An Indoor Study to Evaluate A Mixed-Reality Interface For Unmanned Aerial Vehicle Operations in Near Earth Environments

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ABSTRACT

As the appeal and proliferation of UAVs increase, they are beginning to encounter environments and scenarios for which they were not initially designed. As such, changes to the way UAVs are operated, specifically the operator interface, are being developed to address the newly emerging challenges. Efforts to increase pilot situational awareness led to the development of a mixed reality chase view piloting interface. Chase view is similar to a view of being towed behind the aircraft. It combines real world onboard camera images with a virtual representation of the vehicle and the surrounding operating environment. A series of UAV piloting experiments were performed using a flight simulation package, UAV sensor suite, and an indoor, six degree of freedom, robotic gantry. Subjects' behavioral performance while using an onboard camera view and a mixed reality chase view interface during missions was analyzed. Subjects' cognitive workload during missions was also assessed using subjective measures such as NASA task load index and non-subjective brain activity measurements using a functional Infrared Spectroscopy (fNIR) system. Behavioral analysis showed that the chase view interface improved pilot performance in near Earth flights and increased their situational awareness. fNIR analysis showed that a subjects cognitive workload was significantly less while using the chase view interface.

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Keywords

UAV, pilot training, mixed reality, near Earth environments

1. INTRODUCTION

Systems like the Predator and Reaper have an incredible success rate conducting medium to high altitude long endurance missions that include surveillance, targeting, and strike missions [3]. However, UAVs are evolving and quickly expanding their role beyond the traditional higher altitude surveillance. Due to advances in technology, small, lightweight UAVs, such as the Raven and Wasp, are now capable of carrying complete avionics packages and camera systems, giving them the capability to fly in environments much too cluttered for the proven large scale systems [3]. As such, changes to the way UAVs are operated, specifically the operator interface, are being developed to address the newly emerging applications.

There are many challenges to face when designing new UAV interfaces and trying to incorporate high situation awareness and telepresence for a UAV pilot. For one, the pilot is not present in the remote vehicle and therefore has no direct sensory contact (kinesthetic/vestibular, auditory, smell, etc.) with the remote environment. The visual information relayed to the UAV pilot is usually of a degraded quality when compared to direct visualization of the environment. This has been shown to directly affect a pilot's performance [10]. The UAV pilot's field of view is restricted due to the limitations of the onboard camera. The limited field of view also causes difficulty in scanning the visual environment surrounding the vehicle and can lead to disorientation [4]. Colors in the image can also be degraded which can hinder tasks such as search and targeting. Different focal lengths of the cameras can cause distortion in the periphery of images and lower image resolution, affecting the pilot's telepresence [5]. Other aspects causing difficulties in operations are large motions in the display due to the camera rotating with the UAV and little sense of the vehicle's size in the operating environment. This knowledge is highly important when operating in cluttered environments.

Prior research from the authors [7] has introduced a mixed-reality chase view interface for UAV operations in near Earth environments to address many of these issues. Near Earth in this work represents low flying areas typically cluttered with obstacles such as trees, buldings, powerlines, etc. The chase view interface is similar to a view from behind the aircraft. It combines a real world onboard camera view with a virtual representation of the vehicle and the surrounding operating environment. The authors' prior research in [7] also presented the development of an indoor gantry system that can be used to evaluate UAV operations in near Earth environments. The 6 degree of freedom indoor robotic gantry was used to safely test and evaluate the chase view interface using different pilots and mission scenarios without the risk of costly crashes. Inside the gantry workspace is a recreation of a real world flight environment. The dynamics of the gantry end effector (holding the UAV sensor suite) is driven by the output from a flight simulation program. The author's prior results of indoor gantry trials showed an observed improvement in pilot control and precision positioning of an aircraft using the chase view interface as compared with a standard onboard camera view. These results supported the efforts toward a more extensive human factor study to validate the early claims.

Not previously studied was the cognitive workload of the subjects while using the chase view system. Data about operator cognitive workload and situational awareness are very important aspects of safe UAV operation. Low situational awareness requires higher cognitive activity to compensate for the lack of intuitive cues. Complex mission scenarios also inherently involve high cognitive workload. If a pilot can perform well using the interface but requires a high level of mental processing to do so, they may not have a suitable level of mental resources available during the flight to safely handle unexpected events such as faults or warnings. Current techniques in UAV training and pilot evaluation can be somewhat challenging for cognitive workload assessment. Many of these types of studies rely partly on self reporting surveys, such as the NASA Task Load Index (NASA-TLX) [6]. However, this is still susceptible to inconsistencies in the subject responses over a series of tests.

