
Ohio University DURIP Award- Summary Report

Award Period: April 2003- December 2004

Recipient: Ohio University, Russ School of
Electrical Engineering and
Computer Science

20050520 011

REPORT DOCUMENTATION PAGE

AFRL-SR-AR-TR-05-

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports (0704-4302). Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not have a valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

the
inc
-
ently

0157

1. REPORT DATE (DD-MM-YYYY) 31-12-2004		2. REPORT TYPE Final		May 2003 - December 2004	
4. TITLE AND SUBTITLE "An Integrated LIDAR/IMU/GPS Navigation and Surveillance"				5a. CONTRACT NUMBER F49620-03-1-0285	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER N/A	
6. AUTHOR(S) Uijt de Haag, Maarten				5d. PROJECT NUMBER N/A	
				5e. TASK NUMBER N/A	
				5f. WORK UNIT NUMBER N/A	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Ohio University 105 Research & Technology Center Athens, Ohio 45701				8. PERFORMING ORGANIZATION REPORT NUMBER N/A	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Unlimited					
DISTRIBUTION STATEMENT A Approved for Public Release Distribution Unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT The goal of our DURIP proposal was to establish new research areas in multi-sensor integration for aerial vehicle navigation and surveillance using Light Detection and Ranging (LIDAR) sensors. Research performed with NASA Langley over the last five years on real-time terrain database integrity monitor systems showed results which encouraged the Ohio University Avionics Engineering Center to submit the DURIP proposal in 2002. The DURIP proposal has allowed Ohio University's Avionics Engineering Center to obtain and flight test a LIDAR system. The four research areas proposed which utilize the equipment purchased with the DURIP award are as follows: terrain navigation using integrated LIDAR, Inertial Measurement Unit (IMU) and terrain data; hybrid GPS and Terrain navigation using integrated LIDAR, IMU; and terrain data for aerial vehicles; integration of LIDAR, IMU, GPS, and terrain data for surveillance purposes; and LIDAR data compression and processing techniques. These topics as well as the educational component of these topics are covered in this technical report.					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF: U			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 13	19a. NAME OF RESPONSIBLE PERSON James Rankin
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U			19b. TELEPHONE NUMBER (include area code) (740) 593-1514

1 Introduction

The goal of our DURIP proposal was to establish new research areas in multi-sensor integration for aerial vehicle navigation and surveillance using LIght Detection and Ranging (LIDAR) sensors. Research performed with NASA Langley over the last five years on real-time terrain database integrity monitor systems showed results which encouraged the Ohio University Avionics Engineering Center's to submit the DURIP proposal in 2002. The DURIP proposal has allowed Ohio University's Avionics Engineering Center to obtain and flight test a LIDAR system.

The four research areas proposed which utilize the equipment purchased with the DURIP award are as follows: terrain navigation using integrated LIDAR, Inertial Measurement Unit (IMU) and terrain data; hybrid GPS and Terrain navigation using integrated LIDAR, IMU; and terrain data for aerial vehicles; integration of LIDAR, IMU, GPS, and terrain data for surveillance purposes; and LIDAR data compression and processing techniques. These topics as well as the educational component of these topics are covered in this technical report.

