

Improving Unmanned Aerial Vehicle Pilot Training and Operation for Flying in Cluttered Environments

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Abstract—Future applications will bring unmanned aerial vehicles (UAVs) to new environments such as urban areas, causing a change in the way that UAVs are currently operated. However, UAV accidents still occur at a much higher rate than the accident rate for commercial airliners. Therefore, there is a need to better train UAV pilots and augment their performance to minimize accidents. In this paper, the authors present two methods for generating a chase view point (similar to the view of being towed behind the aircraft). Through use of these viewpoints, the authors propose to increase the situational awareness of UAV operators when flying in cluttered environments. The chase view combines a rotated onboard camera view with a virtual representation of the vehicle and the surrounding operating environment. Experiments were conducted evaluating a chase view versus a traditional onboard camera view during UAV flights using a 6 DOF gantry system. Results showed that the chase view improved UAV operator performance.

I. INTRODUCTION

Advances in technology are allowing UAVs to extend their role beyond the traditional high altitude surveillance. Small, lightweight UAVs are now capable of carrying complete avionics packages and camera systems, allowing them to fly in environments much too cluttered for the popular large scale systems such as the Predator. There is also a desire to have UAVs move beyond their typical actions of passive interaction in the environment (surveillance) to active interaction with objects in the environment (air cargo transport and med-evac missions). This will cause a change in the way that they are currently operated. However, the potential for damage to property and risk of injury can not be overlooked as UAV accidents are almost 100 times more common than commercial airline accidents, and are increasing [1]. Many civilian applications will put these vehicles in low flying environments typically cluttered with buildings, power lines, and more importantly, human bystanders. This demands that these vehicles are operated very safely. The authors believe that during operation in typical cluttered environments, a system that is agile but under full control of a human operator is a desired method due to current limits of artificial intelligence.

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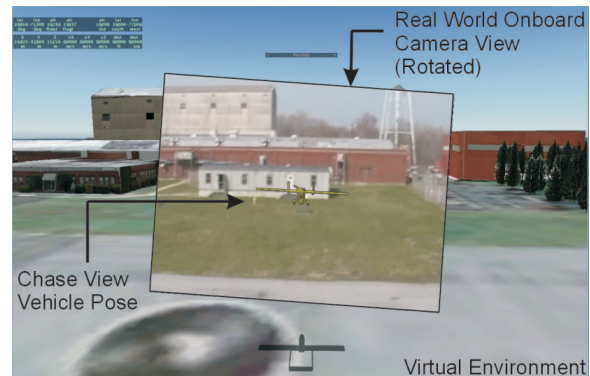


Fig. 1. Screenshot of the Graphical Interface for the UAV pilot demonstrating our chase viewpoint during UAV operation in a near-earth environment.

Safe and efficient remote operation of a UAV requires that the pilot have a good sense of the state of the vehicle and the surrounding environment that the vehicle is operating in. This awareness of the state of the vehicle and its surroundings is called situational awareness (SA). The accepted definition of SA comes from [2] where SA is broken down into levels. Level 1 SA is the perception of the elements in the environment within a volume of time and space. Level 2 SA is the comprehension of their meaning and Level 3 SA is the projection of their status in the near future. Situational awareness is effected by many factors. Current remote and autonomous systems are limited in what information is relayed from the vehicle back to the UAV pilot/operator. The operator's physical separation from the vehicle eliminates all motion feedback where as manned aircraft pilots utilize this motion to help in vehicle control. Currently, onboard camera viewpoints limit UAV pilots in many ways such as reducing the field of view and requiring more intensive mental mapping of the environment by the pilot due to changing camera angles. The limited field of view also makes it difficult for the pilot to know the location of the extremities of the vehicle, which the authors believe to be critical knowledge when operating in a cluttered environment. The constantly changing camera angles also can lead to vertigo for the pilot. These limitations combined with a high workload lead to a lower SA thereby increasing the chance for a mishap or accident. Successful use of UAVs for civilian applications requires that we design systems and protocols that can prevent UAV accidents, better train UAV operators, and augment pilot performance.

In prior work, the authors investigated the use of motion platform technology to relay motion cues to a UAV pilot [3].

In this paper, we investigate an alternative approach to improving SA that utilizes sensor packages common on most UAV systems. The approach uses an onboard camera and an inertial measurement unit to generate a mixed-reality chase viewpoint to the operator as seen in Fig. 1. The mixed-reality notion comes from the fact that the surrounding environment displayed to the pilot (outside of the onboard camera field of view) is a virtual representation. There are two methods that we are developing to generate the mixed-reality chase viewpoint. In Method I, the surrounding environment is created by real-time mapping of planar features extracted from the onboard camera view. In Method II, as seen in Fig. 1, the surrounding environment is created using the GPS position and IMU attitude of the aircraft and a prior model of the operating environment. For the chase viewpoint, the onboard camera view is relayed to the pilot and is rotated, keeping the horizon level, and keeping the perspective consistent with the displayed chase viewpoint. This allows the pilot to see the entire aerial vehicle pose and surrounding environment as if they were following a fixed distance behind the vehicle. The benefits of this viewpoint are an increased awareness of the extremities of the vehicle, a better understanding of its position in the environment, easier mental mapping of the environment, and a stable horizon.

A major contribution of this paper are the results from studying the differences when piloting a UAV in an cluttered environment while using a chase viewpoint versus using an onboard camera viewpoint. Also presented is the continuing work toward developing this approach for real world testing. The rest of this paper is organized as follows: section II gives background on the previous work conducted in the area of improving situational awareness for UAV pilots; section III presents the methods for generating a chase view for UAV operation; section IV presents the experimental setup for evaluating UAV pilot skills in cluttered environments with different viewpoints; section V presents the results from the study; and section VI concludes the paper with a discussion and future work.

II. PREVIOUS WORK

Situational awareness for operators of robotic ground and aerial vehicles has been investigated by a few researchers such as in [4]. It was reported that robots being operated at a post World Trade Center site were being operated with some sort of operator error 18.9% of the time due to poor interfaces and lack of functional presence [4]. Research such as this and others have lead to proposals on ways to improve UAV pilot situational awareness such as new designs for head up displays, adding tactile and haptic feedback to the control stick and larger video displays. Synthetic vision, in recent years, has been studied and shown to improve situational awareness for remotely piloted vehicles [5]. Synthetic vision displays to the operator an onboard camera view with a field of view enhanced by virtual terrain data. It is mostly used to depict the planned trajectory for support in guidance and control. A few concepts for exocentric views have been explored for ground vehicles [6], [7].

Closely related to the work of this paper is the work conducted by [8], [9]. In [8], they used simulated video data of a high altitude UAV flight and augmented it with pre-loaded map data (satellite imagery). The down-looking onboard camera view was rotated to match the preloaded terrain map and a silhouette of the UAV is displayed on the map showing its heading. Their results showed that the augmented image helped the observers comprehension of the 3D spatial relationship between the UAV and points on the earth. In [9] they investigated the effects of displaying a simplified "wing-view" of the UAV to the operator via a PDA display that showed the roll and altitude of the aircraft. This display helped with the operator's understanding of the instantaneous relationship between the UAV and the world.

III. METHODS TOWARD GENERATING CHASE VIEW

UAVs, especially those flown in urban environments, will be small so they can maneuver between obstacles with relative ease. The small size limits the payload capacity of the vehicle. Laser range sensors, like those used in [7], can be too heavy to add to a typical UAV sensor suite that already includes an IMU, GPS and an onboard camera. Utilizing the IMU and onboard camera, the authors of this paper show two methods for generating a chase view point for UAV pilots.

Method I utilizes an onboard camera, GPS, and IMU to generate a 3D map of the environment. Method II utilizes the onboard GPS and IMU of the aircraft and prior knowledge of the operating environment to generate a surrounding 3D map. The advantage of Method I is that a map is created based on a very recent interaction with the environment and can be used without prior knowledge of the operating area. It can also be adapted to work in areas without GPS. Method I however comes at a cost of computation power, which limits the speed at which the UAV is able to fly safely in the environment. Method II allows for much faster flight as the environment is already mapped. However, should the environment change, the pilot will be forced to mentally remap the surrounding environment during the flight using the onboard camera view.

A. Method I

A chase viewpoint requires three dimensional measurements of the surrounding environment and accurate knowledge of the state of the vehicle. Researchers are currently working on methods to gather this information from only one onboard camera using Structure from Motion (SFM) methods [10]. The added benefits of this is that UAVs can be smaller, and the vehicle is capable of map building in areas with no GPS signal. As these methods are currently computationally expensive, the authors of this paper chose to use information from an onboard IMU, GPS, and camera for the initial work toward developing the chase viewpoint. The technique for Method I is presented in the following sub sections.

1) *Feature Detection and Tracking*: Creating a map of the surrounding environment from the onboard camera view requires that three-dimensional information be extracted from multiple two-dimensional camera images. Features in each

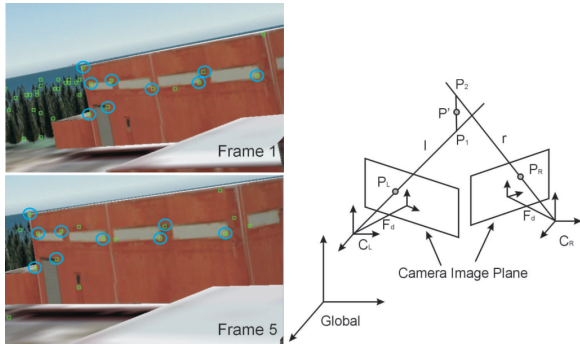


Fig. 2. Left: Feature tracking across multiple frames. The tracked features used in reconstruction are highlighted by circles. The frames contain a rotated view (aircraft is rolling) side of a warehouse building where most of the features detected are window corners. Right: Camera reconstruction geometry. Due to noise in the measurements, rays passing through the feature in the first and second camera image, CL and CR, plane may not intersect. The midpoint of the closest point between the two rays is taken as the feature measurement.

image must be found and tracked from frame to frame. The authors use a 7×7 feature detection window and calculate the spatial gradient matrix as the window scrolls through the camera image. Features are chosen such that they are the strongest features in the image, don't overlap, and only a set number of features desired by the user are kept.

Tracking of the feature points is conducted using a pyramidal implementation of the Lucas Kanade feature tracker (KLT) [11]. The pyramidal implementation allows for much larger movement between two images. Currently the authors are using a 3 level pyramid which can track pixel movement 8 times larger than the standard Lucas Kanade tracker.

The tracking (50 features) is at sub pixel resolution and is currently running at 10 FPS on a 2.33GHz dual core machine. A UAV's onboard camera typically transmits real-time images at 30 frames per second to a ground-station computer. The onboard camera view at this frame rate can still be transmitted to the pilot. It is the reconstructed surrounding viewpoint that is limited to the 10 FPS, however, the program is being modified using vision graphic libraries such as OpenVC to improve this.

2) *Reconstruction and Mapping*: For the initial development, we are utilizing a simulated environment modeled in the flight simulation package X-Plane from Laminar Research. Since the authors chose to use an IMU and GPS along with the camera, structure from motion methods are not needed and the 3-Dimensional locations of the feature points can be found through euclidean reconstruction [12]. The extrinsic parameters for the camera are extracted from GPS and IMU measurements in the X-Plane simulation. The intrinsic parameters of the camera are calculated prior to the tests using multiple images of a known grid pattern. Calibration experiments found the focal length for the camera in the X-Plane environment to be 320.469 mm. Each feature point is stored in its initial frame and then tracked. If the feature point is successfully tracked for 5 frames, it is used in the reconstruction algorithm as seen in Fig 2.

Currently the method is run without any filtering of the

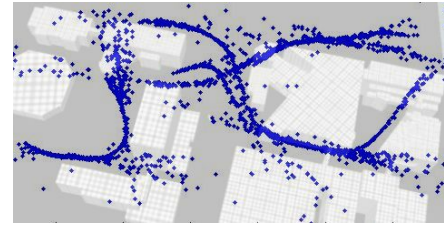


Fig. 3. Top down view of raw (non-filtered) reconstruction of feature points with flight environment overlaid over the data. Most data points far away from building edges are points reconstructed from features detected on the ground.

data so the results are somewhat noisy as seen in Fig. 3.

Adapting a method for mapping similar to that presented by [13], we will merge the feature points into planar regions for use in SLAM. The benefits of planar regions is that it dramatically reduces the number of stored feature points needed to create a map. Much of urban terrain contains rectangular buildings. Therefore, many detected features can be turned into planar regions that represent building walls and rooftops. The chase viewpoint will then be generated by taking the created map and surrounding the onboard camera view. This method of generating the chase view allows for a current map of the environment to be relayed to the operator at the expense of high computation requirements and limited flight speed.

B. Method II

As stated earlier, Method II requires much less computation during the flight as the operating environment is modeled prior. In urban terrain, most buildings will not change much, if at all, between modeling and flight which makes Method II valid. For this paper, X-Plane flight simulation software is used to model the UAV operation environment during flight tests. Aircraft position and attitude in the real world is matched in the virtual world using GPS and IMU measurements from the avionics sensor suite onboard the UAV. The virtual aircraft is positioned identically in the virtual world to that of the real world which allows for the virtual environment to match up with the real world environment. The onboard camera images from the UAV are rotated based on the roll angle received from the onboard IMU, leveling the horizon. The rotated onboard camera image is then overlaid on top of the virtual world image. An avatar of the aircraft is positioned and oriented to match with the perspective of the views and completing the chase view interface.

IV. EXPERIMENT SETUP

To test and evaluate efforts toward generating a chase viewpoint for UAV pilots, experiments were setup to assess pilot skills operating in a cluttered environment using an onboard camera viewpoint and a generated chase view point. The ideal scenario is to have a chase-view of the actual environment built from the real sensor data. Method I is the work we have done toward that goal. However, results are noisy and the update rate is slow. To evaluate the utility of a chase view, we conducted tests using Method II. The

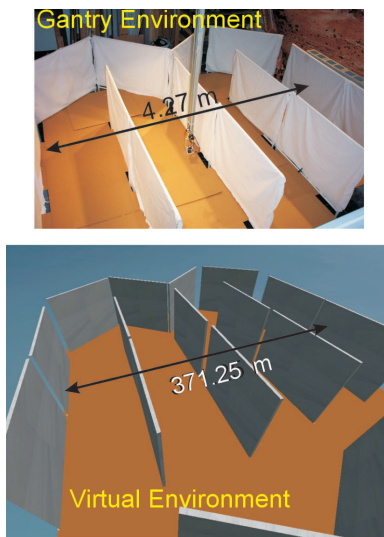


Fig. 4. Comparison showing the real world scale flight environment with the H0 scale (1:87) SISTR environment. The white gates create narrow corridors representative of flight between large buildings in an urban environment.

experiment results presented later in this paper are a result of this.

A. Hardware

Field testing at the current stage of the project is risky and requires a long process of approvals to operate a UAV in restricted airspace. Tests using only a flight simulator would help validate the design notion but it is difficult to simulate the mechanical systems/sensors used in real world tests and environmental conditions. Because of these reasons, the authors took advantage of the Systems Integrated Sensors Test Rig (SISTR) facility at Drexel University to conduct flight experiments in a scaled environment with actual UAV system hardware. SISTR is a 3 degree of freedom (DOF) gantry system with a workspace of 18'x14'x6' [14]. To match the size of a reasonable real world UAV test environment, SISTR's workspace represented an H0 scale (1:87) environment as seen in Fig. 4. The flight environment consisted of corridors that can be representative of corridors between large buildings in an urban environment.

SISTR's end effector is used to represent the location of the aircraft inside of the scaled environment. Aircraft dynamics during the experiments are handled by a flight simulation package and the H0 scaled translational position of the aircraft is relayed from the flight simulator to SISTR's controller via User Datagram Protocol (UDP) at a rate of 20HZ.

The aircraft's control surface deflections are commanded by the subject (pilot) via a joystick. The resulting angular position of the aircraft, generated by the flight simulator, is relayed to a 3 DOF yaw, pitch and roll (YPR) unit attached to SISTR's end effector as seen in Fig. 5. The YPR unit was specifically designed such that it represented the Euler angles of the aircraft; yaw is applied first, then pitch, then roll. It was also designed to have a small footprint due to operation in a

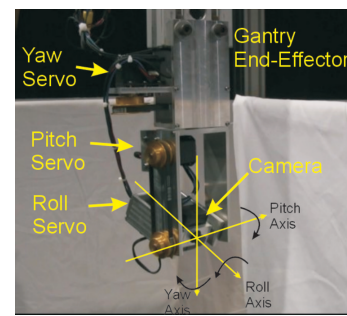


Fig. 5. Yaw, pitch and roll unit used to recreate the angular position of the aircraft inside of SISTR. The unit is designed based on the Euler angles of the aircraft. Yaw is applied first, then pitch, then roll.



Fig. 6. The MAKO UAV developed by NAVMAR was modeled in X-Plane and used for experiment flights.

scaled environment. A 640x480 resolution wireless camera with 70 degree field of view, seen in Fig. 5, was attached to the YPR unit. The images from the camera represented the onboard camera view from the aircraft and were relayed to the experiment subject (pilot) at a rate of 15 frames per second.

B. Software

Aircraft dynamics and the virtual environment are generated using a commercial flight simulator software known as X-Plane. X-Plane incorporates very accurate aerodynamic models into the program based on blade element theory and allows for real time data to be sent into and out of the program. During the experiment, flight commands are input into X-Plane by the subject via a joystick and X-Plane generates and sends the translational and angular positions of the aircraft through UDP to the SISTR controller. X-Plane is also used during the chase view experiments to render the surrounding virtual view of the aircraft environment. The H0 scale environment in SISTR was built to match the full scale corridor environment we created in X-Plane. The optics of the onboard camera are accounted for by adjusting the aspect ratio in X-Plane so that the virtual environment matches up with the onboard camera view.

A UAV model was created that represents a real world UAV, known as the Mako, currently in military operation. The Mako, as seen in Fig. 6, is a military drone developed by Navmar Applied Sciences Corporation. It is 130lbs and has a wingspan of 12.8ft. For safety reasons, the simulated version of the Mako was modified so it was lighter weight with less horsepower effectively decreasing its cruise speed to 45 miles per hour in the simulation which corresponds to 9 inches/second in SISTR motion at H0 scale.

C. User Interface

The user interface was created using Visual C#. The program handled the visual presentation to the user and



Fig. 7. Onboard camera view capture during H0 scale flight tests. This shows a view of the corridor environment during a turn maneuver by the aircraft.

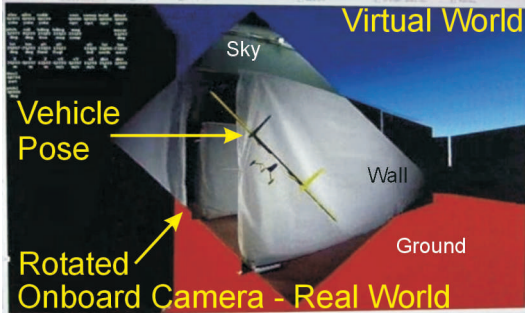


Fig. 8. Chase View Interface during H0 scale flight tests. This shows a view of the corridor environment during a turn maneuver by the aircraft.

also the communication between X-Plane and SISTR. The program collected translational and angular position data from X-Plane, converted it to H0 scale and then transmitted it through UDP to SISTR at 20Hz. During onboard camera tests, only the onboard camera view was shown to the pilots during flights through the environment as seen in Fig. 7. During the chase view tests, the program displayed to the pilot 3 items:

- 1) Rotated onboard camera view so the horizon stays level
- 2) Virtual view of the surrounding environment based on aircraft location and prior model of the environment
- 3) Virtual representation of the aircraft pose to scale with the onboard camera view and surrounding environment

These items, seen in Fig. 8 are relayed in real time to the pilot.

D. Procedure

Twelve subjects were used, all of varying flight simulator experience ranging from 0 hours to multiple years. Prior to the tests, subjects were given time to fly the Mako in an open environment in X-Plane under both simulated onboard camera view and chase view. This allowed them to become familiar with the controls and to get a feel for the response and size of the aircraft. When the subjects felt comfortable with the controls, the experiments began. The subjects were placed in a room, separated from the experiment environment, with a 52" monitor from which to view the user interface. Subjects underwent multiple tests where they flew the aircraft from an onboard camera view or a chase view. During onboard camera tests, the subjects

Onboard Camera View vs. Chase View Pilot Flight Paths

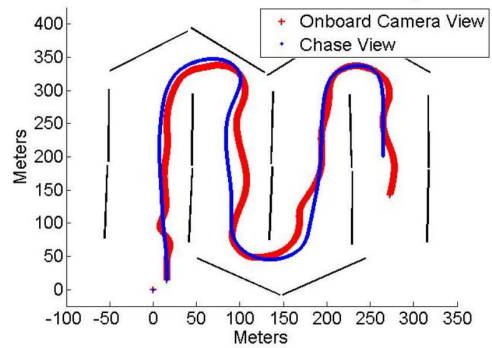


Fig. 9. Example data of the flight path taken (full scale, top view) during an onboard camera and chase view test. The thin line represents the chase view flight path and the thick line represents the onboard camera view flight path. The flight environment is overlaid on top of the graph.

TABLE I

AVERAGE MAGNITUDE ANGULAR ACCELERATION FOR CHASE VIEW (CV) AND ONBOARD CAMERA VIEW (OC) TESTS.

