INTERNATIONAL JOURNAL OF INTELLIGENT CONTROL AND SYSTEMS
VOL.16,NO.2,JUNE 2011,132-141

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

James T. HING, Justin MENDA, Kurtulus IZZETOGLU, and Paul Y. OH

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 nonsubjective 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.**

Index Terms—**unmanned aerial vehicle, UAV, mixed-reality, pilot training, near Earth environments**

1. INTRODUCTION

CHANGES to the way unmanned aerial vehicles (UAVs) are operated, specifically the operator interface, are being developed to address newly emerging UAV applications. UAVs are evolving and quickly expanding their role beyond the higher altitude surveillance activities of their historical counterparts. 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 conduct missions in environments, such as urban areas, much too cluttered for the proven large scale systems like the Predator [1]. These changes in operating capabilities will require a higher level of situational awareness for the operator due to the highly dynamic and obstacle rich nature of urban and near Earth flight (below tree top level). This added need for higher situational awareness is not satisfied by many current UAV operator interfaces.

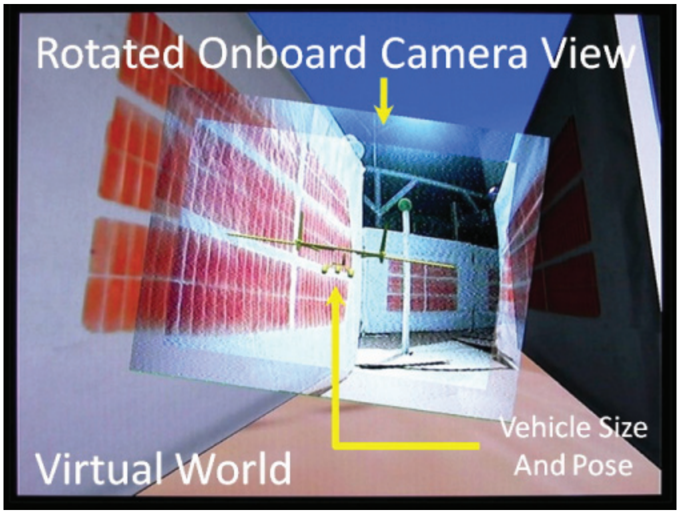


Fig. 1. Screenshot of the graphical interface for the UAV pilot demonstrating the chase viewpoint during UAV operation in a cluttered environment.

There are however many challenges to face when designing a new UAV interface and trying to incorporate high situational 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 [2]. 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 [3]. 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 [4]. Other aspects causing difficulties in operations are quickly changing and significant motions in the camera video feed due to UAV maneuvering, as well as the operators low sense of the vehicle's physical size within its current operating environment. Precise knowledge of the location of the UAVs extremities (e.g. wing/rotor tips) with respect to surrounding obstacles, is highly important when

---

Manuscript received December 10, 2010; The U.S. Army Medical Research Acquisition Activity, 820 Chandler Street, Fort Detrick, MD 21702-5014 is the awarding and administering acquisition office. This investigation was funded under a U.S. Army Medical Research Acquisition Activity; Cooperative Agreement W81XWH-08-2-0573. The content of the information herein does not necessarily reflect the position or the policy of the U.S. Government or the U.S. Army and no official endorsement should be inferred.

J. Hing and P. Oh are with the Mechanical Engineering and Mechanics Department at Drexel University.

J. Menda and K. Izzetoglu are with the School of Biomedical Engineering at Drexel University.

operating in cluttered environments.

Prior research from the authors [5] has introduced a mixed reality chase view interface for UAV operations in near Earth environments to address many of these issues. An example of the interface is shown in Figure 1. Near Earth in this work represents low flying areas typically cluttered with obstacles such as trees, buildings, power lines, 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 in real time. Chase view generation is explained in greater detail in [5]. In summary, the virtual representation of the operating environment can be updated in real time using laser devices (LIDAR), or structure from motion methods (machine vision). This is however very computationally heavy. An alternative, suitable for environments with non-changing major structures, is to pre-build the virtual environment using satellite imagery and forward reconnaissance missions. Onboard the real world UAV, the avionics package outputs its global position and orientation. This information can be used in real time to synchronize with the virtual UAV in the virtual world and the real UAV in the real world. Creation of the final interface involves image masking, perspective matching, and image stitching of the real world camera feed and the virtual scene (with virtual UAV model). While real world cameras are limited to physical constraints such as field of view, the surrounding virtual image can be expanded as large as desired.

A similar approach was employed by Drury et al. [6], supported by their continuing work to define and evaluate situational awareness in unmanned vehicle operations (see [7]). Their findings indicated that an augmented display improved comprehension of spatial relationships between a UAV and elements of the environment in observational tasks, similar to those performed by payload operators for high-altitude UAVs. Cooper et al. [8] found similar results for search tasks using a mixed reality system. In their studies, they also found that giving subjects navigation control (i.e. setting waypoints) while conducting the search task helped in flight path recollection, which in turn, improves target localization. These works support the use of a mixed reality interface in UAV operations for higher altitude missions and waypoint control of the aircraft. However, future applications will require small UAVs to fly low and in urban/cluttered environments. The present work focuses on direct piloting of the UAVs in near Earth environments, where such comprehension of spatial relationships is crucial. We make use of an indoor robotic gantry system, which was developed as a safe means to evaluate factors relevant to UAV operations in near Earth environments.

Not previously studied in [5], is 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 [9]. 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) [10]. 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 [11]. 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], [13]. The fNIR results can also be used to enhance the self reported (subjective) workload results.

2. HYPOTHESES

The authors' prior results of indoor gantry trials (see [5]) supported the efforts toward a more extensive human factor study to validate the early findings. Based on previous results, the following hypotheses were formulated for this work:

2.1. *Behavioral Hypothesis*

The chase view interface will improve a pilot's comprehension of the three dimensional position and orientation of the aircraft with respect to the surrounding environment. Because of this, it will also help pilots to produce more efficient flight paths (i.e. tighter turns around obstacles).

2.2. *Cognitive Hypothesis*

Cognitive workload of the pilot will decrease when operating the UAV via an external tethered view (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 (i.e. cognitive workload) for subjects operating a UAV via an onboard camera view (Onboard View) that is higher than subjects operating a UAV via our generated external view (Chase View). The higher blood oxygen levels are due to increased cognitive processing for understanding position and orientation in the flight environment.

3. EXPERIMENTAL SETUP

A 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 accidents. This system was chosen instead of a pure simulation based environment because it can be difficult to

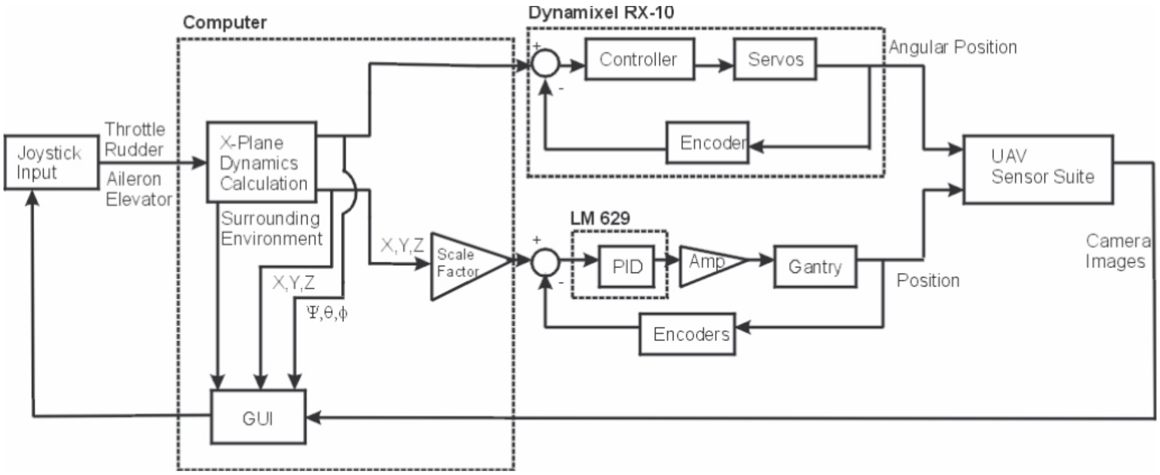
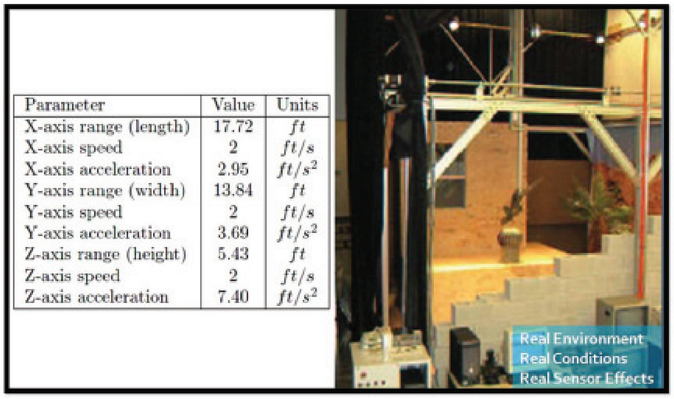


Fig. 3. Block diagram of the experiment setup.



Parameter	Value	Units
X-axis range (length)	17.72	ft
X-axis speed	2	ft/s
X-axis acceleration	2.95	ft/s^2
Y-axis range (width)	13.84	ft
Y-axis speed	2	ft/s
Y-axis acceleration	3.69	ft/s^2
Z-axis range (height)	5.43	ft
Z-axis speed	2	ft/s
Z-axis acceleration	7.40	ft/s^2

Fig. 2. Left: SISTR workspace and specifications; Right: Image of the Systems Integrated Sensor Test Rig (SISTR) setup with a UAV sensor suite attached to the end effector. This image was adapted from [14].

