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14. ABSTRACT A three degrees of freedom Hardware In the Loop Simulator was designed and built. This HILS system was built using modular parts to simplify future modification. All parts of this system were printed using a 3 dimensional printer and a laser cutting system. Also, slip rings were used to allow the platform unrestricted motion in pitch roll and yaw angles. This HILS system was used to calculate the latency in autopilot's IMU data. The delay in IMU was measured against the CPU clock and was found to be 20ms. To synchronize GPS, the entire autopilot system					
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## Report Title

Third Generation Gimbaled Platform and the Effect of Synchronization on Target Geolocation Acquisition.

### ABSTRACT

A three degrees of freedom Hardware In the Loop Simulator was designed and built. This HILS system was built using modular parts to simplify future modification. All parts of this system were printed using a 3 dimensional printer and a laser cutting system. Also, slip rings were used to allow the platform unrestricted motion in pitch roll and yaw angles. This HILS system was used to calculate the latency in autopilot's IMU data. The delay in IMU was measured against the CPU clock and was found to be 20ms. To synchronize GPS, the entire autopilot system was driven alongside targets of known GPS coordinates. Both Video and GPS streams were then synchronized relative to CPU clock. Large errors in GPS data were observed. GPS latency was found to vary greatly between different runs. This was attributed to GPS drift and could be minimized by using a better quality GPS system. Overall, being able to synchronize GPS, IMU and Video streams is expected to greatly reduce errors in target geolocation.

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**List of papers submitted or published that acknowledge ARO support during this reporting period. List the papers, including journal references, in the following categories:**

#### (a) Papers published in peer-reviewed journals (N/A for none)

Number of Papers published in peer-reviewed journals: 0.00

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#### (b) Papers published in non-peer-reviewed journals or in conference proceedings (N/A for none)

Number of Papers published in non peer-reviewed journals: 0.00

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#### (c) Presentations

A Hardware In the Loop Simulator for MAV Flight, Presented at;GNC Challenges for Miniature Autonomous Systems Workshop  
October 26-28, 2009

Number of Presentations: 1.00

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#### Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

1. Ivan Walker, "Target Geo-location Acquisition From MAV Video Imagery, a Preliminary Study," ARL Summer Student Research Symposium, Selected Papers, ARL-TM-2009, PP 167-183, August 2009.
2. Joshua Etchison, "Micro Torque Measurement Using a Fly-wheel," ARL Summer Student Research Symposium, Selected Papers, ARL-TM-2009, PP 147-165, August 2009.

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts): 2

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#### Peer-Reviewed Conference Proceeding publications (other than abstracts):

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts): 1

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#### (d) Manuscripts

Number of Manuscripts: 0.00

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**Number of Inventions:**

**Graduate Students**

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
Ivan Walker	0.10
Eliza Dasari	0.15
<b>FTE Equivalent:</b>	<b>0.25</b>
<b>Total Number:</b>	<b>2</b>

**Names of Post Doctorates**

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
<b>FTE Equivalent:</b>	
<b>Total Number:</b>	

**Names of Faculty Supported**

<u>NAME</u>	<u>PERCENT SUPPORTED</u>	National Academy Member
Kamal S. Ali	0.15	No
<b>FTE Equivalent:</b>	<b>0.15</b>	
<b>Total Number:</b>	<b>1</b>	

**Names of Under Graduate students supported**

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
Lemnyuy Bernard Nyuykongi	0.30
William Munn	0.15
Joshua Etchison	0.30
Filmon Berhe	0.30
Brook Kassa	0.30
Carlos Morales	0.30
Christopher Munn	0.15
<b>FTE Equivalent:</b>	<b>1.80</b>
<b>Total Number:</b>	<b>7</b>

**Student Metrics**

This section only applies to graduating undergraduates supported by this agreement in this reporting period

- The number of undergraduates funded by this agreement who graduated during this period: ..... 3.00
- The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:..... 3.00
- The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:..... 3.00
- Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):..... 3.00
- Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:..... 0.00
- The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense ..... 1.00
- The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields: ..... 0.00

