مبادلة
MUBADALA

جامعة نيويورك أبوظبي
NYU ABU DHABI

LOCKHEED MARTIN

New York University Abu Dhabi

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CURRENT TECHNOLOGIES

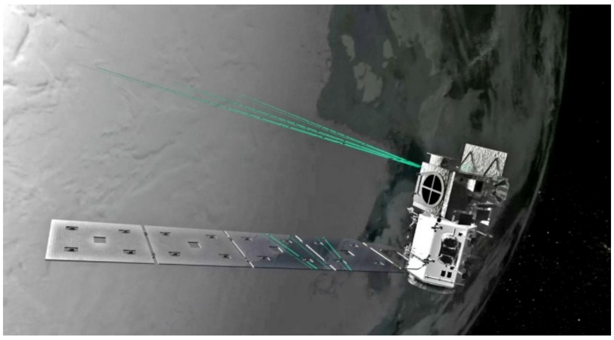
Glacier Modeling:

Current practices for the mapping of glaciers consist primarily of two different methods, depending on the extent of the area involved.

On a localized scale, terrestrial radar interferometry (TRI) is used as a primary collection method of data points for glacial mapping. TRI is a remote sensing tool used to monitor surface deformation; it operates using two moving antennas that measure the phase difference of emitted and reflected microwave signals. The use of a TRI creates a 2D radar image of the glacier; additional elevation data to create a general height profile can be obtained by the addition of stacked antennas i.e. having three separate antennas scanning different elevations. TRI is used to monitor specific areas of glaciers, most notably the terminus edge of an entire glacier system where calving occurs. By mapping the terminus edge, measurements can be made regarding the rate of advancement of the glacier, the flow rate of the ice melange floating in front of the terminus, and the identification of calving events. One drawback that arises from TRI scanning, however, is the existence of an occluded shadow that results from elevated surface structures blocking the further propagation of the emitted microwave signals.

TRI ray-dome at the Jacobshavn Glacier Front, Greenland
Photo Credit: Alexander MacKay

Glacial mapping also occurs on a global scale through remote sensing, for instance NASA's Ice Cloud and Land Elevation Satellite (ICESat) series program and the interim Operation IceBridge airborne mission. These missions conduct spaceborne and aerial LiDAR altimeter measurements and radar scanning of areas of Greenland, Antarctica, and other polar regions to generate data such as those related to ice surface topography, bedrock topography, and grounding line positions of glaciers. Data from these missions has been extensively used by glaciologists, oceanographers, and climate scientists and led to the publication of 34 research papers in 2016 alone.



Idealized image of IceSat 2 surveying Antarctic region
Photo Credit: NASA

LiDAR Mapping:

Geospatial mapping is currently being done through several methods, including by satellite, airplane and UAV; however, each of these methods raises several issues in terms of our use-case despite their positive aspects. First, satellite imaging such as the ICESat and ICESat2 Missions are great for a large area of data collection; however, they are unable to provide data to generate elevation models of highly specific and localized regions. More localized elevation data collection has long been done by airplane, since this allows for large areas to be covered with high precision; however, such methods are expensive and restrictive in terms of accessible locations. Both satellite and airborne collection methods are insufficient in providing high accuracy data for a direct location such as the calving front of a glacier.

Mapping done by UAV's falls under two categories: photogrammetry and LiDAR. Photogrammetry describes the process of taking many aerial photos and stitching them together to create a visual model of the structure in question; this method can be used by any UAV with a camera. The downfall of this method is that data relating to the position of different elements in the model are unable to be determined; additionally, due to the way that similar elements in different images are identified and the model is created, challenges arise with this method when examining a surface that is homogeneous (such as a glacier).

When it comes to LiDAR mapping of glaciers using drones, the main factors of significance are portability, range, and accuracy. First, a UAV must be portable enough to transport to remote expedition camps to be configured on site. Along with this, the glacial structures in question are located several kilometers away from the ground base; as a result, a UAV must be able to cover this distance and return to the camp. These two aspects mean that many large-frame UAVs that carry highly accurate yet heavy LiDAR sensors would not be suitable for this environment. The accuracy of the LiDAR sensor in question is also important; precise measurements must be obtained to create elevation mapping that can be used for research purposes.