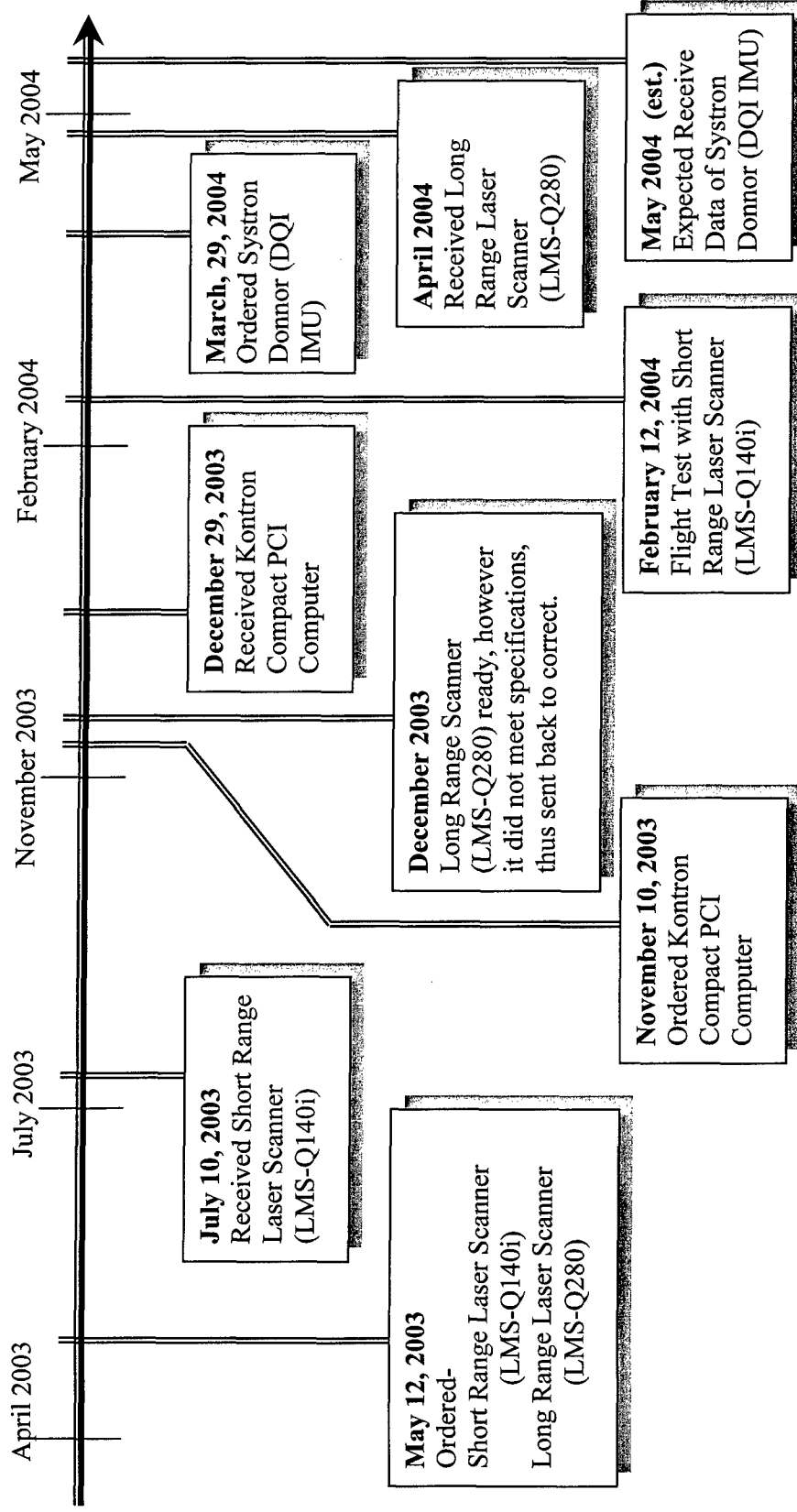
2 Background

The core of the proposed instrumentation package consists of two LIDAR sensors. Like radar, a LIDAR sensor determines distance to terrain and other objects (range-finding) by transmitting and receiving electromagnetic (EM) pulses, followed by the estimation of the time-difference between transmission and reception of the EM pulses. LIDARs operate in the ultraviolet, visible, and infrared region of the EM spectrum (0.9 μm and 1.5 μm for the proposed units). Furthermore, the LIDAR's narrow laser beam is deflected of a rotating polygon to provide a planer scan with an angle of $\pm \theta$ perpendicular to the aerial vehicle's body; θ equals 40° for the short range LIDAR unit and θ equals 45° for the long range LIDAR unit.

Currently, LIDAR-based systems are being used for a variety of applications, including atmospheric analysis, detection of objects and obstacles, and airborne mapping. In airborne mapping, terrain and obstacle database products are derived from the LIDAR outputs. The two important characteristics of a LIDAR are its high accuracy and high resolution. The LIDAR's current limitations are the sensor's high cost driven by a limited market, its lack of an intensity image, and large output data volumes [1]0. Besides its high resolution and high accuracy, most LIDAR sensors, including the ones proposed in this DURIP proposal, are capable of detecting multiple ground returns. This capability enables the sensor to measure the range from the aircraft to both the top-of-the-foliage and the bottom-of-the-foliage. Future LIDAR applications include but are not limited to communications, aviation safety, mapping, ground and airborne transportation, urban landscapes and terrain feature databases, automobile navigation and airborne navigation.

In airborne applications the measurements output by the LIDAR sensor are referenced to the aircraft body frame (a coordinate frame rigidly attached to the aircraft body). To use the LIDAR data for applications that require geo-referenced (Earth-fixed) data, aircraft state information, including attitude, position, and velocity, is required. In most LIDAR systems used for mapping applications this is accomplished by including a Commercial-Off-The-Shelf (COTS) GPS receiver and IMU.

3 Timeline



4 Equipment Purchases and Installation

This section of the program summary describes the equipment purchased with the DURIP award and location of equipment installation. The aircraft used as the test platform for this equipment is the DC-3 flying laboratory owned and operated by the Ohio University Avionics Engineering Center. (CHANGE CHANGE MUDH)

4.1 Riegl LMS-Q140i, Short Range Laser Scanner

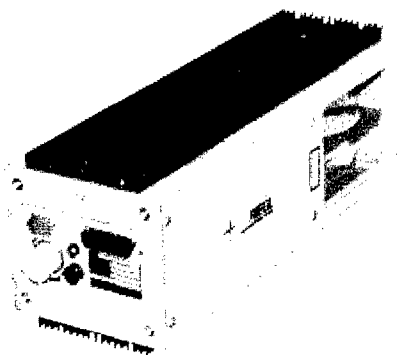


Figure 4.1, Riegl LMS-Q140i Short Range Laser Scanner. *Picture from Riegl Webpage*

The Riegl LMS-Q140i laser scanner, seen in Figure 4.1, is a short range laser scanner designed for use in airborne applications. It has a measurement range up to 450 m for targets of reflectivity of greater than 80% and a range of 150 m for targets of reflectivity of 10%. The LMS-Q140i was ordered on May 12, 2003, and was delivered on July 10, 2003. The LMS-Q140i was installed in the bottom of the DC-3's fuselage pointing nadir. A protective piece of BK-7 glass was ordered to protect the unit from foreign objects.