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**Names of Personnel receiving masters degrees**

<u>NAME</u> Ivan Walker Justin Shumaker <b>Total Number:</b> 2
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**Names of personnel receiving PHDs**

<u>NAME</u>  <b>Total Number:</b>
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**Names of other research staff**

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
<b>FTE Equivalent:</b>	
<b>Total Number:</b>	

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**Sub Contractors (DD882)**

**Inventions (DD882)**

## Third Generation Gimbaled Platform and the Effect of Synchronization on Target Geolocation Acquisition

### Introduction:

The primary component in this research is a Hardware in the Loop Simulator (HILS) that was developed to enhance the quality of attitude data received from autopilots as well as to simulate flight for Micro Air Vehicle (MAV) autopilots. Earlier versions of this system were used to improve the accuracy of an Inertial Measurement Unit (IMU) more than thirty percent. The improved system currently in the development pipeline will have the capability to simulate flight in the laboratory using an FAA approved flight simulator, custom embedded hardware, and a three axis gimbaled platform. A series of stepper motors and optical shaft encoders control angular rotation providing absolute position with high accuracy. Stepper motors actuate the platform to simulated flight, while the shaft encoders reported the platform's exact angular position. Eventually, this system is to be placed into an enclosed chamber with a vacuum pump and a solenoid to control barometric pressure and simulate altitude. Finally, a bellow system will be used to simulate wind speed, while a Peltier element will be used to control temperature. The final system will therefore allow for the complete simulation of flight for a MAV autopilot.

The HILS system (Fig 1.), at its present state, can be used as an inertial frame of reference to which IMU data can be synchronized. During flight simulation, an autopilot is configured to send flight-surface position corrections to a flight simulator. The flight simulator calculates the autopilot's new attitude and actuates the platform and the autopilot accordingly.

### The Problem:

The goal of this research was to use the HILS system developed at Jackson State University to enhance the operation of target geolocation acquisition, especially the ones used or to be used with the smaller MAVs.

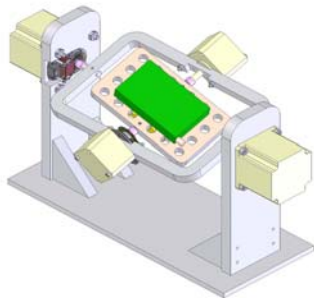


Fig 1. 2 DOF Gimbaled Platform

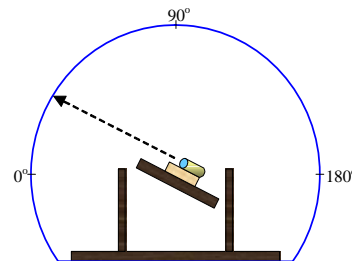


Fig 2. Video synchronization system

The acquisition of a target's geolocation from video image is well defined when altitude and attitude of the video camera are known. For larger Unmanned Aerial Vehicles (UAVs), the system works

well as these UAVs are rather stable. However, as the airframe gets smaller, the system becomes more vulnerable to weather perturbations. Such perturbations can cause large increases in geolocation errors. This is because the error is highly dependant on the rate of change in attitude angles. The slightest shift in IMU, GPS or Video data may cause large errors especially when the velocity component of the Pitch, Roll or Yaw is sizable. We therefore propose to synchronize the video imagery with IMU data through the use of the gimbaled platform (Fig 1. and Fig 2.). Our previous work has shown that an IMU can be calibrated using this platform to reduce errors by as much as 30%. Also it has been shown that this platform can synchronize autopilot systems at the millisecond range. In addition to the calibration and synchronization of IMU and video, we proposed to synchronize GPS data stream both with the IMU and Video data. This will have to be done through actual flight of the system. To further improve geolocation accuracy, we will freeze the selected video frame, allowing for accurate targeting. Upon selection, the system will generate the GPS coordinates for the target. We believe that this system will make it possible to extract accurate target geolocation data from the smallest of MAVs.

