A MOTION PLATFORM INTEGRATED UAV PILOT TRAINING AND EVALUATION SYSTEM FOR FUTURE CIVILIAN APPLICATIONS

James T. Hing
Drexel Autonomous Systems Laboratory (DASL)
Department of Mechanical Engineering and Mechanics
Drexel University
Philadelphia, PA 19104
Email: jth23@drexel.edu

Paul Y. Oh*
Drexel Autonomous Systems Laboratory (DASL)
Department of Mechanical Engineering and Mechanics
Drexel University
Philadelphia, PA 19104
Email: paul@coe.drexel.edu

ABSTRACT

The potential for UAVs to benefit the civilian consumer is driving the demand for the integration of these vehicles into the national airspace. With UAV accidents occurring at a significantly higher rate than commercial airlines, the urgent issue becomes designing systems and protocols that can prevent UAV accidents, better train UAV operators and augment pilot performance. This paper presents three directions of research stemming from the goal of a UAV piloting and training system. Research direction one is the development of a research platform to assess UAV pilot skills and recreate the sensation of shared fate for UAV pilots. The second research direction looks at utilizing flight simulation packages to create virtual tools for training UAV pilots. The third direction covers the investigation of UAV's in near earth environments as future applications will place UAVs in these areas.

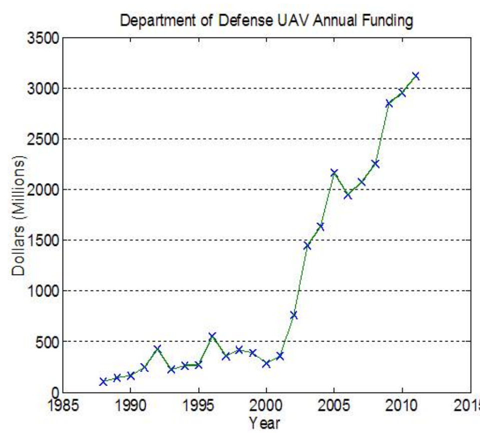

Figure 1. DEPARTMENT OF DEFENSE UAV ANNUAL FUNDING (data [1])

INTRODUCTION

The growth of UAV demand is tremendous and has grown at a significant rate as represented by Fig. 1 on DOD annual funding for UAVs. Progress is being made toward opening up the market for civilian use in national airspace with regulations and standards being developed by a significant number of well qualified groups [3]. There are tremendous opportunities for UAV applications in the civilian and commercial sector such as agriculture, security, fishing, firefighting, science research and much more. With the growing acceptance of unmanned technology in the general public, the dream of UAVs surrounding us and improving our quality of life is working its way to reality. But there is a perfect storm brewing here. The growing demand of UAVs leads to a growing demand for pilots. There are only a few UAV training facilities in the country and most of them are military related. This leads to a bottle neck of too many UAVs and not enough operators / pilots especially when a number of UAV systems take 4 or more operators to run. More importantly, we have been very lucky in the history of UAVs that there have been no reported deaths due to one of the many UAV crashes that have occurred. As Fig. 2 shows, UAV accidents occur at

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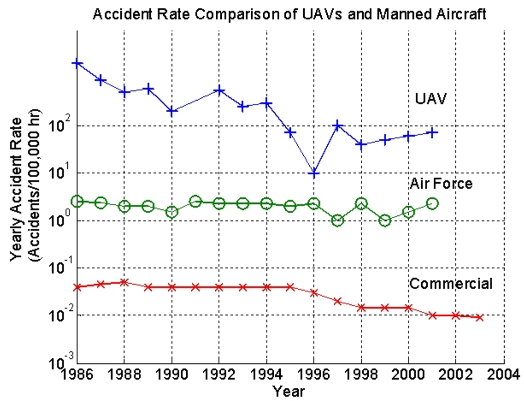

Figure 2. COMPARISON OF ACCIDENT RATES (data [2])

almost 100 times more than commercial airlines and are increasing [2]. The push for these vehicles to take flight in populated airspace will certainly increase the chances of catastrophe unless we design systems and protocols that can prevent UAV accidents, better train UAV operators and augment pilot performance.