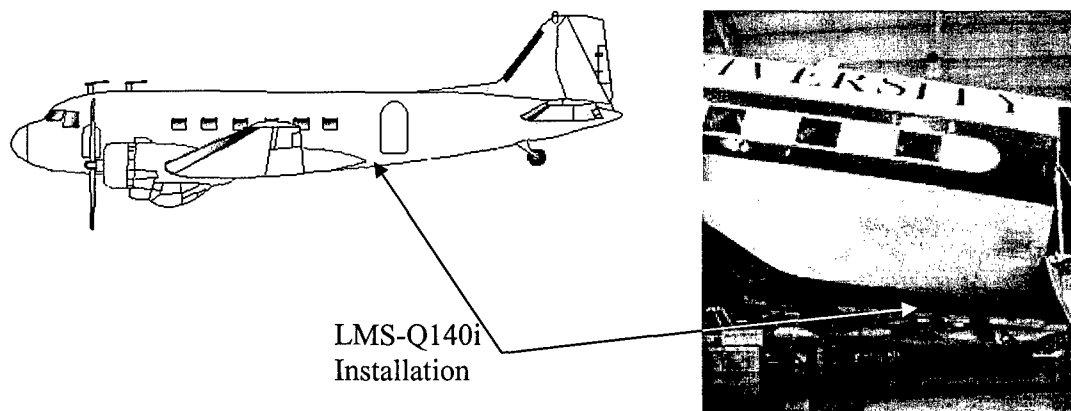


Figure 4.2, Location of LMS-Q140i in the DC-3 Flying Laboratory

Figure 4.2 illustrates the location of the LMS-Q140i as it was installed for the February 12, 2004, flight test. The LMS-Q140i is capable of measuring 10,000 points per second with a typical accuracy of an inch. The unit is specified at a Class 1 eye safe laser for the scanned, 900 nm wave length laser. Data collected with this laser scanner on the DC-3 flying laboratory can be seen in section 5.

4.2 Riegl LMS-Q280, Long Range Laser Scanner

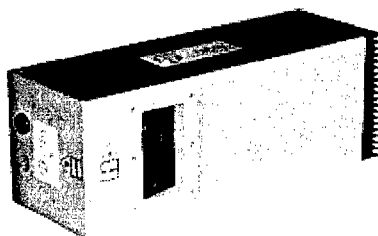
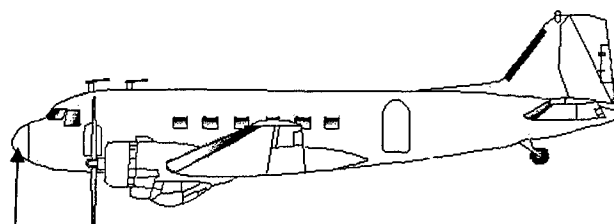


Figure 4.3, Riegl LMS-Q280 Long Range Laser Scanner. *Picture from Riegl Webpage*

The Riegl LMS-Q280 laser scanner, seen in Figure 4.3, is a long range laser scanner designed for use in airborne applications. It has a specified measurement range up to 1200 m for targets of reflectivity of greater than 40%. The LMS-Q280 was ordered on May 12, 2003. The unit was ready for delivery at the beginning of December, 2003, however it did not meet the designed specifications in range thus it was returned to the factory for repairs. The unit was delivered April 21st, 2004. The LMS-Q280 is planned to be installed in the nose of the DC-3 allowing for both downward pointing and forward pointing orientations, see figure 4.4. A protective piece of BK-7 glass was ordered to protect the unit from foreign objects.



LMS-Q280
Proposed Installation

Figure 4.4, Proposed Location of the LMS-Q280 in the DC-3 Flying Laboratory

The laser in the LMS-Q280 is more powerful than the LMS-Q140i and would not be eye safe if it operated at the same wavelength, however, it operates at a wavelength of 1500 nm. The eye is over 100,000 times less sensitive at 1.5 μm than .9 μm . As a result the LMS-Q280 LIDAR unit is also a Class 1 eye safe unit [2].

4.3 Kontron Compact PCI Computer

The Kontron Compact PCI computer was ordered on November 10, 2003, and received on December 29, 2003. It is a 4U, 19" rack mountable computer with a 1.6 GHz Intel M processor. It has redundant power supplies and up to 14 serial ports, 2 Ethernet ports, and 1 parallel port, allowing for sensor interfacing. QNX 6.1 real-time operating system is loaded on the computer and the interfacing software is currently being written in C.

4.4 Systron Donner Inertial Measurement Unit (IMU)

The Systron Donner BEI Motionpak was listed to be purchased in the DURIP proposal, however before it was purchased it was learned that Systron Donner was developing a new IMU, the DQI (Digital Quart IMU), with better performance and digital outputs. The inclusion of the digital outputs eliminated the need to purchase the Strathnuey data acquisition board from Nallatech Inc. Because the DQI is expected to arrive in May 2004, it could not be used for the flight tests on February 12, 2004. Data from the ship mounted Honeywell HG1150 Inertial Reference System was used to perform initial experiments. Although the Honeywell HG1150 is a high-quality unit and good enough for initial system evaluation it does not allow to research new methods for sensor integration as the DQI will. The Systron Donner DQI, seen in Figure 4.5, will be rigidly mounted to the LMS-Q280 LIDAR to measure the precise orientation of the LMS-Q280.