Smaller MAVs are susceptible to wind perturbations, causing a jittery image and a sizable rate of change on all IMU values. The slightest latency between IMU, GPS and video data can then cause massive errors in target geolocation. The system we propose will allow for accurate synchronization of these values, greatly reducing errors in geolocation. The proposed system will use a semi-circular rigid graduated strip. This strip will be placed around the platform. The platform will move in a triangular fashion and data from the IMU, Optical Shaft Encoders and the corresponding video frames will be collected. The angular deflection of the camera will be extracted from the images and will be plotted against the IMU data.

### **IMU-Video Synchronization:**

Rather than using a graduated strip, equidistant marks were placed on a wall opposite the platform while the platform moved at a frequency of 1Hz spanning approximately 45 degrees of shift. By plotting and extrapolating for the maxima and minima of the video and IMU data, latency between the two streams of data could be established. This experiment was repeated at higher and lower frequencies yet the latency was found to be consistently around 180ms. Clearly such an experiment will have to be repeated should a new autopilot or video system be used. Latency may vary depending on the IMU model, it's filtering software, as well as the video system used.

### **GPS-Video Synchronization:**

For optimum target geolocation information, GPS will also have to be synchronized as well. To do so, techniques not involving this gimbaled system were employed. Initially, the autopilot and camera system were flown over targets of known GPS coordinates. Keeping the UAV directly over the target or even flying the UAV where all targets could be seen was found to be rather difficult. The experiment was therefore redesigned using a ground vehicle. All equipment (Autopilot and video system) were mounted into a vehicle and driven alongside targets that were about 200 feet apart. The GPS coordinates of these targets were recorded prior to starting the experiment. By time stamping both video and GPS streams using the CPU wall clock, it was possible to find the latency between GPS and video data. Unfortunately, this latency was found to differ between different runs although identical methodology was employed. This was

attributed to GPS drift. Another factor, however, could have been the quality of GPS receiver system used.

The latency measured between GPS and Video was significant (ranging from 200 to 400 ms). Although these latencies were consistent with a single experiment, they did vary between different experiments. One reason for the large deviation in latency was attributed to GPS drift and quality of GPS receiver system used in our autopilot. In future work, other GPS systems will be examined to ascertain the cause of this drift.

### **Conclusions:**

Through experimentation, it was found that there is a considerable time lag between IMU, Video and GPS streams of data in the MAV system under examination. These latencies can have a direct effect on the accuracy of target geolocation information extracted from these three data streams. Eliminating these latencies should greatly reduce errors in target geolocation data.

### **Future Work:**

1. Repeat GPS synchronization experiment with different GPS system to ascertain cause of latency.
2. Fly the complete system over targets to determine improvement in geolocation accuracy gained by synchronization.
3. Implementing end-user software to allow for frame freezing and target selection.

### **Deliverables:**

The following goals/deliverables were achieved:

1. A two and a three degrees of freedom gimbaled platforms were designed and built.
2. The design, especially that for the three degrees of freedom platform, was modularized to facilitate future modification to the system.
3. Dedicated electronic circuitry was developed and constructed to control this HILS system.
4. The HILS system was used to synchronize Video and IMU data. A latency of 180ms was observed between the two data streams.
5. GPS and Video data streams were also synchronized experimentally. A latency ranging from 200ms to 400ms was observed. No definite cause for the large latency difference could be found. More experiments are necessary to find the cause of this latency differential.
6. Data from this research was presented at the ION: GNC Challenges for Miniature Autonomous Systems Workshop, Fort Walton Beach, FL, October 26-28, 2009.
7. Data from this research was presented at the Louis Stokes Mississippi Alliance for Minority Participation Bridge for the Doctorate Program April 2009.

8. Data from this research was also presented and published at the Cohorts 6 and 7 Army Research Laboratory (ARL) Summer Student Research Symposium, August 2009.
9. Two graduate and eight undergraduate students were supported under this STIR, and were all involved in UAV type research.

### **Bibliography:**

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3. "Miniature Autopilot Evaluation System" Kamal S. Ali, Lamarius Carter, American Journal of Applied Science, Journal of Computer Science 4 (1): 30-35, ISSN 1549-3636 , 2008.
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