DESIGN FEATURES:

The features that have been identified as crucial to the development of a UAV and payload system suitable for glacier modeling are as follows:

1. Large area of data collection; long range of flight
2. High accuracy in LiDAR measurements
3. Navigational deployments adaptable in the field to adjust waypoints based on position of the glacier
4. Robust build to be used in rugged, isolated conditions
5. Portable and easily deployable

Our team has designed a payload to integrate onto the Lockheed Martin INDAGO UAV to fulfill these criteria.

GLACIER GLiDAR

The Glacier GLiDAR is a payload for the Lockheed Martin INDAGO UAV that will enable the creation of computational three-dimensional modeling of remote glaciers. Using a LiDAR sensor, accurate distance measurements can be collected during a flight which can then be used to generate density elevation models of the investigated surface. The combination of the INDAGO and a Glacier GLiDAR will create the most suitable mapping system currently on the market to achieve the objectives aligned with glacier modeling.

TECHNICAL DESIGN:

For the technical design of the Glacier GLiDAR, three components of the payload have been identified: the sensor, the housing, and the gimbal mount.

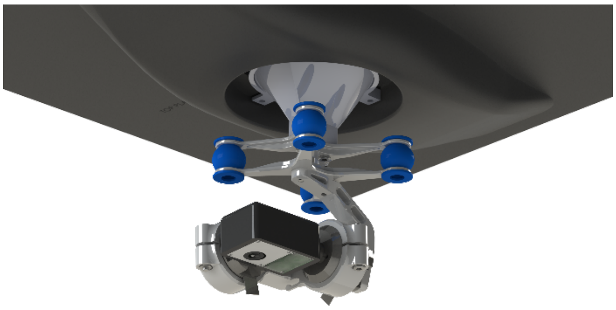
In discussion of our objectives with the LiDAR sensor manufacturer LeddarTech, we have identified the LeddarTech M16 as the most suited sensor to our needs. This replaces the LeddarTech Vu8, our previously determined sensor. The sixteen data segments of the M16 allow for a greater resolution than the eight segments of the Vu8. The M16 is listed to have a lower optimal range than the Vu8; however, our team has decided to prioritize the higher resolution obtained with the M16 as compared to the increased range of the Vu8.

LeddarTech M16 LiDAR Sensor
Photo Credit: LeddarTech

The M16 has multiple beam angles available; our team has identified the largest beam angle (95°) to be the most suited for our use-case. At 100m above the surface to be tested, this give a footprint of 200m, or 12.5m per segment. This is an acceptable size for the resolution sought for this modeling, with the knowledge that finer detail can be established by flying at a lower height above the glacier surface.

The second component is the main housing. This component will contain the payload microcomputer, an IMU unit and an SD card. We will use a RaspberryPi for input control, data writing and power monitoring. An IMU unit will also be contained in the housing upon the sensor so that accurate measurements can be obtained from the sensor directly as opposed to relying on the IMU of the INDAGO itself. Also, a microSD card will act as data storage during the flight, allowing time-stamped measurements related to sensor distance and amplitude, GPS coordinates, and IMU information to be retrieved at the base camp for processing. This method for data storage has been selected considering that real-time data transferral is unnecessary for our use-case, therefore having a reliable and large data storage device on the payload is appropriate and efficient for data acquisition.

The last component is the gimbal mount for the payload. This will automatically stabilize the LeddarTech M16 sensor at the desired angle of data collection (immediately downwards) against disturbances in the pitch and roll directions. Connection through the RaspberryPi will also allow for intervention to control the sensor direction to examine particular features. The gimbal will also aid the sensor in handling vibrations from the vehicle; however, given the intended continuous data collection while in motion, the vibrations of the aircraft are of less concern than if the machine were hovering.

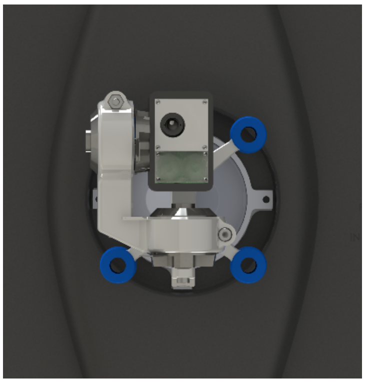


Rendering of Glacier GLiDAR payload
Photo Credit: Raitis Pekuss

The payload design described and represented above fulfills the design envelope required for use with the INDAGO. The following table indicates the mass of each of the individual components, leading to an estimated total payload mass of 435g.