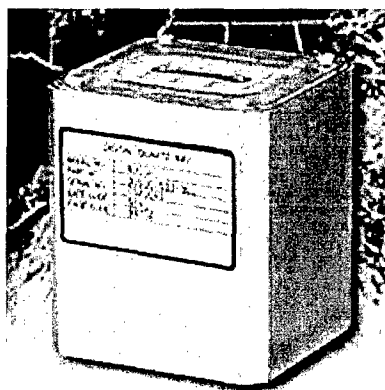


Figure 4.5. Systron Donner DQI, picture from Systron Donner web page

4.5 NovAtel GPS Receiver

The NovAtel OEM 4 GPS receiver listed in the DURIP proposal was not purchased. This was due to several reasons; first, the cost of the Kontron Compact PCI PC was above budget; second, two additional pieces of high optical quality glass were purchased to protect the laser scanners; and lastly, a purchase of laser scanner mounting hardware was required. However, data from a NovAtel GPS receiver was available for the test flight described in this paper courtesy of a separate research experiment which was flown on the same flight. At this time it is expected that the NovAtel GPS receiver used in the February flight test will be available for future flights.

5 LIDAR Research

This section discusses the areas of active research which have been made possible due to the DURIP award. Three areas covered are as follows: the proposed topics listed in the DURIP proposal, additional research which has been possible, and conference papers which are related to the research.

5.1 Proposed Topics

Four proposed research areas that utilize the equipment awarded were identified in the DURIP proposal. They were as follows: Terrain Navigation Using Integrated Laser Scanner, IMU and Terrain Data; Hybrid GPS and Terrain Navigation Using Integrated Laser Scanner, IMU, and Terrain Data; Integration of Laser Scanner, GPS, and Terrain Data for Surveillance Purposes; and LIDAR Data Compression and Processing Techniques. Data collected on the February 12, 2004, flight test is presented in this section to illustrate the possibilities of a LIDAR navigation system.

The February 12, 2004 DC-3 flight test provided the opportunity to validate the ability to record time-tagged LIDAR sensor data and process the collected data. The LMS-Q140i short range laser scanner was mounted on the bottom of the DC-3 fuselage as seen in Figure 4.2. Position data was recorded from a NovAtel OEM 4 GPS receiver and attitude data was recorded from a Honeywell HG1150 Inertial Reference System (IRS). Unlike the Systron Donner IMU, the Honeywell IRS is a navigation grade, ship mounted, ring laser gyro IRS. The Honeywell IRS is mounted just aft of the co-pilot about 20 ft forward the LMS-Q140i laser scanner. The 20 ft separation can introduce data processing errors due to the decorrelation of the IRS and laser scanner attitude measurements; this measurement decorrelation is caused by flexing of the aircraft fuselage. The Systron Donner IMU is significantly smaller than the Honeywell IRS; this will allow the Systron Donner IMU to be rigidly mounted to the LMS-Q140i laser scanner resulting in an improved accuracy of the laser scanner attitude measurement. The scanning rate of the LMS-Q140i was set to 30 Hz with a pulse repetition frequency of 30 kHz. With these laser scanner settings the terrain measurement resolution was higher than 2 m by 2 m. A block diagram describing the use of the data generated from the sensors on the DC-3 is shown in Figure 5.1.

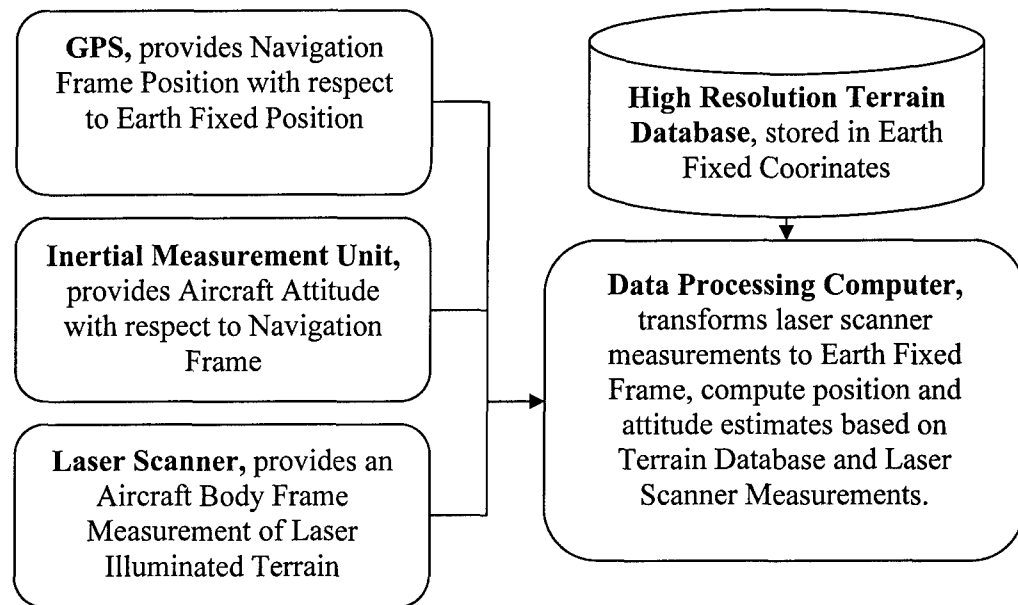


Figure 5.1, Block Diagram of LIDAR Navigation System

The blocks seen in Figure 5.1 provide an overview of the Ohio University Avionics Engineering Center's high accuracy terrain navigation system.