The use of functional near-infrared (fNIR) brain imaging in these studies enables an objective assessment of the cognitive workload of each subject that can be compared more easily. The Drexel Optical Brain Imaging Lab's fNIR sensor uses specific wavelengths of light introduced at the scalp. This sensor enables the noninvasive measurement of changes in the relative ratios of de-oxygenated hemoglobin (deoxy-Hb) and oxygenated hemoglobin (oxy-Hb) in the capillary beds during brain activity. Supporting research has shown that these ratios are related to the amount of brain activity occurring while a subject is conducting various tasks [8]. By measuring the intensity of brain activity in the prefrontal cortex, one can obtain a measure of the cognitive workload experienced by the subject [12, 11]. The results can also be used to enhance the self reported (subjective) workload results.

2. HYPOTHESES

Based on previous results found in [7], the following hypotheses are formulated:

2.1 Behavioral Hypothesis

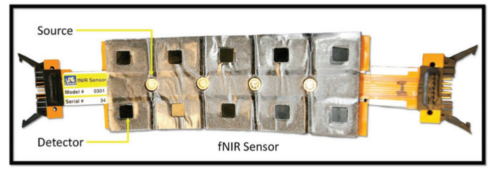

Figure 1: fNIR sensor showing the flexible sensor housing containing 4 LED sources and 10 photodetectors.

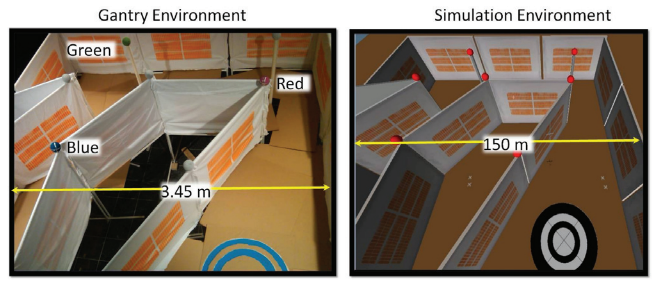

Figure 2: Left: Flight environment inside the gantry built at 1:43.5 scale. Highlighted in the image are the colored markers for the second level of the environment. Right: Simulated full scale environment.

The chase view interface will improve a pilot's understanding of the 3D spatial relationship of the aircraft and its surroundings. It will also help pilots to produce more efficient flight paths (ie. tighter turns around obstacles).

2.2 Cognitive Hypothesis

Cognitive workload of the pilot will decrease using chase view. This is due to the stabilized camera image (horizon remaining level) and more of the environment displayed in the image. fNIR will detect a change in blood oxygenation (ie. cognitive workload) for onboard camera view subjects that is higher than chase view subjects due to the increased mental mapping and prediction of aircraft position required while using the onboard camera perspective.

3. EXPERIMENTAL SETUP

A majority of the experimental setup is the same as the setup described in [7]. Integration of the fNIR system, changes to the gantry environment, and changes to the chase view interface as well as the onboard camera interface are highlighted.

3.1 fNIR

The fNIR sensor consists of four low power infrared emitters and ten photodetectors, dividing the forehead into 16 voxels. The emitters and detectors are set into a highly flexible rectangular foam pad, held across the forehead by hypoallergenic two-sided tape. Wires attached to each side carry the information from the sensor to the data collection computer. The components of the fNIR systems are seen in Figure 1.

3.2 Flight Environment

The gantry environment (Figure 2) consists of two flight levels. The lower level contains corridors and two tall pole

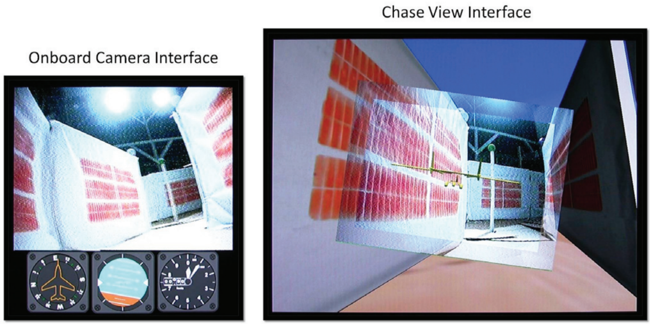

Figure 3: Left: Onboard camera view with virtual instruments positioned below the image to relay information about the vehicle state. Right: Chase view with alpha blended borders.

obstacles. The upper level contains a series of colored spherical fiducials attached to the top of the corridor walls and obstacles. The physical workspace of the gantry environment is the same as in [7] however this environment is built to 1:43.5 scale to allow for accurate representation of the UAV wingspan with the width of the gantry end effector. For this study, a model of a Mako UAV with a 13 foot wingspan was used. Due to the temporal resolution of the fNIR sensor on the order of seconds, the environment was designed to continually require the pilot to update their path planning. The close quarters and multiple obstacles help to extract metrics during flights to test the hypotheses.

3.3 Interface Modifications

Discussions with subjects from earlier work raised an issue about the border between the rotated onboard camera and the surrounding virtual image for the chase view interface. At times there was a high contrast between the border which distracted subjects and drew their attention away from the center of the interface. The new design for the chase view interface, shown in Figure 3, addressed this issue with an added alpha blended border between the previous border of the rotated camera image and the surrounding virtual view. This helped to dramatically reduce the border contrast as well as increase subject immersion into the environment.

The onboard camera interface was modified to give a better representation of the information currently available to internal UAV pilots. Predator pilots have a heads up display superimposed onto the onboard camera images. This heads up display gives them a sense of the aircraft relative to the artificial horizon, bearing angle, and altitude. For lower computer proccessing load, the heads up display was replaced with virtual instruments as seen in Figure 3, similar to the instruments used on manned aircraft. These virtual instruments were placed directly below the onboard camera image, in clear view of the subject. The instruments displayed the aircraft relative to the artificial horizon, bearing angle, and altitude.

4. PROCEDURE

To assess the efficacy of the two interfaces, eleven laboratory personnel volunteered to test the conditions and to finalize the methodology; 1 female and 10 males. Differently from [7], for these tests, the subjects were separated

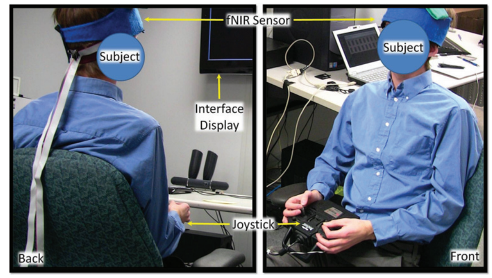

Figure 4: Subject operating environment. The fNIR sensor is shown strapped to the forehead of the subject with a blue felt cover to block ambient light.

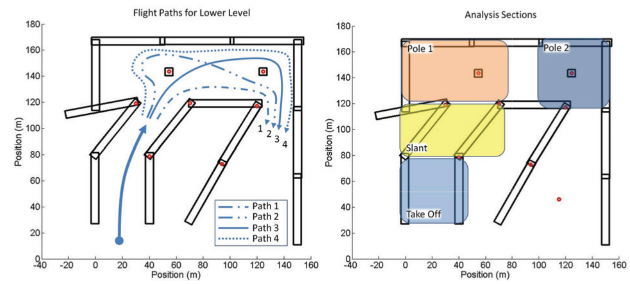

Figure 5: Left: Top down view of the environment with the 4 flight paths through the lower level highlighted with different patterns. Right: Analysis sections of the environment

into two groups. Six subjects operated the aircraft using only the chase view interface (chase view) and five subjects operated the aircraft using only the onboard camera interface (onboard view). One chase view and two onboard view subjects had over 200 hours of flight sim experience. These same subjects also had prior remote control aircraft training. Only one subject (chase view) had no flight sim experience at all. The rest of the subjects fell in between 1 to 200 hours of flight sim training.

There were a total of nine sessions, of which eight were recorded flight sessions. The fNIR sensor was placed on the participant's forehead during all eight flight sessions as seen in Figure 4. In all, 374 flights through the environment were recorded.

Before the beginning of each flight, an individual's cognitive baseline was recorded. This was a 20 second period of rest while the fNIR recorded oxygenation levels.

4.1 Session One

The subjects had a fifteen-minute introduction and free-flight session to get familiar with the dynamics of the aircraft and the flight controller.

4.2 Sessions Two through Nine

During each of these sessions, the subjects conducted four flight trials. Each trial represented a different flight path to follow through the environment as well as a different marker setup for the second level. The four flight paths can be seen in Figure 5. An example of the marker setup can be seen in Figure 2 where the subject is required to fly over the blue marker, then the red marker and finally the green marker. All four paths were flown during each session but were presented to the subject in random order. The marker setup was also presented in random order, however there was a total of 20 possible marker combinations.

During the flight sessions, subjects had four goals. The first goal was to fly through the test environment while maintaining a safe distance from the corridor walls and obstacles. The second goal was to correctly fly in the appropriate path around obstacles placed inside the environment. For the third goal, there was a ground target located near the end of the flight environment. The goal was to trigger a switch on the joystick when the subject felt that they were directly over the target. After the target is reached, the aircraft is automatically raised to the second level of the environment, above the corridor walls. The final goal was to fly directly over the center of the colored targets in the correct order supplied to them prior to flight. At the completion of each session (four flights in a session), the subject completed the NASA-TLX.

Starting with session seven, subjects were shown a top down view of their flight trajectory and target triggering location. This was introduced because it was noticed that most subjects' performance were saturated after six sessions. For session one through six, there was no feedback given to the subjects about their performance other than the visuals received from the interface itself.

4.3 Session Ten

The final session (session ten) was performed immediately after session nine was completed. The subjects were asked to fly through the gantry environment using the interface from the group they were not a part of (e.g. onboard view group used chase view interface). Every subject flew the same path (Path 2). Distance to pole objects during turns was recorded for each flight. After the two flights, the subjects were asked to fill out a multiple choice questionnaire on their thoughts about the interface they just used.

5. DATA ANALYSIS

5.1 Behavioral Data

The data analysis focused mostly on the assessment of a subject's behavioral data obtained through the measurement of aircraft positions (distances from the obstacles and targets of interest), accelerations, and operator inputs during each flight.

The environment was sectioned into four Locations(take off, slant, pole1, pole2) as seen in Figure 5. The flight variables [mean obstacle distance (ObDistance), mean magnitude angular acceleration(MagA), mean magnitude joystick velocities(jMagV)] were assessed for each flight path (1, 2, 3 and 4). The effects of View (onboard, chase) and Location (take off, slant, pole1, pole2) for each variable were evaluated using a Standard Least Squares model that evaluated each factor as well as the interaction between these factors using a full factorial design. In the event that significance was detected for location, multiple comparison Tukey tests were conducted ($\alpha = 0.05$).

In addition to the flight variables, the error variables [target error, marker error] were analyzed. The error variables contain the magnitude of the planar distance from the center of the target when the target switch is pulled (TargetError) and the magnitude of the planar distance from the nearest point on the flight path to the center of the markers (MarkerError). Chase and onboard view groups were compared for each of the error variables using a Wilcoxon nonparametric test ($p<0.05$ for significance). For all flight and error variables, a Spearman correlation was used to evaluate the relationship between the variable and session number for both chase view and onboard view. JMP Statistical Software (Version 8, SAS Institute, Cary, NC) and $p<0.05$ was taken as significant for all statistical tests.

Table 1: Significant effects and interactions for Paths (1,2,3,4) using Standard Least Squares Model

Eff. or Int.	ObDist	MagA	jMagV
View	3	1,2,3,4	2,4
Location	1,2,3,4	1,2,3,4	2,3,4
View*Location	1,2,3,4	1,2,3,4	

5.2 Subject Workload Data

Chase and onboard view subjects NASA-TLX data was compared for each of the variables [adjusted weight rating, mental demand] using a Wilcoxon nonparametric test ($p<0.05$ for significance).

The hemodynamic response features from the fNIR measures (i.e., mean and peak oxy-Hb, deoxy-Hb, oxygenation) were analyzed by the Optical Brain Imaging Laboratory [9]. Analysis was run on all subjects and flights for session two through session six. It is believed that the change in session seven through session nine (showing the subjects their results) would alter the fNIR analysis so these three sections were excluded from the current fNIR analysis. A repeated measures ANOVA was run across all flights, sessions two through six, and views for each voxel. If needed, then a *Tukey-Kramer Multiple-Comparison test* was used to determine any significant differences between chase view and onboard view subjects ($\alpha = 0.05$).

6. RESULTS AND DISCUSSION

6.1 Behavioral Data

The results of the flight path analysis described earlier are shown in Figure 6, 8, 10 and the results of the Standard Least Squares Model are shown in Table 1.

6.1.1 Mean Angular Acceleration (MagA)

The results of mean magnitude angular acceleration for each path are shown in Figure 6. For all flight paths, the main effects of view (all $p< 0.0001$) and location (all $p< 0.0001$) were significant as shown in Table 1. In addition, at a given view and location, significant interactions were observed ($p=0.001$, $p<0.0001$, $p=0.007$, $p=0.004$ for Path 1 to Path 4 respectively) as shown in Figure 6. All paths showed a significantly higher angular acceleration at the locations of Pole 1 and Pole 2. Each of these locations requires a sharp turn which leads to an increase in the angular velocity. The higher accelerations can be explained by visual observations of the subjects' behavior during the flights. Onboard camera subjects would make very large sweeping roll maneuvers with a high amplitude in the angle. As a side result, they would overshoot their desired angle and would then proceed

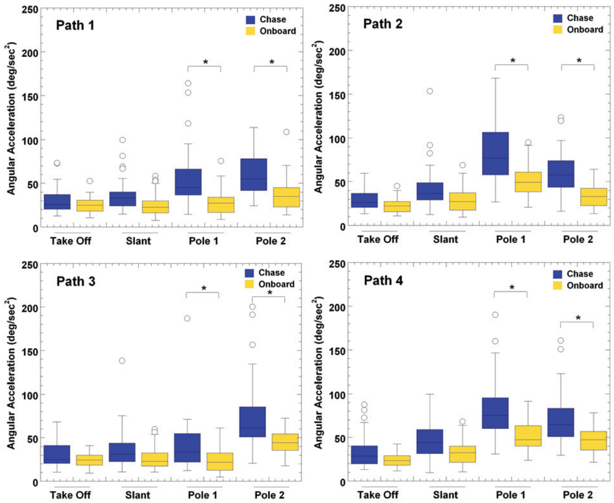

Figure 6: Mean Magnitude Angular Acceleration for locations Take Off, Slant, Pole 1, and Pole 2. Significance, if any are, highlighted by an asterix with a line leading to the significant sets.

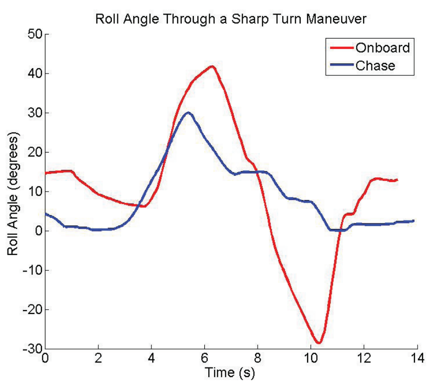

Figure 7: Example roll angle through a sharp turn for an onboard view subject (red) and a chase view subject (blue).

to make large and long roll maneuvers back to stabilize the aircraft. This occurred in a number of onboard view subjects because most relied on optic flow to gain awareness of the aircraft roll angle rather than the artificial horizon instrument gage. The reliance on optic flow required a relatively large roll motion before the optic flow was large enough to gather awareness from. Chase view subjects on the other hand could easily see their aircraft angle as they rolled and more easily predicted their approach to the desired angle. This allowed for much faster and more minute motions to control the roll angle. An example plot (Figure 7) shows the larger sweeping roll angles by an onboard camera subject and the smaller and minute angle corrections of a chase view subject through a sharp turn.

For all Flight Paths combined, a Spearman correlation indicated a significant negative relationship with Session for (chase view) subjects 3 (ρ = -0.19, p = 0.03), 9 (ρ = -0.29, p = 0.00), and 12 (ρ = -0.19, p = 0.04) and (onboard

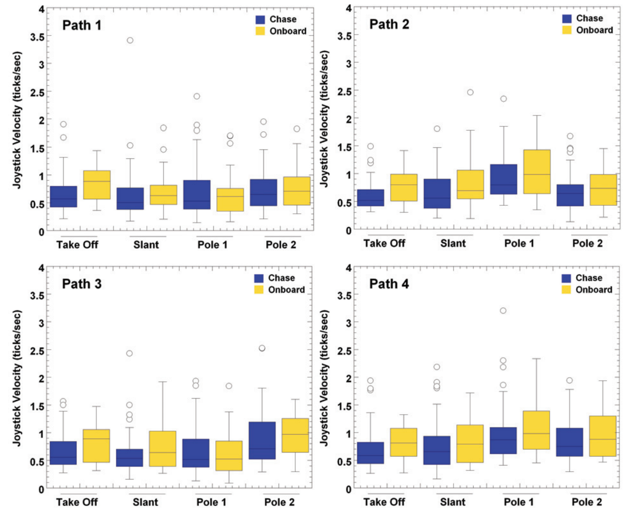

Figure 8: Mean Magnitude Joystick Velocities for locations Take Off, Slant, Pole 1, and Pole 2. Significance, if any are, highlighted by an asterix with a line leading to the significant sets. Top:Path 1 Results Bottom: Path 2 Results

view) subjects 4 (ρ = -0.39, p = 0.00), 6 (ρ = -0.35, p = 0.00), and 8 (ρ = -0.38, p = 0.00). (chase view) Subject 10, however showed a significant positive relationship (ρ = 0.85, p = 0.02) with session however the values of Angular Acceleration are relatively consistent. This also helps to demonstrates an improvement in control over sessions.

6.1.2 Mean Joystick Velocity (jMagV)

The results of mean magnitude joystick velocity for each path are shown in Figure 8. For all flights, no significant interaction was observed (p=0.32, p=0.58, p=0.34, p=0.98 for Path 1 to Path 4 respectively) (Table 1). For Path 2 and Path 4, the main effects of View (p=0.03, p=0.02 respectively) and Location($p<0.0001$ for both paths) were significant while Path 3 only showed the main effect of Location as significant ($p<0.001$). Path 1 had none (p=0.36) for both View and Location. Observing Figure 8, while not significantly different, the onboard view subjects mean magnitude joystick velocities were higher across all paths. This leads to the conclusion that onboard view subjects were manipulating the joystick controls more than chase view subjects. This supports the claim that onboard view subjects had lower awareness of the vehicle state and stablility, thereby requiring more joystick corrections.

A Spearman correlation for Mean Joystick Velocity and session number did not show a significant relationship with session. This demonstrates that subjects did not significantly change how they manipulated the joystick across sessions.

6.1.3 Pole 1 and Pole 2

Figure 9 shows the phenomenon where a chase view subject flew tighter to the pole but the onboard view subject flew closer to the walls around the actual Pole 1 and the actual Pole 2. This shows that onboard view subjects tended to take wider turns to go around the obstacle which ended up

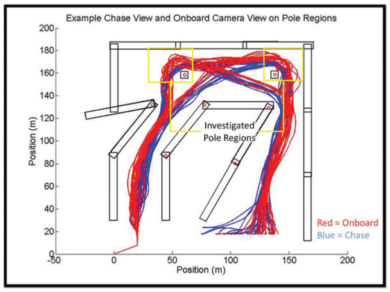

Figure 9: Top down view of the environment with the pole locations highlighted. The red line shows all the trajectories around the poles for an example onboard view subject, the blue line shows all the trajectories around the poles for an example chase view subject.

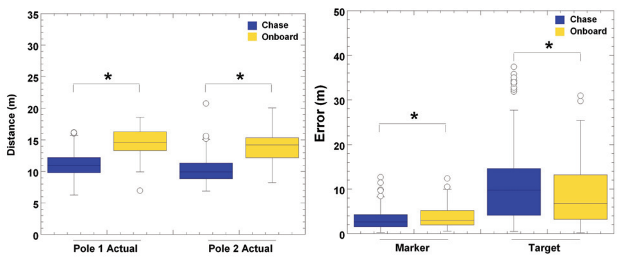

Figure 10: Left: Mean obstacle distance values to the pole obstacles during turning maneuvers. Right: Magnitude error distance of the aircraft from the Target center and center of the Markers. Significant differences are highlighted by the asterix.

taking them closer to the wall. The pole 1 and pole 2 areas were further sectioned as highlighted by yellow boxes in Figure 9. The mean obstacle distance was calculated from the aircraft to the pole itself in these sections. Figure 10 shows that in all flight paths that go around the poles (Flight Path 2,3,4), chase view has a statistically significant closer value ($p<0.0001$ for pole 1 actual, $p<0.0001$ for pole 2 actual). The data supports the behavior hypothesis, stated earlier in Section 2, that chase view enhances awareness of the vehicle's extremities by allowing the subjects to visually see when the aircraft wing tips had safely passed the obstacle. This allowed for more efficient turn paths.

6.1.4 Target and Marker Error

Shown in Figure 10 are chase view and onboard view results of the Target Error and Marker Error. According to the behavior hypothesis, one would expect significantly lower error with chase view versus onboard view. The chase view would give a better 3D spatial awareness of the vehicle with respect to the surrounding environment. Only the data for Marker Error supports this. The Marker Error was significantly higher ($p=0.02$) for the onboard view subjects when compared to the chase view subjects. The opposite was true for Target Error where the chase view group was significantly higher ($p=0.006$). This result can be explained by perceptual error and perspective.

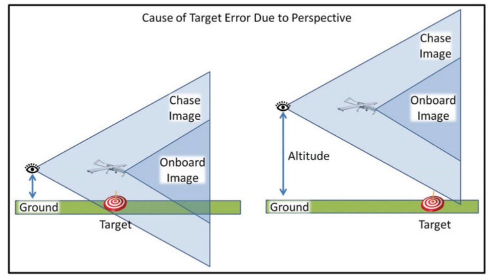

Figure 11: Left:Demonstration of how the target can be out of the onboard camera view but still in the chase view when under the aircraft. Right: Demonstration of how the target can be out of both views and still be ahead of the aircraft.

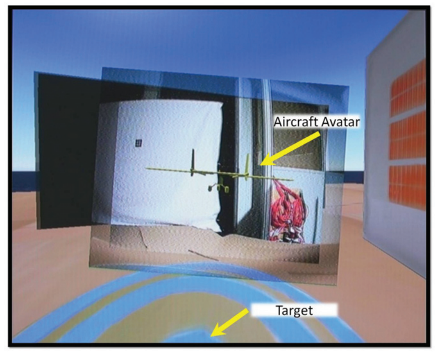

Figure 12: Screenshot showing potential perspective error.

As shown in Figure 11 when the object of interest passes out of the onboard camera image, onboard view subjects predict how long they have to wait until the aircraft is over the object. The higher up the aircraft, the longer they have to wait. Chase view subjects have the same requirement, however the object stays in view longer due to added virtual view. When low enough, the object can still be seen as it passes under the vehicle. However when higher, chase view subjects still have to wait after the target has exited even the chase view image. In early tests, chase view subjects did not understand this perspective issue and tended to trigger over the target when the virtual image appeared under the the aircraft avatar, well before the actual target area. The problem lies in that the chase view is trying to represent three dimensional information (aircraft pose in the environment) on a two dimensional display. Without proper training to account for the loss of depth perception, errors can occur. This can be seen in Figure 12 which shows a screen shot of the target task where the target appears below the aircraft avatar but due to the altitude, is well ahead of the aircraft. In early tests, not a single chase view subject triggered after the target had already passed which supports the perspective claim. During the second level flights, all subjects were closer to the height of the markers, lessening the perspective error, and thereby improving the chase view subject's results. Increased training can compensate for the potential perspective error however, using a three dimensional display for the interface would alleviate this problem.

For both Target Error and Marker Error, a Spearman

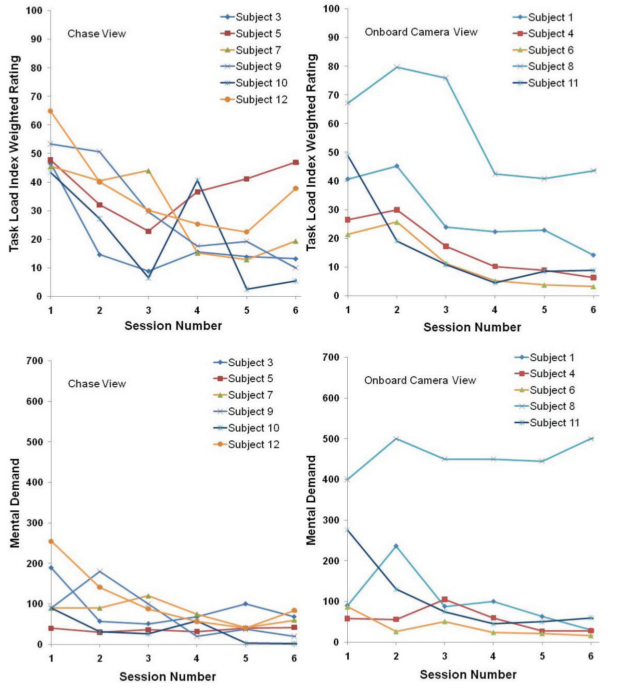

Figure 13: Task Load Index Weighted Rating across sessions. Left:chase view subjects Right:onboard view subjects

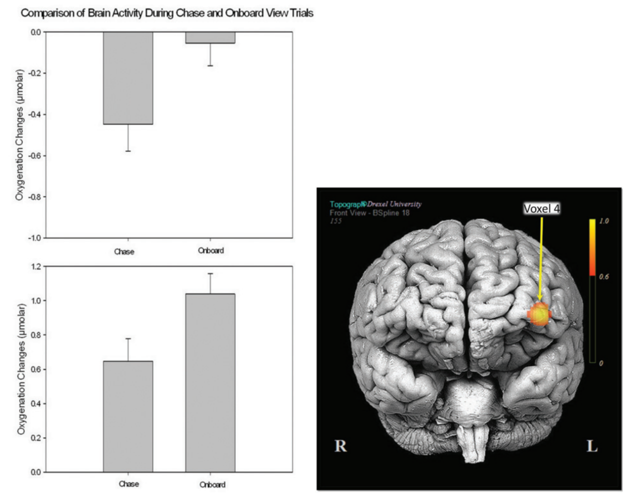

Figure 14: Average Oxygenation Changes for chase view and onboard view Subjects. For comparison of the oxygenation changes, signal level is important. Top: Average Oxygenation changes for chase view and onboard view group. Plot shows onboard view group's levels are higher. Bottom: Maximum Oxygenation changes for chase view and onboard view groups. Plot shows onboard view group's levels are higher. Right: Voxel 4 location highlighted on the brain.

correlation indicated a significant negative relationship with session for both chase view (ρ = -0.49, p $<$ 0.001) and onboard view (ρ = -0.36, p $<$ 0.001). As expected, a decrease in the amount of error is seen, after Session six, when the subjects were able to see their performance.

6.1.5 Workload Data

The cognitive hypothesis would suggest that the task load of the subject, specifically the mental demand of the subject, would be statistically lower for chase view. The NASA-TLX results are shown in Figure 13. When comparing the task load and mental demand were not found to be statistically significant (p=0.103, p=0.395, respectively) between chase view and onboard view. Further tests with more subjects as well as tasks that focus more on mental stimulation may help to support this hypothesis.

While the subjective tests showed no significance, the fNIR analysis showed otherwise. The difference of average oxygenation changes for all chase view and onboard view groups were found to be significant ($F_{1,361} = 6.47, p < 0.012$). These results are shown in the top of Figure 14.

The difference of maximum oxygenation changes for chase view and onboard view groups were found to be significant ($F_{1,361} = 5.94, p < 0.016$). Figure 14, bottom, shows that onboard view group had higher maximum oxygenation change when compared with the chase view group.

These comparisons were on voxel four. The location of the fourth voxel measurement registered on the brain surface is shown in Figure 14 [1]. Activation in the brain area corresponding to voxel four has been found to be sensitive during completion of standardized cognitive tasks dealing with concentration, attention, and working memory [2]. Higher oxygenation in this area is related to higher mental workload of the subject. Chase view subjects' average oxygenation levels for voxel four was lower than onboard view subjects, revealing that subjects using the onboard camera view were using more mental resources to conduct the flights. This result is most likely attributable to the narrower viewable angle and rolling of the environment in the onboard view, which require more cognitive processing by the subject. These results support the cognitive hypothesis.

For the Mental Demand and Overall Task Load (Weighted Rating) measures in the NASA-TLX, a Spearman correlation indicated a significant negative relationship with session for both chase view(ρ = -0.30, p = 0.03) and onboard view(ρ = -0.45, p = 0.00). Displaying results after session six, does not show a clear change in this negative trend. These results indicate that subjects became familiar and comfortable with the environment and tasks as the sessions progressed. In other words, workload seemed to decrease for all subjects as they learned what to expect and how to respond.

6.1.6 Session Ten

In session 10 the subjects performed two flights using the other view (ie. subjects in the chase view group used the onboard view interface). The main purpose of this session was to gather opinions about the alternate view point. It was expected that performance would decrease for each subject because they were used to operating the aircraft with their specific view point. Two flights is not enough to run a statistical analysis, however, the data showed an interesting trend. As Figure 15 shows, 4 out of 5 subjects who switched from an onboard camera view to a chase view produced a tighter more efficient turn around the obstacle. All of the

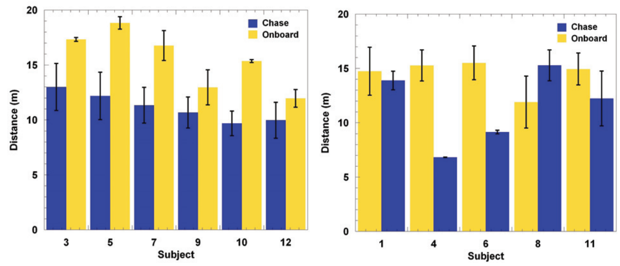

Figure 15: Mean distance from Pole 1 obstacle. The left bar is the mean distance (during a turn around the pole) for the 8 trials using the normal view, the right bar represents the mean of the 2 flights using the alternate view. Left: Chase view subjects Right: onboard view subjects

chase view subjects when switching to onboard camera view produced a much larger turn radius around the pole. This can be attributed to a lower awareness of the vehicle extremities and provides further support of the hypothesis.

After the tenth session, subjects filled out a survey about their thoughts on the view used during the session. In summary, the majority of the subjects felt that the chase view produced better awareness of the aircraft extremities and a better awareness of obstacles in the surrounding environment. Eight out of the eleven subjects preferred the chase view interface. Two of the subjects who preferred the onboard camera view stated that they would prefer the chase view interface if it was further enhanced with similar instrumentation like the onboard camera interface had. They would also have preferred the chase view if they had more flights to get used to the change in perspective.

7. CONCLUSIONS

The main hypothesis for the chase view interface is that it enhances a pilot's awareness of the vehicle's extremities and three dimensional spatial location in the flight environment. This will be very important during future UAV operations in near Earth environments. A series of human performance experiments were developed to test the hypothesis. Results of the studies show a significant difference between the flight paths taken by pilots using the chase view and those using the onboard camera view. The enhanced awareness allowed pilots to fly a more efficient path in a near Earth environment. Self reported preferences showed that the majority of subjects preferred the chase view interface over the traditional onboard camera perspective. All subjects reported that chase view gives a better awareness of the aircraft extremities in the flight environment and the majority report a greater awareness in the aircraft pose.

Included in these studies was a collaboration with the Drexel Brain Optical Imaging Laboratory that introduced the fNIR sensor into the evaluation and analysis of pilot performance. During the study, the fNIR sensor measured a subject's brain activity and produced an objective assessment of the subject's cognitive workload. Analysis of the fNIR data found that chase view subjects' average oxygenation levels for voxel four was significantly lower than onboard view subjects, revealing that subjects using the onboard camera view were using more mental resources to conduct the flights. This result is most likely attributable to the narrower viewable angle and rolling of the environment in the onboard view. This requires more cognitive processing by the subject to construct an accurate working mental model of the environment and the aircraft's position in it. The benefit of a lower cognitive workload while using the chase view interface is that a pilot would have more mental resources available to handle any warnings, system faults, or other unexpected events that might occur during the flight.

The resulting designs presented serve as test beds for studying UAV pilot performance, creating training programs, and developing tools to augment UAV operations and minimize UAV accidents during operations in near Earth environments.

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