Component	**Mass (g)**
M16 LiDAR Sensor	180
2-Axis Gimbal Mount	135
Housing, including microcomputer, circuitry and microSD	120
Total	435

Additionally, the size boundaries of the design envelope will not be exceeded. The approximate dimensions of the Glacier GLiDAR are 120mmx110mmx120mm (LxWxH). No components will interfere with any mechanical functioning of the drone; also, the centre of gravity will be located very close to the centre mount, well within 50mm of this point.



Underside view of Glacier GLiDAR
Photo Credit: Raitis Pekuss

In terms of power supply, the M16 Sensor requires a 12 or 24VDC input and consumes 4W of power; this will be supplied from the INDAGO via the RaspberryPi. The gimbal mount will also be supplied via the vehicle with control through the microcomputer, with power consumption optimized at 12V with approximately 2.4W of power draw depending on conditions. The microcomputer itself requires 5V input and draws approximately 1W of power.

High accuracy position and inertial measurements are of significance for the successful development of the Glacier GLiDAR. The current GPS/Galileo/Glonass system present on the INDAGO leads to an error of approximately 2 - 4.5m in terms of position of the UAV; it is worth noting, however, that at high latitudes such as the regions to be mostly studied, the accuracy of these systems increases. That being said, additional accuracy is important for successful 3D modeling of glacial structures. As a result, our team would seek to work with Lockheed Martin's INDAGO team of engineers to implement Real Time Kinematic (RTK) coordinate measurements onto the drone, which can increase the accuracy of this data to just one-centimeter uncertainty.

The navigation of the INDAGO UAV will be governed by waypoint missions created in the field. Due to the nature of the moving structure of a glacier, flying the same route at different points will not yield comparable data; instead, new coordinates along the calving front will be identified in the field using positions obtained by contemporaneous TRI measurements, allowing for the same feature of the glacier to be examined at different times.

Although the Glacier GLiDAR does not require a camera to operate, the additional implementation of the developed Adapter may be considered. Doing so would not be necessary for the proper functioning of the payload; however, it would provide a video stream to the base station for the user that could support its use. This design decision can be made later in the process and is possible due to the significant weight remaining in the design envelope and because of current low data streaming via Ethernet to the ground station.

The implementation of an elevation warning system is also under consideration; this system would monitor the elevation readings being obtained from the LeddarTech M16 LiDAR sensor, and if these readings indicated proximity to the surface (e.g. <10m of elevation), then a warning could be returned to the INDAGO Virtual Pilot controller to allow for a pilot to take over control of the vehicle.

DESIGN METHODOLOGIES:

Our team will incorporate several design methodologies in the development of the Glacier GLiDAR payload relating to the design of the payload, the development of the corresponding software, and its appropriate use in the field.

To support the construction of the pilot prototype to be implemented onto the INDAGO, 3D modeling, upscale prototyping and test stand assessments will be used. Three-dimensional modeling software will be used to design the structural aspects of the payload and their overall assembly. This includes the main circuitry housing, a component that will be 3D printed and will contain the motherboard and data storage for the device. Upscaled prototyping will be utilized to assemble a functional unit of the payload to be tested before further development is completed to fit the criteria of the design envelope. This includes building of the initial breadboard which will validate the electrical interfaces of the final unit. Once an established prototype has been built, this unit will be tested upon the INDAGO test stand to actualize and validate their compatibility.

Software must also be developed to perform the data analysis process to provide models suitable for research intentions. This involves the computational creation of a global coordinate system upon which the point cloud for density elevation mapping; this process requires data corresponding to vehicle position, inertial measurements, LiDAR distance and amplitude signals, and continuous time stamping. Existing software will be utilized in this process, notably CloudCompare for initial data processing and testing, and ArcGIS for model creation.