5.1.1 Terrain Navigation Using Integrated Laser Scanner, IMU and Terrain Data

The proposed integrated LIDAR/IMU system is intended for autonomous aircraft terrain referenced navigation not subject to the drift errors associated with current navigation grade inertial navigators. The system's autonomy refers to its independence on radio navigation aids. Data from the laser scanner will be processed and combined with a high resolution terrain database to provide position estimates on the order of a meter. These accuracy results were achieved using data collected by NASA Langley and Ohio University on NASA Dryden's DC-8 with an Optech LIDAR system. Results from this flight test are discussed [3]. Data from the Ohio University February 12, 2004 flight test using the laser scanner purchased with the DURIP award will allow for continued research in this area. A plot generated from the February 12, 2004 flight test can be seen in Figure 5.2.

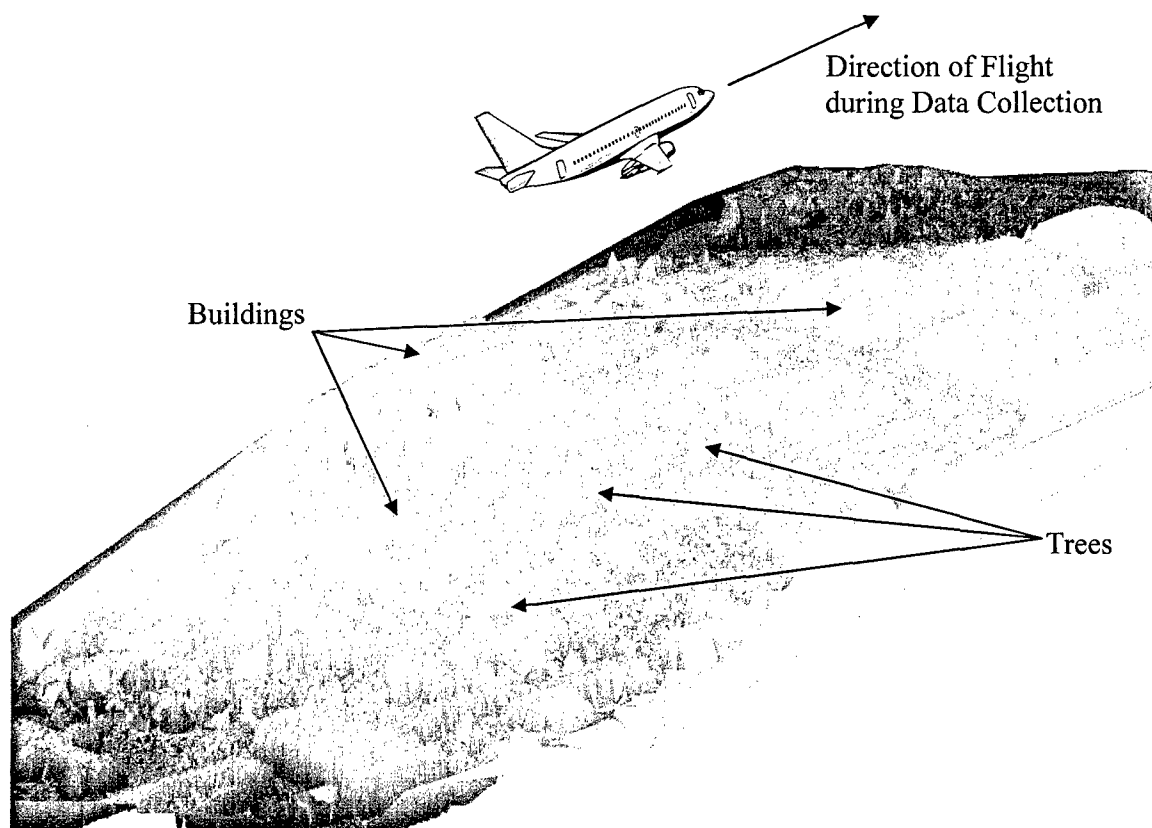


Figure 5.2, College Green of Ohio University Campus, generated with the LMS-Q140i Laser Scanner

Figure 5.2 shows the laser scanner measurements transformed to an Earth fixed reference frame. It can be seen that the resolution of the data allows identification of buildings and trees. Currently research is being conducted with this data to produce navigation solutions.