In this present study, a novel method of integrating motion platform technology for UAV training, piloting, and accident evaluation is proposed. The system uses a motion platform, small scale aircraft, UAV avionics packages and flight simulator software. The aim is to have a system that improves pilot control of the UAV and in turn decrease the potential for UAV accidents. The setup will allow for a better understanding of the cause of UAV accidents associated with human error through recreation of accident scenarios and evaluation of pilot commands. This setup stems from discussions with cognitive psychologists on a phenomenon called shared fate. The hypothesis explains that because the ground operator does not share the same fate as the UAV flying in the air, the operator often makes overly aggressive maneuvers that increase the likelihood of crashes. The authors believe that giving the UAV pilot motion cues will enhance operator performance. By virtually immersing the operator into the UAV cockpit, the pilot will react quicker with increased control precision. This is supported by previous research conducted on the effectiveness of motion cueing in flight simulators and trainers for pilots of manned aircraft, both fixed wing and rotor craft [4,5]. Also, future applications of UAVs in the civilian market will most likely place them in near earth environments which are low flying areas typically cluttered with obstacles such as buildings, trees, power lines etc. This system will help to train and evaluate UAV pilots operating in these scenarios and will give more insight on the technical requirements of performing such UAV missions.

This paper will cover three directions of research stemming from the main goal of a UAV piloting and training system. The first section motivates this work by discussing current limitations in UAV operation. The following section begins with research direction one which is the development of a research platform to asses UAV pilot skills and recreate the sensation of shared fate for UAV pilots. This is done through the integration of a motion platform to generate the motion cues to the pilot. The next section covers research direction two which utilizes a flight simulation package to create virtual tools for training UAV pilots with the shared fate platform and assessing accident scenarios. The third section covers research direction three which is the investigation of UAV's in near earth environments. The final sections present and discuss experimental results, the conclusions and outline future work.

UAV OPERATIONS AND LIMITATIONS

A major percentage of UAV accidents are caused by equipment failure but recently, human error has been found to be a significant causal factor in UAV mishaps and accidents. The statistic range from 21% to 68% across UAV types [6, 7]. Many believe the answer to this problem is full autonomy. However, there are limitations of current autonomous systems. They can take an extensive amount of time to preplan for missions. This becomes especially true for fully autonomous aircraft like Global Hawk. Even with extensive planning, it is difficult to predict the response of the vehicle to all possible contingencies and events that can occur. For example, a UAV programmed to fly and conduct a mission in a specified location, unless it is programmed to recognize a person in distress along the way, if it passes someone, will never divert from its mission. In contrast, manned aircraft are certainly able to dynamically adjust their mission plans.

Strong reliance on sensors can also be dangerous in mostly autonomous systems as operators can experience out of the loop syndrome where they lose the sense of the state of the vehicle. This causes a much slower response to recover from system faults [8]. Sensors themselves can fail causing catastrophic accidents that could be prevented from direct pilot control of the vehicle. For example, an incident with Firescout, the NAVY's unmanned rotor craft, occurred when a sensor malfunction caused the vehicle to think it was 2 feet off the ground during a landing routine and it shut off its engine (a typical landing procedure). In actuality, the vehicle was 500 feet off the ground [9]. In our own experience with autonomous rotor craft an accident occurred when a sensor malfunction caused the vehicle to think it was upside down when it wasn't and tried to right itself.

Systems that have a pilot in direct control of the vehicle (pilot in the loop) such as the Predator system, are also limited. Current state of the art ground stations, like those for the Predator, contain static pilot and payload operator consoles. The pilot controls the aircraft with a joystick, rudder pedals and monitoring screens. This is very different from manned aircraft as those pilots have visual, aural, and motion cues that add to situational awareness which occasionally leads pilots to override automation when necessary [3]. For ground pilots however, thier decisions are based solely on automation or through visual contact. Other factors that degrade their performance are limited field of view, delayed control response and feed back [7]. These factors lead to a low situational awareness and a decreased understanding of

Figure 3. INTEGRATED PHYSIOLOGICAL TRAINER (IPT) 4-DOF MOTION PLATFORM FROM ETC BEING WIRELESSLY CONTROLLED WITH THE MNAV.

Table 1. SELECT ETC GYRO IPT II MOTION SYSTEM CAPABILITIES

Degree of Freedom	Displacement	Speed	Acceleration
Pitch	$\pm$25 deg	0.5-25 deg/sec	0.5-50 deg/sec^2
Roll	$\pm$25 deg	0.5-25 deg/sec	0.5-50 deg/sec^2
Continuous Yaw	$\pm$360 degrees continuous	0.5-150 deg/sec	0.5-15 deg/sec^2

(For complete specs please see ETC website)

the state of the vehicle during operations. In turn, this increases the chance of mishaps or accidents.

Human factors research has been conducted on UAV ground station piloting consoles leading to proposals on ways to improve pilot situational awareness. Improvements include new designs for head up displays [9], adding tactile and haptic feedback to the control stick [10, 11] and larger video displays [12]. To the author's knowledge, no one is trying for maximum fidelity of being inside of the cockpit for UAV pilots through relaying motion, vibrations, sounds etc.; all of the cues used by a manned pilot to understand the state of the aircraft.

RESEARCH DIRECTION ONE

Initial thoughts are that motion platform can help to recreate the sensation of shared fate by relaying motion of the UAV back to the ground pilot through the use of motion cueing. The effect being that the sensation of shared fate will improve a pilot's decision making and lower their chances of taking unnecessary risks. This return to "seat of the pants" flying for ground pilots may be advantageous as it helps manned aircraft pilots control their vehicles and it can also possibly reduce some of the overwhelming reliance on the visual representation of the state of the UAV in ground stations.

Motion Platform

To relay the motion of the aircraft to the pilot, the authors utilized a commercially available 4-DOF flight simulator platform from Environmental Tectonics Corporation (ETC) shown in Fig. 3. The motion system capabilities are shown in Tab. 1. The motion platform generates the appropriate motion cues to the pilot based on the angular velocities that it receives from the ground station. For the IPT motion platform, angular rate data streaming from the inertial measurement unit is filtered and then pitch and roll rates are washed out [13]. The yaw rate is fed straight through due to the continuous yaw capabilities of the IPT motion platform.

Sensors

Wireless communication of the motion of the UAV is handled using a robotic vehicle sensor suite developed by Crossbow inertial systems. The MNAV100CA (MNAV) is a 6-DOF inertial measurement unit (IMU) measuring on board accelerations and angular rates at 50 Hz. The MNAV is attached to the Stargate, also from Crossbow, which is an on board Linux single board computer. The Stargate is set to transmit the MNAV data at 20 Hz to the ground station via wireless 802.11 link.

Motion Platform Control with MNAV

Aircraft angular rates are measured using the MNAV and this information is transmitted down to the ground station via a 20 Hz wireless link. To evaluate the connection, the authors tested the MNAV's ability to communicate with the ground station and control the IPT. The MNAV was held in hand and commanded pitch, roll and yaw motion to the IPT by rotating the MNAV in the pitch, roll and yaw directions as seen in Fig. 3(showing pitch).

Control of Aircraft Servos

Pilot commands inside the motion platform are relayed through encoder positions of the flight stick, rudder pedals, and throttle. The signals are routed through a PC to RC circuit that converts the integer values of the encoders to pulse position modulated (PPM) signals. The PPM signals are sent through the buddy port of a 72 MHz RC transmitter which then transmits the signal to the RC receiver on board the aircraft. The PPM signals are routed to the appropriate servos to control the position of the ailerons, elevator, rudder, and throttle of the aircraft. The positions of the IPT flight controls are currently sent through the PC to RC link at a rate of 15 Hz.

Field Test

Before taking the motion platform out to a field to test the system as a whole, aircraft flight data and visuals were collected to be later replayed on the IPT. A RC Giant Sig Kadet model airplane with 80" wingspan is used as seen in Fig. 4. It offers a very stable platform for initial tests and is comparable in size to some

Figure 4. THE SIG GIANT KADET MODEL AIRCRAFT USED AS THE TESTING PLATFORM.

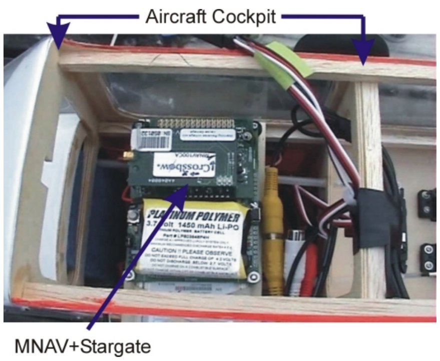

Figure 5. MNAV AND STARGATE IN THE COCKPIT OF THE AIRCRAFT (TOP VIEW)

of the more back packable UAVs such as the FQM-151 Pointer and Raven [1]. The IMU was placed inside the aircraft cockpit (Fig. 5) and the aircraft was manually flown through radio control as data was collected.

RESEARCH DIRECTION TWO

Before utilizing a system like this in a mission it is important to have properly qualified pilots. How do we train UAV pilots to deal with a range of scenarios under different conditions and situations? It can become rather expensive to train beginning internal and external UAV pilots through a buddy box system, especially with setbacks such as accidents. This is where the virtual world offers an advantage. Instead of conducting field tests with the Sig Kadet and motion platform, the Sig Kadet can be easily replaced in the virtual world with any UAV. The same motion cues would be relayed back to the IPT and we would have full control of the conditions. It is certainly cheaper and less risky to operate with the advantage of also being able to reconstruct accident scenarios and train pilots in those situations. Since the simulation utilizes the same motion platform and cockpit that will be used for the real world UAV field tests, the transfer of the training skills to real world operation should be very close to 100%. There are a few commercial UAV simulators available and the numbers continue to grow as the use of UAV's become more popular. However, most of these simulators are developed to replicate the state of the art training and operation for current military type UAVs. The authors utilize a commercially available flight sim and modify it to fit the needs for this project.

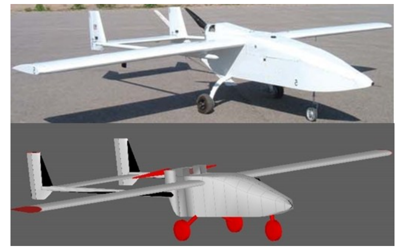

Figure 6. TOP: MAKO UAV DEVELOPED BY NAVMAR APPLIED SCIENCES. BOTTOM: MAKO UAV RECREATED IN X-PLANE.

Flight Simulator and UAV Model

X-Plane from Laminar research offers a low cost flight simulation program that has very accurate aerodynamic models and is highly modifiable. It is also Federal Aviation Administration (FAA) certified. A very good description of X-Plane and how it works can be found from [14]. Users are able to control many aspects of the program and obtain a wide variety of data variables through UDP connections and plug-ins.

A number of academics have utilized X-Plane for UAV research. [15] built a small Maxi-Joker R/C rotor craft in X-Plane. They utilized the generated flight dynamics of the model of the rotor craft and used it to evaluate their autonomous flight controllers. [16] also used X-Plane to evaluate their fuzzy logic controller on a R/C helicopter model. To start development of our training and evaluations system, the authors modeled a Mako UAV seen in Fig. 6 using the built in Plane Maker program packaged with X-Plane. The Mako is a military drone developed by Navmar Applied Sciences Corporation. It is 130lb, has a wingspan of 12.8ft and is operated via an external pilot for takeoff and landings and is under computer assisted autopilot during flight. For initial testing, this UAV platform was ideal as it could be validated by veteran Mako pilots in the author's local area. Other models of UAVs are currently available online such as the Predator A.

It is important to note that X-Plane is a flight simulation package originally created for recreating a manned aircraft pilot experience. Utilizing it as a tool for UAV operations takes some manipulation through user created plug-ins and external programs. The authors started the modification by developing the external and internal pilot's viewpoints through plugins written in C++. The external pilot view as seen in Fig. 7 was created to maximize the ground peripheral vision and has an auto zoom function that keeps the UAV from getting too pixilated in the image. The internal pilot viewpoint is programmed such that it represents the restricted field of view to the pilot from the nose camera also shown in Fig. 7.

Two other functions were developed for the simulator. Shown in Fig. 7 right is a plugin that can place the UAV in any location, orientation and velocity. Currently the figure shows the UAV in a catapult launch situation. It can also be utilized to place the aircraft in different scenarios like landing approaches or in a situation just before an accident. The other function uses an external interface developed in Visual Basic (not shown) to control

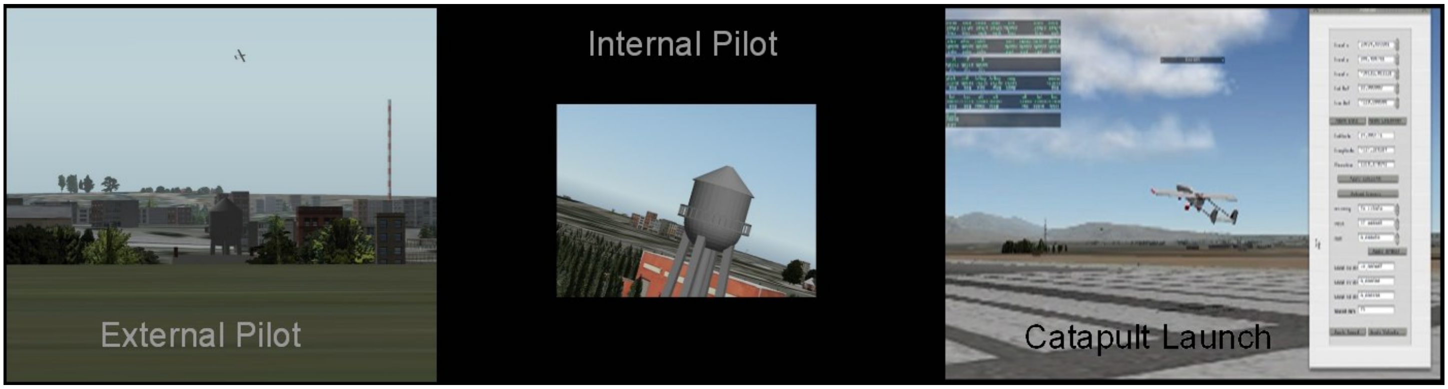

Figure 7. SIMULATOR SCREEN SHOTS USING THE MAKO UAV MODEL. LEFT: EXTERNAL PILOT VIEW POINT. MIDDLE: INTERNAL PILOT VIEW POINT. THE VIEW SIMULATES A NOSE CAMERA POSITION ON THE AIRCRAFT AND REPLICATES THE RESTRICTED FIELD OF VIEW. RIGHT: PLUGIN DEMONSTRATING SIMULATED CATAPULT LAUNCH.

the amount of time lag between data communication, representing real world communication delay in actual UAV operations.

Human Factor Studies

Discussions with experienced UAV pilots of Mako and Predator A & B UAVs on current training operations and evaluation metrics for UAV pilots has helped establish a base from which to assess the effectiveness of the proposed motion integrated UAV training/control system. The external pilot of the Mako and internal pilot of the Predator systems learn similar tasks and common flight maneuvers when training and operating the UAVs. These tasks include taking off, climbing and leveling off. While in the air, they conduct traffic pattern maneuvering such as a rectangular course and flight maneuvers such as Dutch rolls. On descent, they can conduct traffic pattern entry, go around procedures and landing approaches. These tasks are conducted during training and mission operations in various weather, day and night conditions. Each condition requires a different skill set and control technique. More advanced training includes control of the UAV during different types of system failure such as engine cutoff or camera malfunction. Spatial disorientation in UAVs as studied by [17] can effect both internal and external pilots causing mishaps. The simulator should be able to train pilots to experience and learn how to handle spatial disorientation without the financial risk of losing an aircraft to an accident.

Assessing the effectiveness of integrating motion cueing during piloting of a UAV will be conducted by having the motion platform provide cues for yaw, pitch and roll rates to the pilots during training tasks listed earlier. During simulation, the motion cues will be based on aircraft state information being fed out of the X-Plane simulation program. During field tests, the motion cues will be received wirelessly from the IMU on the aircraft itself. The proposed subjects will be groups of UAV internal pilots (Predator) with manned aircraft experience, UAV internal pilots without manned aircraft experience, and UAV external pilots without manned aircraft experience. Results from these experiments will be based on quantitative analysis of the recorded flight paths and control inputs from the pilots. There will also be a survey given to assess pilot opinions of the motion integrated UAV training/control system. The work done by [18] offers a comprehensive study addressing the effects of conflicting motion cues during control of remotely piloted vehicles. The conflicting cues produced by a motion platform were representative of the motion felt by the pilot when operating a UAV from a moving position such as on a boat or another aircraft. Rather than conflicting cues, the authors of this paper will be studying the effects of relaying actual UAV motion to a pilot. We are also, in parallel, developing the hardware as mentioned earlier for field testing to validate the simulation. The authors feel that [18] is a good reference to follow for conducting the human factor tests for this study.

RESEARCH DIRECTION THREE

Future civilian applications for UAV's will place these vehicles in near earth environments. Unlike traditional high altitude environments common to military UAV use, near earth environments are usually cluttered with obstacles such as people, trees, buildings, power lines, etc. Even more important, vehicles in these environments will most likely encounter situations where interaction with the surrounding civilian population is needed. An example of this would be external load transportation or rescue. These types of operations demand extreme situational awareness and quick adaptation to the ever changing dynamic environment. Whether or not these vehicles are directly controlled by a pilot or are fully autonomous, it is necessary to operate in similar environments and situations before actual testing in the final desired locations. These preliminary tests serve to train the pilots for flying the vehicle in specific conditions and for fully autonomous systems, they help to refine the control algorithms. However, for the preliminary tests, field testing with all the hardware can be very time consuming and costly, especially after an accident. It is also very difficult to control most of the

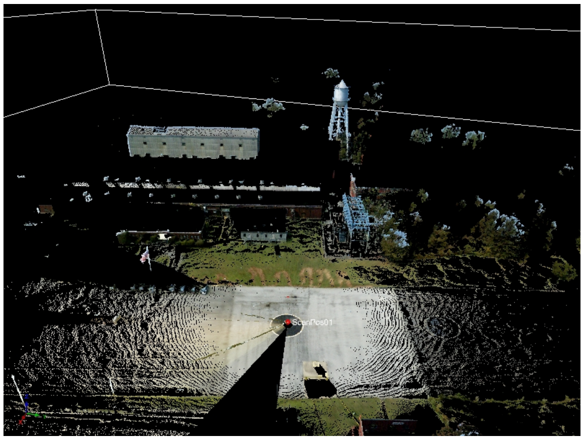

Figure 8. 3D LASER SCAN OF A NEAR EARTH ENVIRONMENT

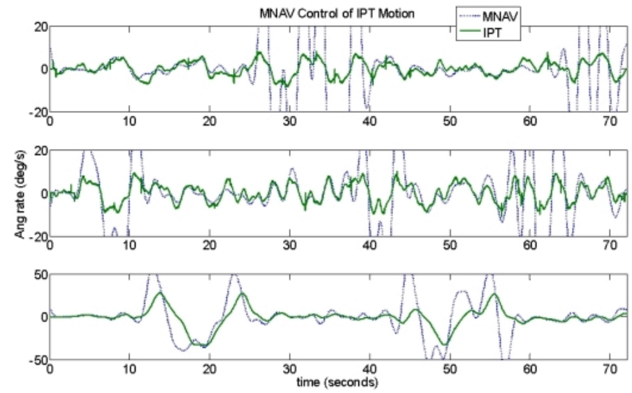

Figure 11. COMPARISON OF THE ANGULAR RATES DURING MNAV CONTROL OF THE IPT.

environmental variables in the testing area. This is where simulation offers an advantage as it is certainly cheaper to operate and environment conditions are more controllable.

Recently, simulators have been utilized in the unmanned aerial vehicle community to help develop more robust autonomous flight controllers. However, very few have utilized simulation tools for UAV pilot training and evaluation in near earth and urban environments. [19] utilized the Real-time Interactive Prototype Technology Integration/Development Environment (RIPTIDE) with a Yamaha RMAX helicopter dynamics model to develop a graphical environment that simulated and evaluated autonomous helicopter landing in an urban setting. Their parking lot scenario for landing included buildings, street lights, cars and trees. They showed that the simulation environment proved to be an effective tool for the performance evaluation of the machine vision algorithms even though the images were computer generated. [20] have presented a paper on the development of a realistic urban simulation environment to study the performance of cooperative control algorithms for UAVs in and around the urban landscape. As of 2006, their simulator included people, ground vehicles, buildings, flight dynamics models for UAVs and models of steady-state winds and turbulence. With X-Plane, users can create their own very detailed terrain and environment. This was valuable to the authors because of the ability to develop an environment exactly like the field testing arena. The authors were able to use laser scan data (Reigl LMS-Z210) as seen in Fig. 8, physical measurements and satellite imagery to recreate a real world near earth environment as seen in Fig. 9. The area is the Piasecki Facility in Essington, PA. It is a good representation of a near earth environment because of the buildings, trees, power lines, etc. With detailed texturing, the environment can look very realistic. As mentioned in [19], simulated camera views can be used for vision algorithms such as feature detection which is important for tasks such as identifying safe landing zones for autonomous rotor craft.

UAVs are typically smaller and lighter than their manned counterparts. This makes them very susceptible to changing weather conditions such as wind, including turbulence, and precipitation. Operators of UAVs, both internal and external, are susceptible to changes in the visual field as ground station operators utilize the view from the on board UAV camera and external pilots rely on direct line of sight with the vehicle. X-Plane includes a comprehensive weather model that models fog, clouds, wind, turbulence, rain, snow, hail and thunderstorms. Users have full control of all these conditions. Also shown in Fig. 10 top is an example of the Piaseki compound under heavy rain conditions and in thick fog. Shown in Fig. 10 is the environment under varying lighting conditions (different times of the day) and during night using night vision. It is valuable to train UAV pilots and test control algorithms under all possible conditions that could be encountered during real world tests. X-Plane offers this advantage.

INITIAL TEST RESULTS AND DISCUSSION

In this section, the authors present initial test results from the hardware control portion of the UAV system. In this prototyping stage, development focused on motion platform control using the MNAV and recording of actual flight data from the MNAV to replay on the IPT. Motions of the MNAV and IPT were recorded during hand held MNAV control of the IPT . Figure 11 shows a plot comparing MNAV and IPT data. The IPT is designed to replicate actual flight motions and therefore is not capable of recreating the very high angular rates commanded with the MNAV during the hand tests in the roll and pitch axis. The IPT handles this by decreasing the value of the rates to be within its bandwidth and it also filters out some of the noise associated with the MNAV sensor. Overall, the IPT tracked the motion being commanded by the MNAV fairly well. The IPT is limited by its reachable work space which is why the amplitude of the angles does not match. Of considerable interest is the lag between the commanded angular rates and the response from the IPT motion platform, particularly with the yaw axis. This may be a limitation of the motion platform and is currently being assessed. Minimal lag is desired as significant differences between

Figure 9. LEFT: REAL SATELLITE IMAGE OF A NEAR EARTH ENVIRONMENT; RIGHT: RECREATED IN THE VIRTUAL WORLD

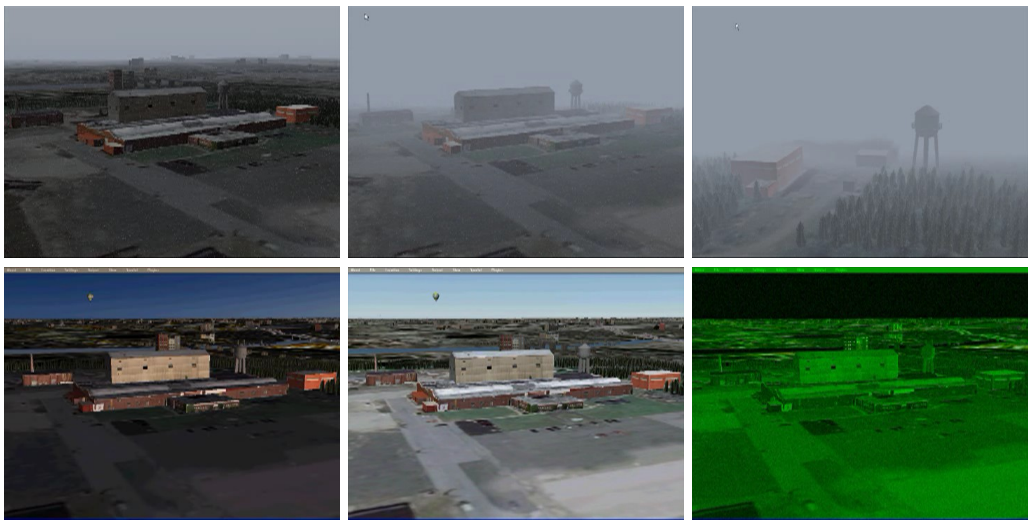

Figure 10. TOP: CHANGES IN WEATHER FROM DOWNPOUR LEFT TO INCREASED FOG RIGHT; BOTTOM: CHANGES IN LIGHTING CONDITIONS (NIGHT VISION FAR RIGHT)

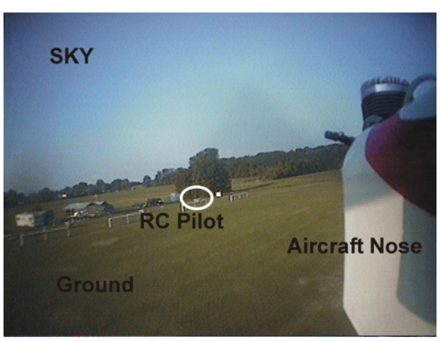

Figure 12. ONBOARD CAMERA VIEW OFF OF THE LEFT WING DURING FLIGHT.

the motion cues from the IPT and visuals from the video feed will cause a quick onset of pilot vertigo.

During recording of real flight data, recorded video and flight data was streamed down to the ground station. The data simulates the real time streaming information that would occur during a field tele-operation experiment. A still shot of the on board video recording is shown in Fig. 12. During this stage, the authors had problems with the IMU pitch rate measurement not matching what was observed in the flight video and it has halted this progress as we assess other IMU packages.

CONCLUSION AND FUTURE WORK

Validation of the fidelity of X-Plane for UAV applications is an ongoing process. [21] has already presented some work on comparison of PID control of a modeled helicopter in X-Plane versus the PID control of its real world counterpart with good results. Future validations are required to verify the fidelity of the effects of precipitation and wind on the modeled UAVs, especially in urban environments. While avionics sensor packages and vision sensors can be modeled with X-Plane, unlike RIPTIDE, to the author's knowledge, it has yet to be shown that X-Plane can be used to simulate other sensors such as LADAR. Future work will most certainly evaluate this potential. This paper has presented the development of the first steps toward a novel tele-operation paradigm that employs motion cueing to augment

UAV operator performance and improve UAV flight training. This method has the potential to decrease the number of UAV accidents and increase the applicability of unmanned technology. Leveraging this work, future development includes research to eliminate, reduce, or compensate for the motion lag in the motion platform. Utilizing the system for near earth applications, especially for UAV rotor craft, will also be assessed. The net effect is that from such understanding, one can analytically design systems to better control UAVs, train UAV pilots and help eliminate UAV accidents.

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