To better understand proper usage of aerial data collection for glacier modeling, field work will be conducted using UAV's at the Jacobshavn calving front in Western Greenland. By operating a UAV while near the calving front, a better understanding of the necessary range of flight, of the creation of appropriate waypoints and of the regulations surrounding UAV use in this region will be developed. Additionally, photographic data will be obtained to enable photogrammetric analysis, which will deepen our teams' understanding of the methods underlying the building of similar three-dimensional models.

DATA PIPELINE:

Our data workflow has been broken down into three divisions: collection, processing & storage, and modeling. We need to design a data pipeline that quickly and reliably combines and transforms raw data into a 3D visualization through several steps:

Collection:
First, raw data is obtained from three inputs.

LiDAR: The sensor returns low level data about distance and signal amplitude for 16 segments simultaneously with a refresh rate of approximately 50 Hz.
(interface: SPI or USB, serial)

GPS: Location data received by RTK module. As the UAV performs it flight path, continuous coordinates are collected to support the appropriate positioning of LiDAR-obtained elevation points.
(interface: 3.3V ttl with adapter)

IMU: high accuracy inertial measurements obtained for payload specifically from independent IMU component.
(interface: serial)

Processing & Storage

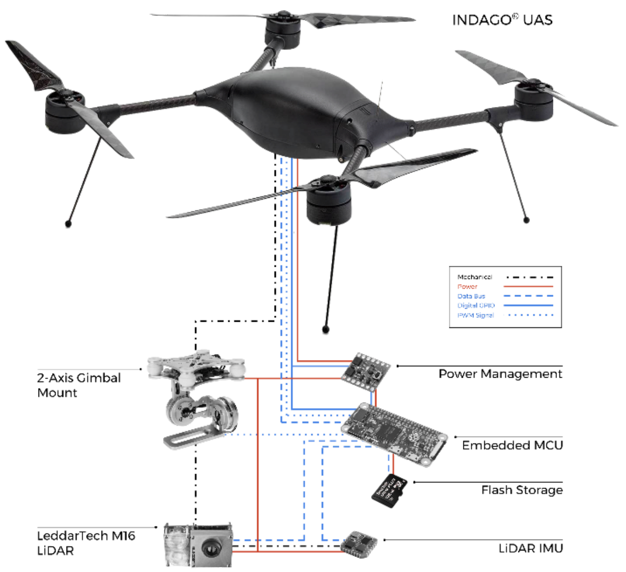
Data processing will be performed in two stages.

First, intermediary processing will be conducted within the computational framework of the payload. RaspberryPi has been chosen as the most suitable microcomputer for our payload, considering its higher performance than other candidate components (e.g. Arduino) and the ability to install a full Linux kernel. The onboard processing units' task is to timestamp, bundle, compress and store the data collected from the independent sensors. These data packages will then be written to a microSD card.

After the completion of the flight mission, the microSD card is retrieved and the bundles are exported onto a field computer. Geo-referencing of the LiDAR data points is then conducted at the expedition base camp to create a point cloud of the obtained data (.las format). For data working on the ground, Python has been selected as the processing language of choice given its qualities for easy development, less errors, and the presence of libraries for matrix manipulation on multiple CPU cores that will be essential for this data working (e.g. Point Data Abstraction Library - PDAL)

Modeling:

Once a point cloud is generated, the final level of analysis can be performed to create the density elevation model of the structure examined. This task will require the use of third party software to visualize the point cloud model of the glacier in a format where researchers can interact with the data. CloudCompare and ArcGIS have been identified as relevant software to be used in this final modeling step.



RESEARCH OUTCOMES:

The Glacier GLiDAR aims to support research currently being conducted to study glaciers and the effect that these structures have on climate change and sea level rise. Obtaining three dimensional models of glacier features such as the calving front, crevasses, moulins and melange can lead to significant research outcomes. Some of these outcomes are identified below by current scientists in this field of study:

> "The future of the Greenland and Antarctic Ice Sheets in a warming global climate holds great importance to humankind in terms of potential sea-level rise in coastal inhabited regions. The process by which sea-level could change is not well understood, in large because of a lack of observations in critical regions, such as at the calving front of major outlet glaciers. Developing new technology that can make appropriate observations, such as a lidar traveling over a calving front, could provide invaluable new data to push the science of projecting global sea level forward. Observations from a lidar at a Greenland calving front, can feed into models of sea-level projection, something that is of significant value to coastal sea level planners, in Abu Dhabi, the UAE in general, and elsewhere around the globe."
>
> Dr. David Holland,
> *Principal Investigator*
> *Center for Global Sea Level Change*
> *Abu Dhabi*