5.1.2 Hybrid GPS and Terrain Navigation Using Integrated Laser Scanner, IMU, and Terrain Data

Research in section 5.1.1 covers terrain navigation without any GPS augmentation, GPS may be considered to design an integrated navigation system with an increased integrity, availability, continuity of service, and anti-jam capability with respect to standalone GPS. While research into this area has not been explored at this time, data made available by the equipment purchased with the DURIP award will make this research possible.

5.1.3 Integration of Laser Scanner, GPS, and Terrain Data for Surveillance Purposes

The long range laser scanner has not yet been installed on the DC-3 flying laboratory because it has just recently been received from the manufacturer. Performing forward looking surveillance tests was therefore not yet possible. However, results from the February 12, 2004, flight test show the ability of an airborne laser scanner to detect baseball stadium lights (obstacles). The ability to detect stadium lights provides a strong indication that the use of LIDAR for surveillance applications is feasible. Figure 5.3 and 5.4 show a picture of the baseball stadium and a plot of the baseball stadium at Ohio University respectively.

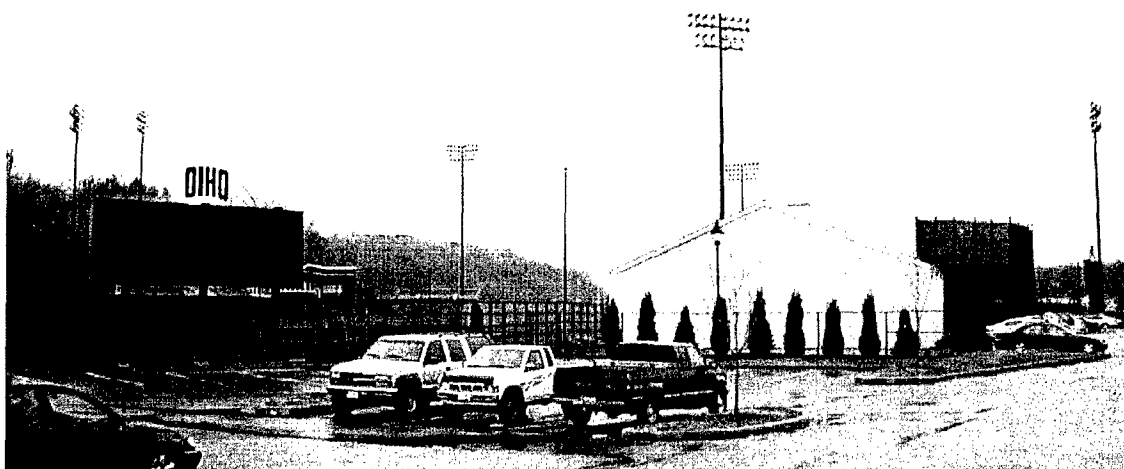


Figure 5.3, Photo of Ohio University Baseball Stadium

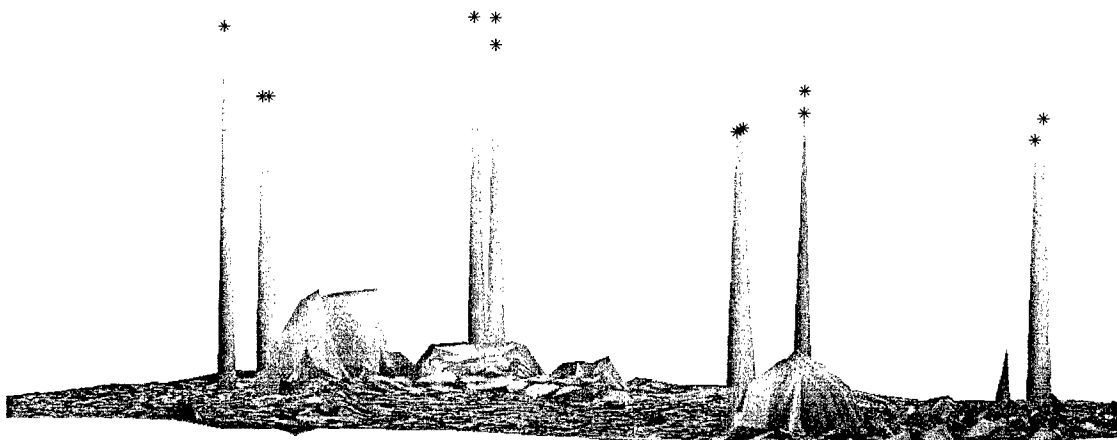


Figure 5.4, Plot of Ohio University Baseball Stadium, generated from February 12, 2004, DC-3 Flight Test, the Blue Stars indicate Laser returns from the Stadium Lights

It can be inferred from Figures 5.3 and 5.4 that the dense measurement cloud obtained from the laser scanner is suitable for obstacle detection, especially when this sensor is pointing forward to increase the probability of obstacle detection. Figure 5.5 provides a prospective view of data collected by the LIDAR system installed on the DC-3.

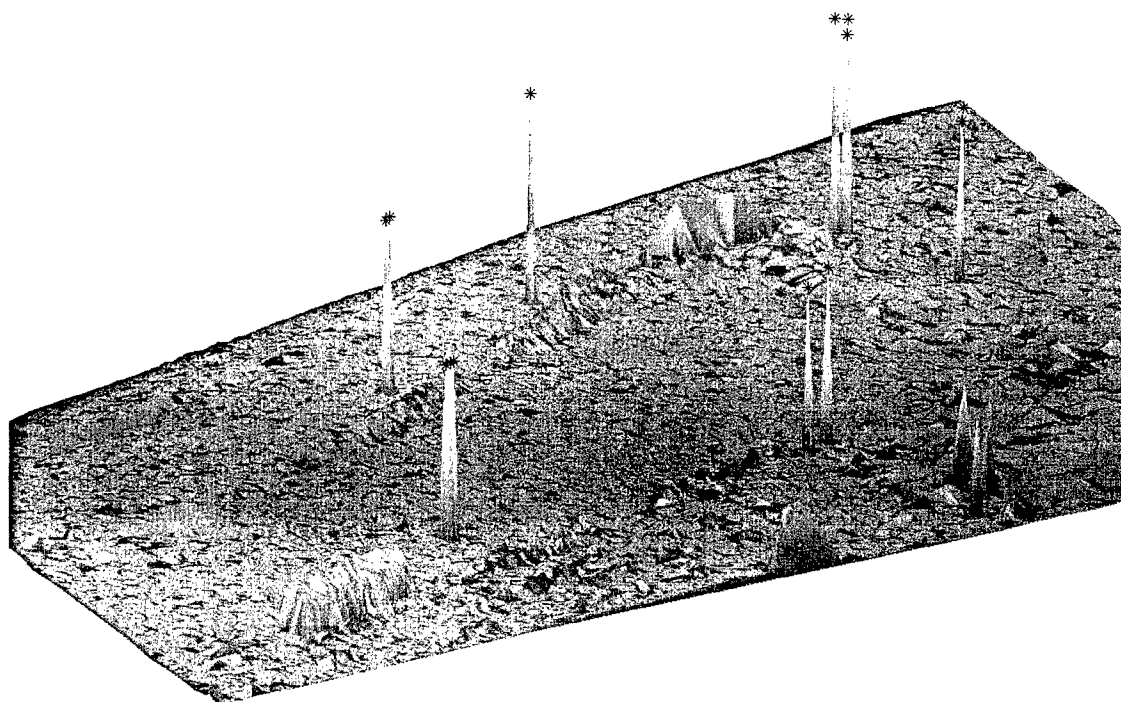


Figure 5.5, Perspective View Plot of Ohio University Baseball Stadium, generated from Feb. 12 Flight Test, the Blue Stars indicate Laser returns from the Stadium Lights.

Figure 5.5 illustrates that a forward looking LIDAR would be capable of surveillance, which among other things, can be used as part of a runway incursion detector. The installation of the LMS-Q280 long range laser scanner, purchased with the DURIP award, will enable proof of concept of surveillance with the actual hardware configuration.

5.1.4 LIDAR Data Compression and Processing Techniques

Due to the high data rate of the LIDAR sensor, large volumes of data must be processed in an efficient manner to meet the real-time requirements set by the navigation procedures and object-detection applications. The LIDAR data compression and processing research area, therefore, investigates computationally efficient methods such as data compression algorithms and parallel computational structures performed on the data output by the LIDAR sensor. To date at Ohio University, this area of research has primarily focused on the storage of the terrain database.

Depending on the method of data collection, terrain databases are primarily stored in a point grid, triangulated point cloud, or as vector contours. Currently methods of storing triangulated point cloud data are under investigation due to their ability to accurately represent both flat terrain data and steep gradient terrain data.

5.2 Additional Research

The DURIP award has enabled additional research areas at Ohio University. One area of great interest is weather related atmospheric attenuation. If a system for aircraft navigation is to be developed, it is necessary to identify the operational constraints of the system. For a laser ranging system one of these constraints is the amount of atmospheric attenuation in different weather conditions. Empirical studies on weather related atmospheric attenuation on lasers have been done, however many of these studies contain relatively small sample sets and are for a limited number of weather conditions [4]. Research being performed by a graduate student at Ohio University using the LMS-Q140i laser scanner will help provide a more complete picture on weather related atmospheric attenuation.

5.3 Conference Papers

Research at the Ohio University Avionics Engineering Center is documented in numerous publications in conference proceedings and journals. In the area of LIDAR-based systems research, two papers have been presented and published in conference proceedings, and a third paper has been accepted for a conference. The papers mentioned above are as follows:

Campbell, J., M. Uijt de Haag, F. van Graas, S. Young, "Light Detection and Ranging-Based Terrain Navigation "A Concept Exploration," Institute Of Navigation (ION) GNSS 2003, Portland, OR, September, 2003.

Campbell, J., M. Uijt de Haag, A Vadlamani, S. Young, "The Application Of LIDAR to Synthetic Vision System Integrity," 22nd Digital Avionics Systems Conference (DASC), Indianapolis, IN, October, 2003.

Campbell, J., M. Uijt de Haag, F. van Graas, "Terrain Reference Navigation using Airborne LAser SCAnner (ALASCA) "Preliminary Flight Test Results," Institute Of Navigation (ION) AM 2004 60th Annual Meeting, Dayton, OH, June, 2004. * *Accepted and to be published*

The first two papers use airborne LIDAR data collected from flight tests performed by NASA Langley over Reno, NV in 2003. The third paper includes data collected with the LMS-Q140i laser scanner purchased with the DURIP award on the Ohio University Avionics Engineering Center's DC-3.

6 Educational Proposals

The procured instrumentation will be used and has been used for projects in undergraduate and graduate classes ranging from lecture-oriented classes to senior design projects. Various aspects of the above research areas are addressed in these classes. To follow is a brief description of some of the educational components that support or make use of the research instrumentation purchased under the DURIP award.

EE690 – Introduction to Sensor Fusion and Multitarget Tracking

This graduate course is currently ongoing (Spring quarter 2004) and is meant for students that are interested in knowing more about the combination of various sensor and database outputs to detect, track and identify objects such as aircraft, buildings, robots, and many more. The processes involved in accomplishing this task are discussed in the course lectures. The course will include a basic treatment of the data outputs and characterization of popular fusion sensors such as Millimeter Wave Radar (MMWR), Forward Looking InfraRed (FLIR), Electro-Optical Sensors (EO), Synthetic Aperture Radar (SAR), and the Light Detection and Ranging Sensor (LIDAR). Course topics include the data association and correlation problem, single target tracking, multi-target tracking, attribute estimation, identity declaration, situation assessment, decision fusion, and sensor resource management. Course projects include processing of some of the data collected with the current LIDAR installation on Ohio University's DC-3.

EE490 – Intelligent Vision Hardware Design

This special topics course is targeted to both undergraduate and graduate students and has been going on since last quarter (Winter 2004 and Spring 2004). The course is a hands-on design experience in which the students design computational structures that are able to process large amounts of sensor information using Field Programmable Gate Arrays (FPGAs). The target sensors are both regular cameras and the LIDAR equipment.

EE485/585 and EE486/586 – Electronic Navigation Systems I & II

These two courses are dual-listed (advanced undergraduate and beginning graduate level) and provide an introduction to electronic navigation principles and systems. LIDAR technology represents approximately 10% of the course materials. Results obtained from the DURIP-funded equipment are used in these classes to illustrate LIDAR principles.

Educational Project: Autonomous Lawnmower

One of our EE senior design groups, which consist of 4 undergraduate students, has been working on an autonomous lawnmower design. The DURIP-funded equipment has helped them in making design decisions for the lawnmower. This year's design does not have a LIDAR, but

it is anticipated to be added by next year's design group, when additional safety and navigation challenges are included in the project requirements.

Educational Project: Indoor Search & Rescue Robot

One graduate student has been working on a search & rescue robot that uses LIDAR and inertial navigation for its guidance. The LIDAR sensor is used to map the inside of the building and to provide navigation inputs to calibrate the inertial navigation system.

Educational Project: Aircraft Sensor Stabilization

Following initial analyses of the LIDAR data obtained from the DURIP-funded equipment, it was found that high-frequency sensor stabilization could significantly improve the performance of the LIDAR data during processing. A graduate student has recently started in this area using the DURIP-funded LIDAR and inertial equipment to investigate advanced sensor stabilization techniques.

Educational Project: Aircraft Final Approach Guidance

This is a new research area, where LIDAR technology is integrated with inertial navigation, radar altimeter, and baro altimeter to provide aircraft final approach guidance after crossing the Final Approach Fix. Currently, one graduate student is working on this topic, which is expected to lead to a large research effort during the next two years. Data obtained from the DURIP-funded LIDAR equipment has enabled this particular research area.

7 References

- [1] Wang, Yangdong and Nidal A. Dahman, "Active Sensors and Modern Photogrammetry," Elevation "A Supplement to Geospatial Solutions and GPS World, September 2001.
- [2] American National Standards Institute, "Safe Use of Lasers," ANSI Standard Z136.1 "2000, Laser Institute of America, Orlando, FL, 2000.
- [3] Campbell, J., M. Uijt de Haag, F. van Graas, S. Young, "Light Detection and Ranging-Based Terrain Navigation "A Concept Exploration," Institute Of Navigation (ION) GNSS 2003, Portland, OR, September, 2003.
- [4] Jelalian, A. V., Laser Radar Systems, ISBN 0-89006-554-3, Artech House, Norwood, MA, 1992.

Avionics Engineering Center

F49620-03-1-0285

Item Description	Amount
Barry E Series Eqpm Mount	\$ 169.62
Misc. connectors	\$ 46.36
WINDOWS 2 BK7	\$ 1,824.87
Misc. Items: Hardware nuts, battery, hose couplings etc	\$ 0.90
Misc. Items: cables, strain relief, plugs	\$ 130.90
Misc. Items: slot covers	\$ 135.62
Glass	\$ 451.00
Misc. Botts	\$ 35.54
Total Miscellaneous	\$ 2,794.81
Q280 & Q140/60 PULSED LASER SCANNING UNIT	\$ 162,459.19
COMPUTER W/PULL OUT MONITOR W/KEYBOARD, INTERFACE, EXTENSION MODULE, COMPACT FLASH, CD ROM	\$ 11,089.00
DQ1 W/ EMI FILTER AND CONN 37 PIN MICRO-D MDM	\$ 17,600.00
Total Equipment	\$191,148.19
Grand Total	\$193,943.00