Subject	Mag(deg/s ²)	Subject	Mag(deg/s ²)
1 OC	95.52	7 OC	46.57
1 CV	22.88	7 CV	15.57
2 OC	45.10	8 OC	47.88
2 CV	42.75	8 CV	15.78
3 OC	73.17	9 OC	180.97
3 CV	63.36	9 CV	160.69
4 OC	89.83	10 OC	110.88
4 CV	60.82	10 CV	107.67
5 OC	57.29	11 OC	72.37
5 CV	25.64	11 CV	58.37
6 OC	69.48	12 OC	54.35
6 CV	71.67	12 CV	65.91

were shown only the raw view from the camera and asked to smoothly fly through the corridors of the environment while keeping a safe distance from the walls. During the chase view tests, the subjects were shown the chase view and asked to fly through the corridors with the same emphasis on safe distance and smooth flight. During each test, aircraft translational and rotational positions and accelerations were recorded.

V. RESULTS AND DISCUSSION

Shown in Fig. 9 is one subject's example that is very much representative of the flight paths taken by most subjects when using the onboard camera view (thin line) and the chase view (thick line). While using the onboard camera view, subjects showed much more of an oscillatory movement than while using the chase view. Not being able to see the aircraft caused some subjects to overcompensate in the controls which led to increased oscillations in the flight. This result is much easier to observe in Fig. 10 which shows the angular positions of the aircraft during the example flights presented in Fig. 9. During the onboard camera view tests, the subjects tended to move through a larger angular range and at a higher frequency than during the chase view tests. This is significant as quick turns under normal UAV operations can

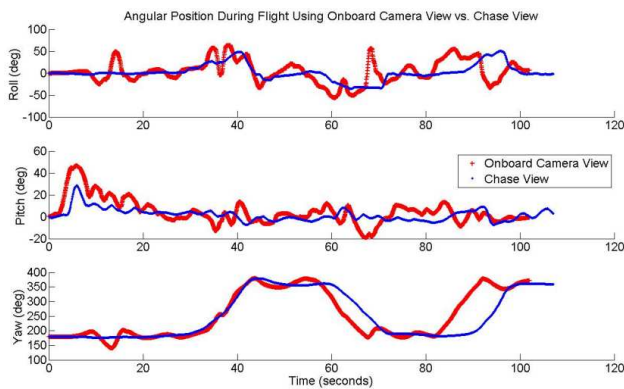


Fig. 10. Example data of the aircraft angular positions during an onboard camera and chase view test. The thicker line represents angles achieved using the onboard camera view the thinner line represents the angles achieved using the chase view.

induce high stresses on the vehicle leading to accelerated wear and tear, which in turn can lead to accidents. Since the goal was to keep the aircraft as stable as possible, angular accelerations were recorded to quantify how well the subjects were able to do this. Table I shows the average magnitude of angular acceleration during chase view for each subject. This value is the average magnitude encompassing data from all chase view trials for that subject. Similarly the average magnitude of angular acceleration during onboard camera view is shown for each subject. The trend in the data leads to the conclusion that the chase view decreases the angular accelerations commanded during the flight. Only 2 subjects showed a higher angular accelerations using chase view over onboard camera view. However the difference was not very large. Interesting to note, some subjects such as subject 2 and 3, did not show a dramatic decrease in the angular accelerations when switching from onboard camera view to a chase view. This shows that the view did not help the subject decrease the amount of movement they were commanding to the vehicle. However, a closer look at their flight paths showed that chase view did accomplish a safer path through the environment. Most subjects after the tests stated that the chase view was much easier to operate with. For some subjects, the onboard camera view was so disorienting that they were unable to complete the course. This was more common among subjects who had very little to no prior flight simulator experience. All of these subjects however were able to complete the course using the chase view within 2 trials. The example results presented in Fig. 9 and Fig. 10 were from a subject with a good amount of prior flight simulator experience. There was still an improvement in his operation when using the chase view over the onboard camera view.

VI. CONCLUSION AND FUTURE WORKS

A. Conclusions

Future applications for UAVs will take them into low flying areas populated with obstacles and civilians. Increased situational awareness for the pilots and operators controlling those UAVs will most certainly help decrease the potential

for crashes and thereby decrease the chances of property damage or harm to civilians. This paper presented the development and evaluation of implementing a chase viewpoint for UAV operations. Results from the experiments show that the chase view method has potential to increase the situational awareness of UAV pilots. The results also showed that the chase view resulted in smoother motions and flight paths for the UAV.

B. Future Works

The chase view method can certainly use more validation. The authors feel a more significant impact for a chase viewpoint can be found when using rotorcraft and also for situations where accurately positioning and orienting the aircraft is important. These tests are scheduled in the near term. Future work involves testing current Predator Pilots and other UAV operators. Real world field tests are also desired for complete validation of the chase view.

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