BLOCK DIAGRAM (see Appendix for larger copy)

"A highly accurate Digital Elevation Model (DEM) of an outlet glacier front is critically important for ice-ocean interaction study. The DEM can illuminate the surface morphology of the glacier calving front, providing fundamental resources for glacier calving study and different physical parameters for glacier modeling, such as crevasse depth and width. Additionally, combining bedrock topography, ice freeboard and surface DEM, the grounding line can be extracted if a floating ice shelf exists. Furthermore, using a time-series' DEM of the glacier front, surface elevation changes caused by ocean tide or basal melting may be extracted. "

Dr. Xianwei Wang
Research Scientist
Center for Global Sea Level Change
Abu Dhabi

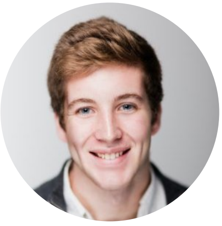
"Glacier calving is a poorly understood physical process responsible for half of glacier mass loss, and it is absent or misrepresented in numerical models. Consequences of changes in calving dynamics due to either natural or human induced causes are unknown but relevant on the human time scale. A huge limitation for understanding calving is lack of observation with high spatial and temporal resolution close to the calving front. High resolution spatial data could be an important step towards future development of process based glacier modeling."

Irena Vankova
Ph.D Student
Center for Atmosphere Ocean Science
New York

TEAM:

Core Team:

Alexander MacKay



Alexander became involved with glacier research as a member of Dr. Holland's expedition team to the Jacobshavn calving front in Western Greenland. As a mechanical engineering student, he was inspired by how technological solutions could be implemented to overcome challenges faced in this remote environment. Alexander is the Project Leader for the Glacier GLiDAR and will oversee the design and building of the payload through to success.

Gábor Csapó

Gabor began working with Dr. Holland's team while completing a data visualization project for displaying hundreds of thousands of oceanographic data points collected along the Western coast of Greenland. Seeing the impact of his application on the team's work inspired him to further pursue projects in collaboration with Dr. Holland; this August he will be joining the expedition team to Greenland to better understand the process of data collection. Gabor is responsible for developing the Glacier GLiDAR associated software that will perform the data processing to construct a final elevation model suitable for research purposes.

Supporting Team:
Dana AlHosani

Dana is majoring in Social Research Public Policy with a concentration in the Environment who became interested in Dr. Holland's research after taking his Global Climate Change course. Dana will focus on the research implications, political influence and public awareness that enhanced understanding of glaciers from this technological development will allow.

Sara Mohamed Aldhaheri

Sara is a mechanical engineering student who is passionate about aerospace systems. She will work to support the conversion of the UAV's inertial reference frame to a global coordinate system to construct an accurate density elevation map.

Raitis Pekuss

Raitis is a civil engineering student interested in sustainable infrastructure and working in isolated communities. His work will focus on the structural analysis of the overall payload and he will also support the technical design of components to be 3D printed.

Advisors:

David & Denise Holland

David & Denise have been conducting field research in Greenland and Antarctica for nearly a decade. Together they have published and supported several high-profile research papers and now form the Principal Investigative team of the Centre for Global Sea Level Change based in Abu Dhabi.

Matthew Karau:

Matt is a lecturer in Engineering Design and the director of the

Engineering Design Studio at New York University Abu Dhabi. He has extensive experience in assisting successful student-led initiatives in the UAE.

SCHEDULE:

July 2 – August 24 (Alex – New York):
· Competition process, design of the payload and skill development at Environmental Fluid Dynamics Lab.

August 17 – 25 (David, Denise & Gabor - Jacobshavn calving front, Greenland)
· Field research expedition; additional task of conducting photogrammetry collections of the glacier.

September 20 (Abu Dhabi):
· Final design confirmed and materials acquired

October 18 (Abu Dhabi):
· Large-scale prototype developed; data acquired from system and modeling processing tested.

November 15 (Abu Dhabi):
· Mountable prototype constructed; assessed upon INDAGO test stand.

