that can follow an object of interest with as little error from the reference flight path as possible.

1.1 Literature review

Generally, UAVs make use of a Global Positioning System (GPS) for a number of positioning functions: position hold, altitude hold, return to home, reporting, waypoint navigation and mapping [4, 5]. This works well for outdoor drone applications, such as agricultural and mapping UAVs as the GPS signals are well received by the drone when there is direct line-of-sight between the drone and multiple GPS satellites orbiting the earth. For UAVs that need to fly indoors, the functionality of the GPS is impeded. Because the UAVs does not have a direct line-of-sight with the orbiting GPS satellites, the GPS signals detectable by the UAVs are limited. For this reason, it is not recommended to fly larger commercial UAVs with a limited amount of GPS satellites, or indoors [6].

Alternative positioning systems would need to be implemented to have the functionality of UAVs realised for indoor applications. These include vision-based algorithms [7] and optical flow sensors [8]. The advantage of using these vision-based systems is that they function independent of the GPS by taking high-resolution images of the surrounding environment and use features in these images to localise themselves and map out the surrounding environment.

The reliability of using these vision-based systems for localisation and navigation is highly dependent on the image quality of the surroundings obtained. The quality of the images acquired is subject to some variables, such as the lighting conditions in the environment, and the number of perceivable visual features in the image [9]. A vision-based system makes use of features and descriptors in the image and runs those through a model in its algorithm for feature extraction and matching. The probability of the feature(s) in the image acquired is matched against a large database of features and the larger the probability, the more accurately the keypoint localisation and orientation assignment can be fit to the acquired image [10, 11].

2 Methodology

To determine the reliability of the vision-based positioning system implemented on a commercial drone, the DJI Mavic Air 2 drone (Figure 1(a)), will be tested in an indoor environment. To ready the drone for the experiments in an indoor environment, there are some settings that need to be changed on the system and the controller to protect the drone and the surrounding environment:

- The Obstacle Avoidance Action is set to "Brake." This will stop the drone in its flight path if it is heading for a collision with a potential obstacle.
- When the remote control is disconnected from the drone, the Signal Lost Action is set to "Hover." This ensures that the drone only hovers in the position where it lost connection and will therefore not fly away or collide.
- Flight mode is set to "Cinematic mode" for slower flight speeds.

To setup the experiment, the following steps were taken:

- Set out a 7 m x 8 m working area underneath the motion capture system, shown in Figure 2(a).
- Place motion capture markers on the drone as shown in Figure 1(a). The markers were placed in such a way that the orientation of the UAV could be deduced when viewed from the motion capture system.
- Place motion capture markers on a hardhat to be worn by the pilot as a reference, as shown in Figure 1(b).
- The Vicon motion capture system is set up and calibrated. Record the current trail on the Vicon system.
- The UAV is placed in the take-off position with the tail side away from the pilot, and the pilot goes through the pre-flight checklist.

- Once the pre-flight checklist is complete, the pilot can move in position to launch the drone.
- Hover the drone at eye level.
- Switch the drone to "Object Tracking mode", select the pilot in the camera screen and activate the mode.

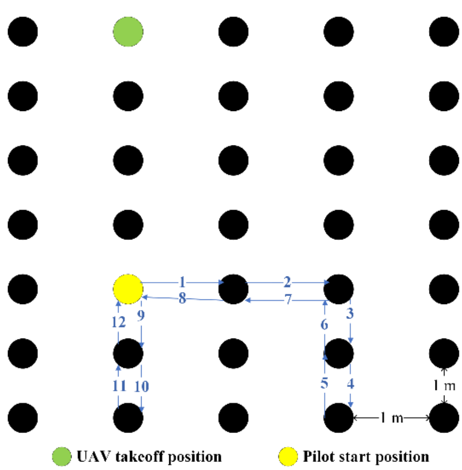
(a) DJI Mavic Air 2 with motion capture reflectors and remote controller

(b) Hardhat with motion capture reflectors

Fig 1: UAV and hardhat with motion capture reflectors

The pilot, as the subject of the experiment, will then move according to the motions depicted in Figure 2(b). The UAV will react to the pilot's movements and its motions will be recorded.

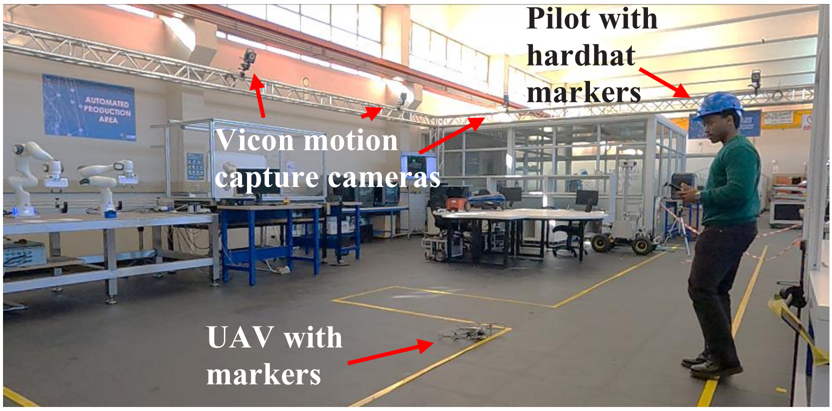
(a) 7m x 8m working area.



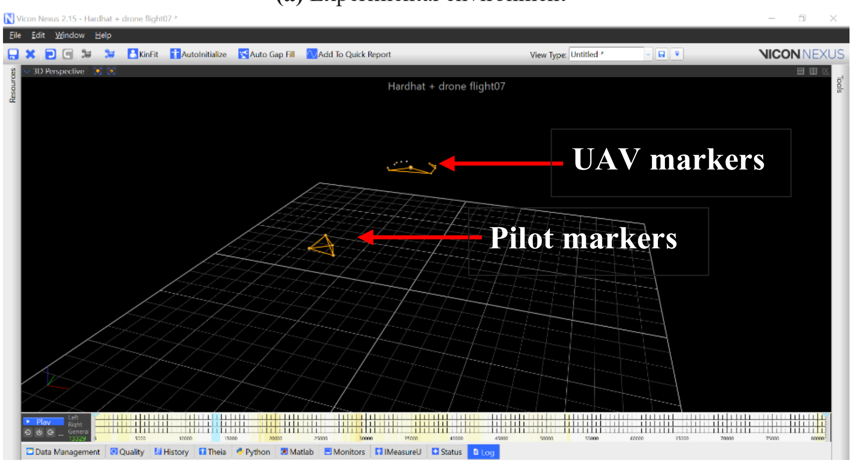
(b) Pilot positions

Fig 2: Experimental area for object tracking experiment.

The experiments were conducted using a Vicon motion capture system, depicted in Figure 3(a), and the results were visualised and recorded in the Vicon Nexus application, depicted in Figure 3(b).



(a) Experimental environment



(b) Motion capture application

Fig. 3. Illustration of the motion capture experimental setup.

Once all the experimental data has been recorded, the UAV's motions will be compared to the subject's reference motions. In this paper, the reliability of the UAV's performance is taken as how closely it can follow match the motions of the object it is tracking. Therefore, the root mean squared error (RMSE) will be determined. The RMSE provides an estimation of the accuracy of the drone's flight in following the reference motion in the same units as those of the reference motions. If there are space restrictions in the operational environment, the RMSE will help determine if the UAV can fly safely within those parameters.

$$RMSE = \sqrt{\frac{\sum((\hat{y}_i - y_i)^2)}{N}} \qquad (1)$$

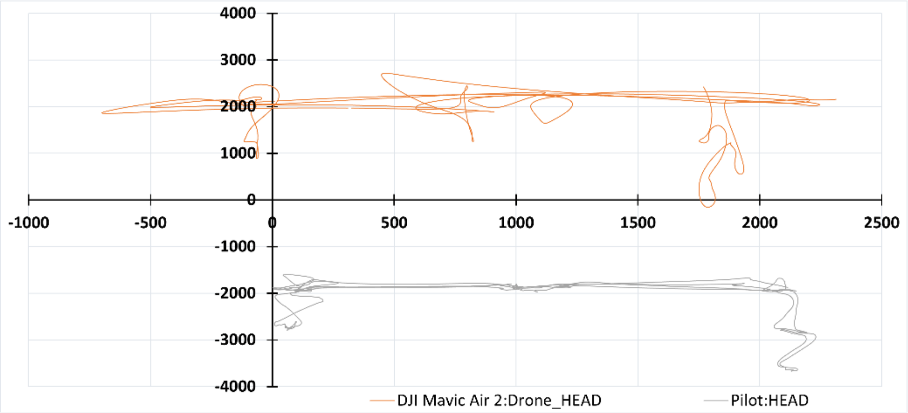
With y_i as the observed value at the i-th position, $\hat{y}_i$ the predicted value at the i-th position and, N the number of points.

3 Results and Discussion

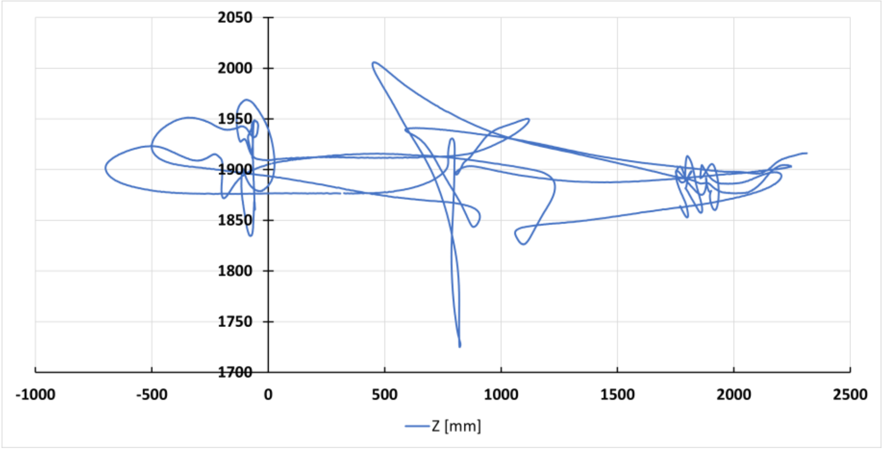
The path followed by the pilot in Figure 3(b) was repeated 3 times during the experiment and the experiment results were recorded. Figure 4(a) depicts one cycle of an x-y-top view of the hardhat markers and the UAV in motion while the UAV operates in object tracking mode. The UAV's trajectories show its movements responding to the pilot in object tracking mode. The UAV would keep an average distance of 3915.23 mm away from the subject. The maximum distance the UAV kept from the subject during the experiment was 4621.46 mm.

With the pilot's motions recorded as the reference and the UAV's motions recorded, the RMSE can be calculated in the x- and y-directions. Using Equation (1), these were 452.47 mm for $RMSE_x$ and 332.66 mm for $RMSE_y$. These RMSE values indicate that the UAV operating in object tracking mode operates with an average error of 452.47 mm and 332.66 mm in the x-axis and y-axis, respectively.

Figure 4(b) shows a x-z-side view depicting the height of the UAV as it operates in object tracking mode. The object tracking mode was activated at a height of 1959.91 mm and it kept an average height of 1895.80 mm and an RMSE of 95.06 mm, meaning the UAV would fly with an average height error of 95.06 mm.



(a) Pilot and UAV trajectories in the x-y-plane



(b) UAV height trajectories in the x-z-plane

Fig 4: UAV and pilot trajectories during object tracking

During the experiment, it was noticed the UAV's object tracking mode would disable itself, and the UAV would hover in place, if it detected that the flying space was too narrow, or if the UAV was close to an object it could collide with. This behaviour was anticipated as the collision avoidance function "Brake" was enabled on the UAV at the beginning of the experiment to protect it from the environment. This shows that the proximity sensors on the UAV work to monitor the surrounding environment and the UAV is then able to execute the collision avoidance functions.

At the start of the experiment, the UAV portrayed some interesting behaviour. Figure 5 depicts the motions of the pilot and the UAV at the beginning of the experiment. When starting the object tracking function, the subject started moving laterally along the x-axis and the UAV would hover in place, yaw, and pan the gimbal to keep the object of interest in the camera frame. This is shown by the UAV remaining at the origin for most of the duration that the pilot's markers move along the x-axis. When the pilot was about 4 m away from the UAV, the UAV would roll and move in the direction of the object of interest to track it. This is shown by the small movement of the drone along the x-axis in Figure 5.

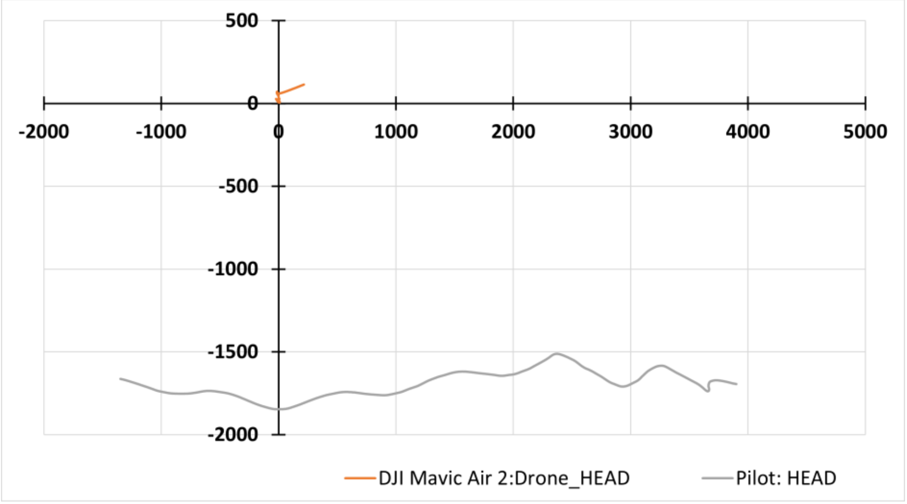


Fig 5: UAV hovering in object tracking mode.

This behaviour shows that the object tracking feature of the UAV would operate differently in smaller environments tracking objects that move near the UAV. Because the object tracking function of the UAV works to keep the object of interest in the camera frame from 4 m away with the gimbal fixed in position, the UAV would struggle to follow the object of interest if it were to go around a corner or through a doorway. From Figure 4(a), it is observed that the UAV only replicates the motions of the object from 4 m away in the y-direction. If the system had some intelligence to monitor and fly to the point where the UAV lost visuals of the subject, which could be before the object moved around a corner or walked through a doorway, the UAV would be a more robust vehicle in tracking objects in dynamic environments.

Therefore, the UAV would operate more effectively in an open plan environment with high ceilings. The UAV would need to be set to hover above people or equipment, with the gimbal tilted down to view the object or person of interest to be tracked. The person or object would be tracked from 4 m away and the drone would keep the subject in good view without the risk of colliding with the environment. This could be useful in monitoring of jobs, services, or processes remotely or tracking an object as it moves through a production line. Another possible application would be to use the UAV in a warehouse to track a person in an aisle that is at least 3 m wide and 11 m high. The use of the object tracking feature of the DJI Mavic Air 2 would be useful along the length of the aisles as the RMSE values in the x- and y-directions would be accommodated by the size of the aisles.

4 Conclusion

For this paper, the reliability of using a visual-based tracking system for a UAV in an indoor environment was studied. A DJI Mavic Air 2 was used to track a reference subject, and the motions of each were recorded under a motion capture system for further analysis. It was found that when the UAV was in “object tracking mode”, it would keep an average of 3915.23 mm in the y-direction away from the subject. The UAV was able to track the subject with a RMSE of 452.47 mm and 332.66 mm in the x-direction and y-direction, respectively. These values indicate that the UAV operating in object tracking mode operates with an error of 452.47 mm and 332.66 mm in the x-axis and y-axis, respectively. Additionally, the UAV was set to track the subject at a height of 1959.91 mm, and it operated at an average height of 1895.80 mm, with an RMSE of 95.06 mm relative to the starting height.

From the results, the UAV could be used effectively in indoor environments such as warehouses. The UAV could follow a subject along the long aisles of the warehouse, or in an open-plan warehouse.

For future work, it would be interesting to study the effect of fixing the gimbal on the UAV to mitigate the position offset in the x-direction between it and the subject. To make the UAV more robust, the UAV could be configured to avoid obstacles instead of braking when it comes across an obstacle. Lastly, investigating the possibility of the UAV to follow the predicted path of the subject without the offset in the y-direction while avoiding objects in the environment if a physical obstruction were to be encountered would make the UAV a more robust vehicle to use in dynamic environments.

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