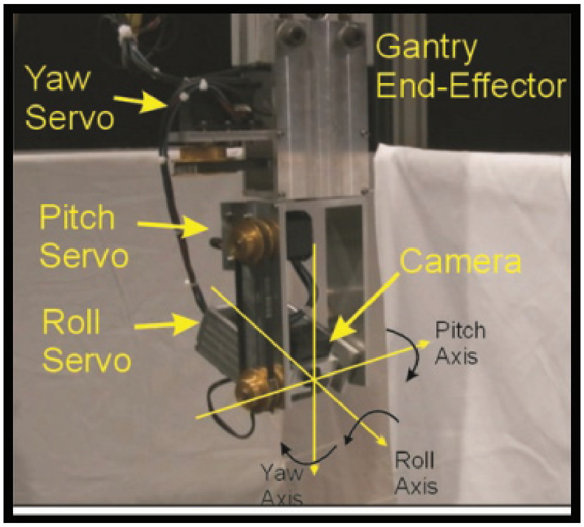


Fig. 4. Yaw, pitch and roll unit used to recreate the angular position of the aircraft inside of SISTR. The unit is designed based on the Euler angles of the aircraft. Yaw is applied first, then pitch, then roll.

accurately model aspects of real world sensor performance in simulation. The Systems Integrated Sensor Test Rig (SISTR) was developed to address these challenges. SISTR, as seen in Figure 2 is a three degree of freedom gantry system with a workspace measuring 18 feet long by 14 wide and 6 feet tall [14]. The gantry has ample workspace to allow construction of replicas of real world environments. In most cases, the real world environment is a scaled model to further augment the active workspace. SISTR was developed as a hardware-in-the-loop test rig and was designed to be used to evaluate obstacle detection sensors (LIDAR, computer vision, ultrasonic, ultrawideband radar, millimeter wave radar, etc.), design sensor suites, and test collision avoidance algorithms. For this work, SISTR was integrated with flight simulation software and was modified to encompass the training and evaluation of full UAV mission scenarios.

A block diagram of the experimental setup is shown in Figure 3. During the experiment, flight commands are input into a flight simulation software package (X-Plane from Laminar Research) by the subject via a joystick. The flight sim generates and sends the resulting translational and angular positions of the aircraft through UDP to the SISTR controller. The flight sim is also used in the chase view experiments to render the surrounding virtual view in the chase view system.

Attached to the end-effector of the gantry is a three degree of freedom servo unit that relays the yaw, pitch, and roll motions of the UAV to a camera situated along the intersection of all three rotation axes as seen in Figure 4. The camera is a commercially available wireless system with a 90 degree field of view; representative of similar types of cameras used on small UAV systems. The camera relays real time images, captured during flight through the gantry environment, back to the computer for generation of the chase view interface.

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

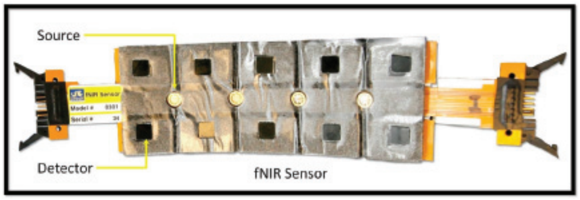


Fig. 5. fNIR sensor showing the flexible sensor housing containing 4 LED sources and 10 photodetectors.

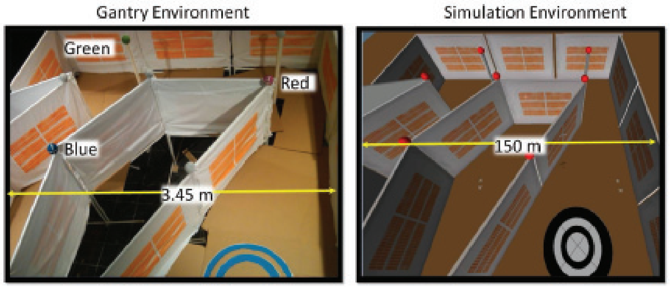


Fig. 6. Left: Flight environment inside the gantry built at 1:43.5 scale. Highlighted in the image are the colored markers for the second level of the environment. Right: Simulated full scale environment.

carry the information from the sensor to the data collection computer. The components of the fNIR systems are seen in Figure 5.

3.2. *Flight Environment*

The gantry environment (Figure 6) consists of two flight levels. The lower level contains corridors and two tall pole 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 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 the UAV Mako (13 foot wingspan) from NAVMAR Applied Sciences was used. For safety reasons, the simulated version of the Mako was modified so it had a lighter weight with less horsepower, effectively decreasing its maximum speed to 40 miles per hour in the simulation which corresponds to 18 inches/second in SISTR motion.

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, thereby allowing blood oxygenation changes (i.e. cognitive levels) to be captured. The close quarters and multiple obstacles help to extract metrics during flights to test the hypotheses.

3.3. *Interface Modifications*

In the system development studies [5], the chase view interface had high contrast between the border of the onboard camera image and the surrounding virtual environment. Subjects noted that this border was quite distracting and significantly lessened the quality of telepresence. The new design for the chase view interface, shown in Figure 7, 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.

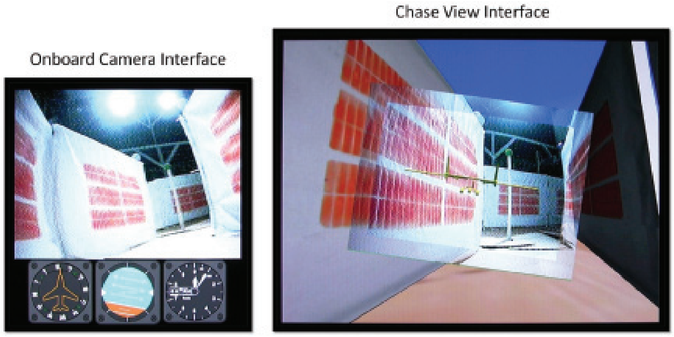


Fig. 7. Left: Onboard camera view with virtual instruments positioned below the image to relay information about the vehicle state. Right: Chase view with alpha blended borders.

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 processing load, the heads up display was replaced with virtual instruments as seen in Figure 7, 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. The artificial horizon panel was not added to the chase view display because the chase view in itself displays that information albeit in reverse (i.e. horizon is always maintained at a horizontal state and instead aircraft motion is seen). Bearing angle and altitude could have been added to the chase view display however, that information was irrelevant to the pilots for this specific study because a specific altitude or bearing angle was not required.

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. The subjects were separated 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 8. In all, 374 flights through the environment were recorded.

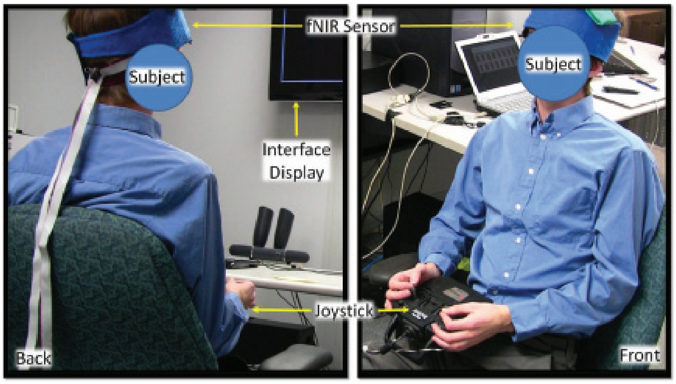


Fig. 8. Subject operating environment. The fNIR sensor is shown strapped to the forehead of the subject with a blue felt cover to block ambient light.

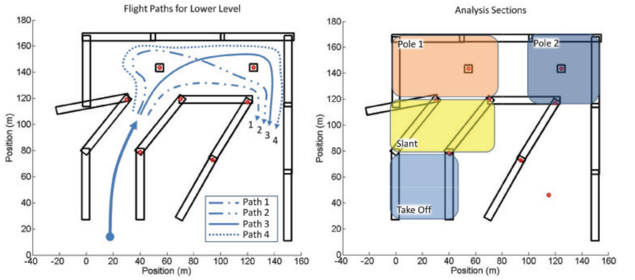


Fig. 9. Left: Top down view of the environment with the 4 flight paths through the lower level highlighted with different patterns. Right: Analysis sections of the environment

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 9. An example of the marker setup can be seen in Figure 6 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' performances 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 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 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 9. 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 and the magnitude of the planar distance from the nearest point on the flight path to the center of the markers. Chase View and Onboard View 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 I
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 and Location	1,2,3,4	1,2,3,4	

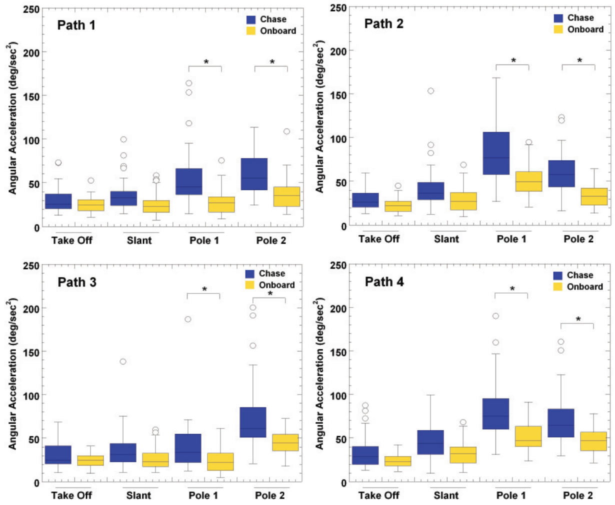


Fig. 10. Mean Magnitude Angular Acceleration for locations Take Off, Slant, Pole 1, and Pole 2. Significance, if any are, highlighted by an asterix with a line leading to the significant sets.

5.2. *Subject Workload Data*

Chase View 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 [15]. 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 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 10, 12, 14 and the results of the Standard Least Squares Model are shown in Table I.

6.1.1) Mean Angular Acceleration (MagA): The results of mean magnitude angular acceleration for each path are shown in Figure 10. 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 I. 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 10. 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. The higher accelerations for the Chase View subjects can be explained by visual observations of the subjects' behavior during the flights. Onboard View subjects would make very large sweeping roll maneuvers with a high amplitude in the angle as can be seen in (Figure 11). As a side result, they would overshoot their desired angle and would then proceed to make large and long roll maneuvers back to stabilize the aircraft. This occurred for 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 gauge. The reliance on optic flow required a relatively large roll motion before the optic flow was large enough to gather awareness from. This may be a result of the low texture level of the test environment and should be studied again on a high texture level environment. 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 11) shows the larger sweeping roll angles by an Onboard View subject and the smaller and minute angle corrections of a Chase View subject through a sharp turn.

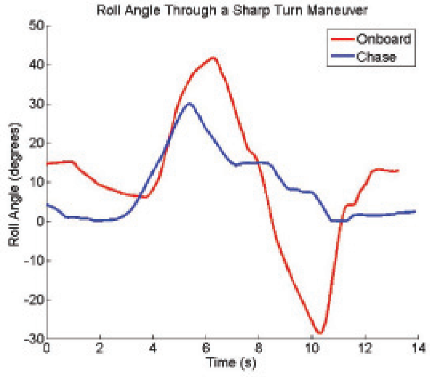


Fig. 11. Example roll angle through a sharp turn for an Onboard View subject (red) and a Chase View subject (blue).

As a side note, higher accelerations may not be a good quality as higher acceleration means higher levels of stress on the mechanical structure of the UAV. This could lead to increased wear and tear on the vehicle, thereby decreasing its useful life. Minimizing accelerations however was not addressed as a requirement in this study. Had we required the minimize acceleration rule, pilot behaviors would have most certainly been different.

For all Flight Paths combined, a Spearman correlation indicated a significant negative relationship across session numbers 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 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

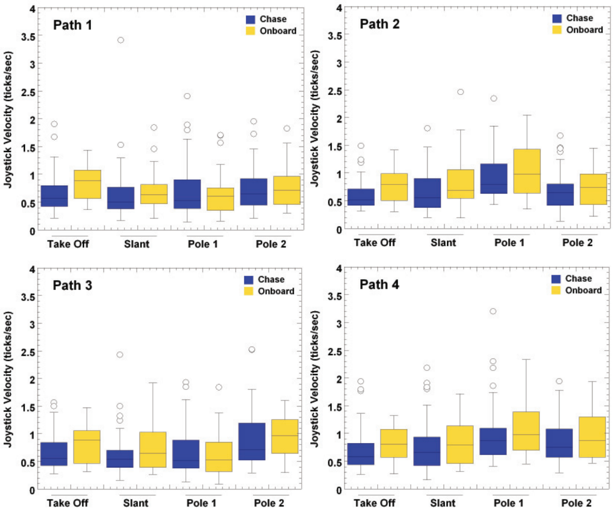


Fig. 12. Mean Magnitude Joystick Velocities for locations Take Off, Slant, Pole 1, and Pole 2. Significance, if any are, highlighted by an asterix with a line leading to the significant sets. Top:Path 1 Results Bottom: Path 2 Results

showed a significant positive relationship ($\rho = 0.85$, p = 0.02) across session numbers however its slope is fairly flat which means not a dramatic increase over time. 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 12. 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 I). 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 12, 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 stability, thereby requiring more joystick corrections.

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

6.1.3) Pole 1 and Pole 2: Figure 13 shows the phenomenon where a Chase View subject flew tighter to the pole but an Onboard View subject flew closer to the walls around the actual Pole 1 and the actual Pole 2. This trend was consistent throughout the study and is illustrated in Figure 14. This shows that Onboard View subjects tended to take wider turns to go around the obstacle which ended up taking them closer to the wall. The pole 1 and pole 2 areas were further sectioned as highlighted by yellow boxes in Figure 13. The mean obstacle distance was calculated from the aircraft to the pole itself in these sections. Figure 14 shows that in all flight paths that go around the poles (Flight Path 2,3,4), Chase 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 that a chase view enhances awareness of the vehicle's extremities by allowing the subject to visually see when the aircraft wing tips had safely passed the obstacle. This enhanced awareness allows for more efficient turn paths.

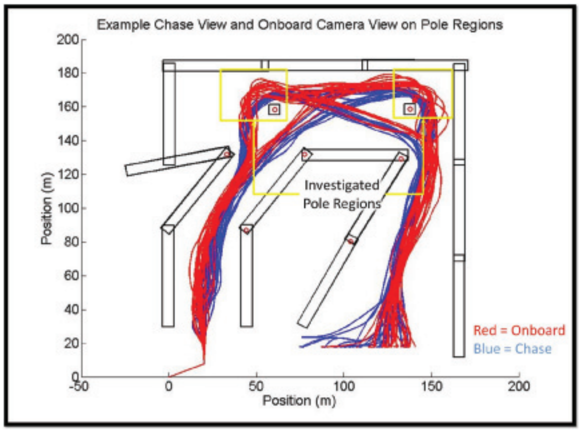


Fig. 13. Top down view of the environment with the pole locations highlighted. The red line shows all the trajectories around the poles for an example Onboard View subject, the blue line shows all the trajectories around the poles for an example Chase View subject.

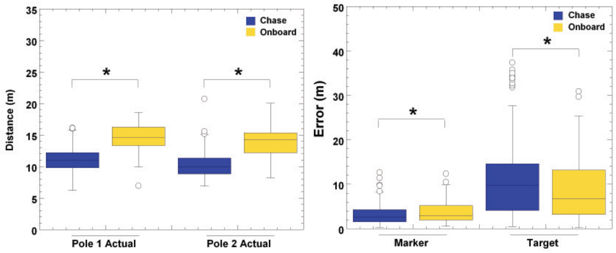


Fig. 14. Left: Mean obstacle distance values to the pole obstacles during turning maneuvers. Right: Magnitude error distance of the aircraft from the target center and center of the markers. Significant differences are highlighted by the asterix.

6.1.4) Target and Marker Error: Shown in Figure 14 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 a chase view versus an 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 Onboard View subjects when compared to 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.

As shown in Figure 15 when the object of interest passes out of the onboard camera image, Onboard View subjects are forced to 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 the added virtual view. When low enough, the object can still be seen as it passes under the vehicle. However when higher,

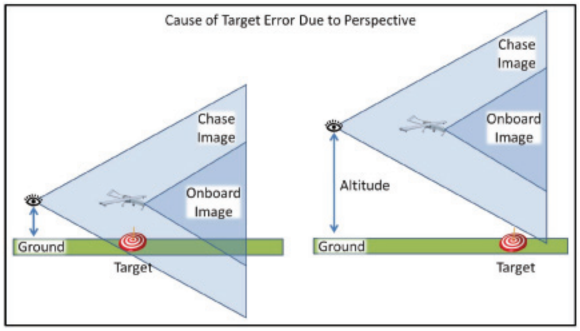


Fig. 15. Left:Demonstration of how the target can be out of the onboard camera view but still in the chase view when under the aircraft. Right: Demonstration of how the target can be out of both views and still be ahead of the aircraft.

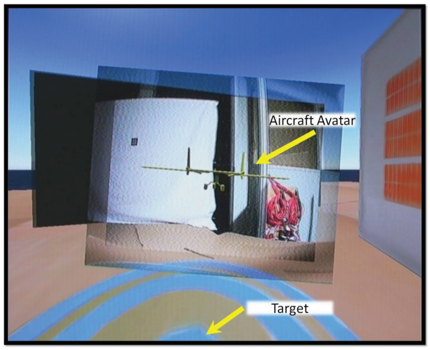


Fig. 16. Screenshot showing potential perspective error.

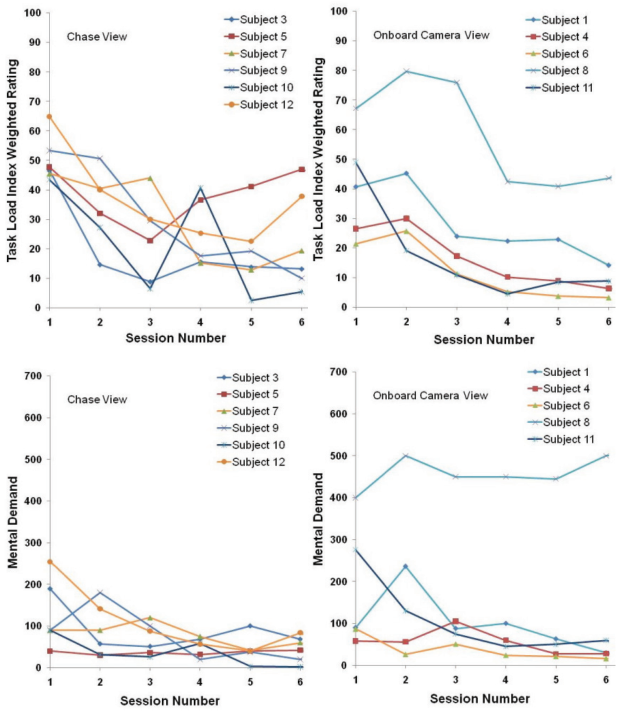


Fig. 17. Task Load Index Weighted Rating across sessions. Left:Chase View Subjects Right:Onboard View Subjects

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 16 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 correlation indicated a significant negative relationship across session numbers for both Chase View (ρ = -0.49, p ¡ 0.001) and Onboard View (ρ = -0.36, p ¡ 0.001) subjects. 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 higher for Onboard View subjects. The higher mental demand would be due to the increased need to mentally map and predict the aircraft position using the onboard camera perspective. The NASA-TLX results are shown in Figure 17. When comparing the task load and mental demand, they were not found to be statistically significant (p=0.103, p=0.395, respectively) between Chase View and Onboard View. Due to the small sample size, further tests with more subjects as well as tasks that focus more on mental stimulation may help to support this 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 across session numbers 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, both Chase View and Onboard View subjects self perceived workload seemed to decrease as they learned what to expect and how to respond.

While the subjective test measures showed no significance in cognitive workload between the two groups, the fNIR analysis showed otherwise. The difference of average oxygenation changes for all Chase 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 18.

The difference of maximum oxygenation changes for Chase View and Onboard View subjects were found to be significant ($F_{1,361} = 5.94, p < 0.016$). Figure 18, bottom, shows that

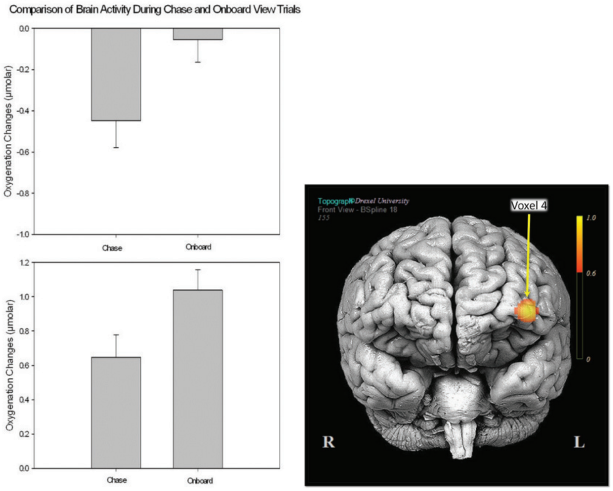


Fig. 18. Average Oxygenation Changes for Chase and Onboard View Subjects. For comparison of the oxygenation changes, signal level is important. Top: Average Oxygenation changes for Chase View and Onboard View subjects. Plot shows Onboard View group's levels are higher. Bottom: Maximum Oxygenation changes for Chase View and Onboard View subjects. Plot shows Onboard View subjects' levels are higher. Right: Voxel 4 location highlighted on the brain.

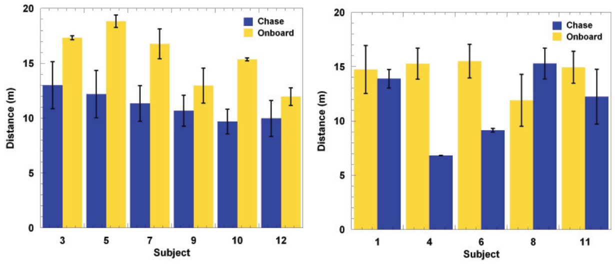


Fig. 19. Mean distance from Pole 1 obstacle. The left bar is the mean distance (during a turn around the pole) for the 8 trials using the normal view, the right bar represents the mean of the 2 flights using the alternate view. Left: Chase view subjects Right: Onboard view subjects

Onboard View subjects 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 18 [16]. 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 [17]. 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 by a statistical significance, 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.

6.1.6) Session Ten: In Session 10 the subjects performed two flights using the other view (e.g. subjects in the chase view group used the onboard camera 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 19 shows, 4 out of 5 subjects who switched from an Onboard View to a Chase View produced a tighter more efficient turn around the obstacle. All of the Chase View subjects when switching to an 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 Session 10, 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 (e.g. 3-dimensional display). They would have also preferred the chase view if they had more flights to get used to the change in perspective.

7. CONCLUSIONS

It is important to emphasize that this study was focused on the development of a new type of interface not currently used in actual UAV operations. It is being developed in anticipation of the need once UAVs start being more utilized in urban environments and near Earth terrain. Also, while this paper focused on an indoor study, an initial feasibility study using a prototype of this system has been tested in the field with promising results. 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 perspective were requiring 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. Higher levels of cognitive processing are then required 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.

REFERENCES

[1] U. S. A. Department of Defense, "Unmanned systems roadmap 2007-2032," Tech. Rep., 2007.

[2] D. B. Kaber, E. Onal, and M. R. Endley, "Design of automation for telerobots and the effect on performance, operator situation awareness, and subjective workload," *Human Factors and Ergonomics in Manufacturing*, vol. 10, no. 4, pp. 409–430, 2000.

[3] J. B. v. Erp, "Controlling unmanned vehicles: the human factors solution," 26-28 April 1999 1999.

[4] M. Glumm, P. Kilduff, and A. Masley, "A study on the effects of lens focal length on remote driver performance," Army Research Laboratory, Tech. Rep., 1992.

[5] J. T. Hing, K. W. Sevcik, and P. Y. Oh, "Development and evaluation of a chase view for uav operations in cluttered environments," *Journal of Intelligent and Robotic Systems*, vol. 57, pp. 485–503, 2010.

[6] J. L. Drury, J. Richer, N. Rackliffe, and M. A. Goodrich, "Comparing situation awareness for two unmanned aerial vehicle human interface approaches," in *Proceedings of the 2006 Conference on Safety, Security, and Rescue Robotics (SSRR)*, Gaithersburg, MD.

[7] J. L. Drury and S. D. Scott, "Awareness in unmanned aerial vehicle operations," *The International C2 Journal*, vol. 1, pp. 1–10, 2008.

[8] J. Cooper and M. A. Goodrich, "Towards combining uav and sensor operator roles in uav-enabled visual search," in *Proceedings of ACM/IEEE International Conference on Human-Robot Interaction*, Amsterdam, The Netherlands.

[9] S. Dixon, C. Wickens, and D. Chang, "Mission control of multiple unmanned aerial vehicles: A workload analysis," *The Journal of Human Factors and Ergonomic Society*, vol. 47, no. 3, 2005.

[10] S. G. Hart, "Nasa-task load index (nasa-tlx); 20 years later," NASA-Ames Research Center, Tech. Rep., 2006.

[11] K. Izzetoglu, "Neural correlates of cognitive workload and anesthetic depth: fnir spectroscopy investigation in humans," Ph.D. dissertation, 2008.

[12] J. Milton, S. Small, and A. Solodkin, "On the road to automatic: Dynamic aspects in the development of expertise," *Clinical Neurophysiology*, vol. 21, pp. 134–143, 2004.

[13] A. Kelly and H. Garavan, "Human functional neuroimaging of brain changes associated with practice," *Cerebral Cortex*, vol. 15, pp. 1089–1102, 2005.

[14] V. Narli and P. Y. Oh, "Hardware-in-the-loop test rig to capture aerial robot and sensor suite performance metrics," in *IEEE International Conference on Intelligent Robots and Systems*, Beijing, China, 2006, p. 2006.

[15] K. Izzetoglu, S. Bunce, B. Onaral, K. Pourrezaei, and B. Chance, "Functional optical brain imaging using near-infrared during cognitive tasks," *International Journal of Human-Comptuer Interaction*, vol. 17, no. 2, pp. 211–227, 2004.

[16] H. Ayaz, M. Izzetoglu, S. Platek, S. Bunce, K. Izzetoglu, and K. Pourrezaei, "Registering fnir data to brain surface image using mri templates," in *IEEE Eng Med Biol Soc*, vol. 1, 2006, pp. 2671–2674.

[17] H. Ayaz, P. Shewokis, S. Bunce, M. Schultheis, and B. Onaral, "Assessment of cognitive neural correlates for a functional near infrared-based brain computer interface system," *Foundations of Augmented Cognition. Neuroergonomics and Operational Neuroscience*, pp. 699–708, 2009.

James T. Hing received his BS, MS and PhD degrees in Mechanical Engineering from Drexel University ('03,'06,'10). He is an alumni of the Drexel Autonomous Systems Lab (DASL). While at Drexel, his work focused on improving UAV safety and operator training.

Justin Menda is currently a PhD student in the School of Biomedical Engineering at Drexel University. He is a member of the Optical Brain Imaging Laboratory part of the Neuroengineering Resource Center. His current work focuses on safe piloting and cognitive function monitoring for unmanned aerial vehicle (UAV) ground control operators.

Kutulus Izzetoglu received his MS in Electrical Engineering from the Middle East Technical University in Ankara, Turkey and his Ph.D. in Biomedical Engineering from Drexel University in 2008. He is a Research Assistant Professor in the School of Biomedical Engineering at Drexel University. He has has been working on development of the fNIR system to measure human neural function. He is currently involved in cognitive workload assessment of UAV operators, sensor and algorithm development for depth of anesthesia monitoring, cognitive baselining and index developments, and cognitive aging research, in particular, attentional network assessment.

Paul Y. Oh Prof. Paul Oh is the Associate Department Head at Drexel's Mechanical Engineering Department. He received mechanical engineering degrees from McGill (B.Eng 1989), Seoul National (M.Sc 1992), and Columbia (PhD 1999). Honors include faculty fellowships at NASA Jet Propulsion Lab (2002), Naval Research Lab (2003), the NSF CAREER award (2004), the SAE Ralph Teetor Award for Engineering Education Excellence (2005) and being named a Boeing Welliver Fellow (2006). He is the Director of the Drexel Autonomous Systems Lab and also the Founding Chair of the IEEE Technical Committee on Aerial Robotics and UAVs. For the past 2 years, he served at the National Science Foundation (NSF) as the Program Director managing the robotics research portfolio.