December 6 (Abu Dhabi):
· Pilot payload constructed and tested upon INDAGO test stand.

February (Abu Dhabi):
· Pilot payload tested upon INDAGO UAV.

Summer 2018
· Payload and INDAGO tested at Jacobshavn glacier front, Greenland

BUDGET:

Item	**Cost (AED)**
Payload Components	
· Lidar Sensor	7900
· Mounted Gimbal	4100
· Microcomputer Package	1100
· External IMU Sensor	1450
· Memory Writing	150
Total payload components	*14700*
Materials and Supplies	
· Memory Cards	580
Total materials and supplies	*580*
Transportation	
· NYU Abu Dhabi – Masdar City (Four Visits)	560
· NYU Abu Dhabi – Techshop (Two Visits)	280
Total transportation	*840*
Other	
· ArcGIS Subscription - Two users, six months	1850
· Assorted Parts - Wiring, breadboards, circuitry, etc. - Minor break out boards - General equipment (tape, solder, etc.)	290
· Tooling Production Costs: - Industrial 3D Modeling (carbon fibre) - Injection Moulding of housing	1900
Total other	*4040*
Overall Total	***20160***

Budget Justification:
The total requested budget is 20160 AED.

This budget is based on the development of two models of the Glacier GLiDAR: an upscaled system for initial testing and a payload prototype. To build these separate prototypes we have requested for two copies of several of the components (see Components List in Appendix). For example, the upscaled system will be programmed and tested on a RaspberryPi 3, while the fully implemented microcomputer for the payload will be a RaspberryPi Zero.

Transportation has been requested for several trips between our university campus and the locations and some of the resources available to our team throughout the design challenge. These are projections of the number of visits that will be conducted throughout the challenge.

Two six-month ArcGIS subscriptions have been requested. This software is necessary to create final product digital elevation models. One of these subscriptions will be on a desktop in the Engineering Design Studio, while the other will be on the personal computer of the team member responsible for the model creation.

Budget has also been requested for tooling production costs. This refers to final production methods that are unavailable to our team at the Engineering Design Studio, on our campus, or within the resources offered through the design challenge. These include possible 3D printing of attachment components to link the gimbal, sensor and housing in carbon fibre. Also included is the possibility of injection moulding for the microcomputer housing.

SUSTAINABILITY

The Glacier GLiDAR will initially be implemented to support current research being done on outlet glaciers in Greenland. The scientists responsible for this research support our project and have expressed interest in incorporating our system into their research practices.

In addition, our team will promote the Glacier GLiDAR to other research bodies studying glaciers. These potential customers include the Canadian National Research Council, the American National Science Foundation, NASA IceBridge Missions, as well as independent scientific research centres.

Our payload could also support initiatives undertaken in the Emirates, such as the plan to harvest freshwater from an iceberg; our system could be used to collect frequent measurements of the mass loss of the iceberg during its trip from Antarctica.

We also imagine that our payload and data analysis can be altered to enhance research of other highly viscous motion. For example, dune encroachment in the UAE could be identified and monitored through 3D modeling. Other areas of potential study include landslide and avalanche areas, and potential industrial use in fields like mining.

With these possibilities of further implementation also comes the need for additional production of the payload. Methods of larger scale production have begun to be investigated and will be further developed throughout the design challenge. This includes support from the manufacturer of our LiDAR sensor for expanded production, along with the possibility of the design of a new sensor to suit our particular use-case.

ABSTRACT:

COMPONENTS LIST:

Component Name	Manufacturer	Part Number	Unit Cost (AED)	Quantity	Total Cost (AED)
M16 LiDAR Sensor	LeddarTech	LED - MOD - 95 - 10	3950	2	7900
Splash Gimbal	SwellPro	N/A	2050	2	4100
RaspberryPi 3 Starter Kit	RaspberryPi	RPi3-SK	380	2	760
RaspberryPi Zero Starter Kit	RaspberryPi	RPi0-SK	380	1	380
Sandisk Extreme 128GB microSD	Sandisk	SDX-128	290	2	580
microSD Card Reader Breakout	Adafruit	Product ID 254	52	2	104
DC/DC Power Controller Breakout	Sparkfun	BOB-09370 ROHS	150	2	300

BLOCK DIAGRAM: