Project Definition Document (PDD): Avalanche Drone

Approvals

Role	Name	Affiliation	Approved	Date
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I. Problem or Need

Current avalanche prediction techniques often require researchers to spend hours digging 1-2 m deep snow pits on the side of avalanche prone areas. This presents an inherent safety risk to those digging as snow pit locations can be difficult to decide as snow depths can have high variability due to changing environmental conditions.

Our project aims to provide the ability to remotely access and monitor snow depth in high risk areas of the Copper Mountain ski resort to help maximize safety and minimize time spent digging these pits. Snow depth data that is collected over a given area for several months would help ski patrol decide where to dig more tactically. Accurate and regularly updated snow depth data can also enhance current avalanche prediction models and can provide information for explosives planning, boot packing, and ski cutting. Equipped with more data, ski patrol will be safer and more efficient when maintaining the mountain resort.

II. Previous Work

The measurement of snow depth is very important during winters, for the safety of transport routes, railway systems and other infrastructure. Sensors for such a task are widely available. For example, *Traffic Products, Inc* provides a variety of sensors that can be mounted to a light pole [3]. These commercially available sensors use opto-electronic sensors with an eye-safe laser sensor to detect snow depth. The company manufacturing the laser sensors claims readings are "millimeter-accurate". The CCTV-like hardware is large and heavy as the sensors are designed for static functionality.

Due to the importance of snow depth measurements in snow models, several techniques have been tested to measure snow depth, including satellites. A research team at KU Leuven worked on snow observations from the Sentinel-1 satellites over the Northern Hemisphere mountain ranges [2]. Snow covers approximately 20% of the Northern Hemisphere and is a critical water resource. The data from Sentinel 1A & 1B satellites has 1 km^2 spatial resolution and weekly temporal resolution. This allows the satellites to cover vast areas of land. However, ground stations coordinated with the satellite provide more precise local measurements. Compared to this method, our customer requires more precision in the spatial and depth dimensions. Using a UAV instead should provide more control and more precision than a satellite.

Using an unmanned aircraft for geological surveying is not a new concept, however, specifically using these tactics to measure the depth of snow is a much less explored field. Snow depth measurements have previously been done on unmanned air systems in a study by University of Genoa, which compared three different techniques for measuring snow depth including photogrammetry, 3D laser scanning, and manual probing. In order to obtain data, a commercial hexacopter was used [1]. This showed the feasibility of using unmanned systems to measure snow depth, but does not explore the conditions and precision required for our project. It lacks testing at high altitudes, at high altitude weather conditions, on steep slopes associated with avalanche terrain on a ski resort. It also focuses on comparing the accuracy of the different methods of obtaining data to each other rather than meeting a certain required level of accuracy.

Manual techniques of sampling have proven to be expensive, time-consuming, and potentially dangerous presenting the need for new methods. Lidar is another remote-sensing tool that has been applied to snow depth measurement. Ground based lidar can provide highly accurate measurements typically with error on the milimeter-scale while air applications can provide measurements with error on a centimeter scale. The trade-off with airborne remote sensing is a much larger swath width allowing for greater coverage at the expense of accuracy. Previous applications have found pointing accuracy decreases at the edges of the scan and with high scan frequencies. Lidar mapping applications for snow depth is still evolving, meaning that sensors and processing techniques are not standardized[5].

III. Specific Objectives

The objectives of this project are found in table 1, which contains the three levels of success determined for our remote sensing vehicle. Tier one focuses on developing a reliable and accurate sensor package which is able to measure snow depth with an acceptable level of accuracy. This sensor would then be mounted on an aircraft capable of flying in high altitudes. The next level of success involves mounting the sensor package on a drone that can stabilize the sensor so it can take accurate snow depth measurements in adverse weather conditions. The second level of success also includes greater sensor accuracy and resolution, autonomous flight capability, and better data visualisation after the flight has been conducted. The final level of success is a drone capable of flying an efficient flight path such that the sensor can gather information as quickly and accurately as possible for the given area. This requirement includes greater sensor accuracy, more precise location data, and an aircraft capable of flying in severe weather conditions. The sensor and drone combination will be tested in high altitude conditions similar to those found on Copper Mountain. Level three success is the design goal of the team.

Level	Snow Data	Position Data and Navigation	Data Processing	Aircraft Design
1	Snow depth measured to within ±15cm with a horizontal resolution of 12m x 12m.	The aircraft must be able to measure its position and altitude precisely enough to avoid terrain collision. The sensor package may require a more accurate altitude measurement to achieve the desired snow depth reading.	Produce 2D heat map of snow depths	Aircraft must be able to maintain steady, level flight at density and altitude conditions found on the top of Copper Mountain with wind gusts up to 10 knot
2	Snow depth measured to within ±10cm with a horizontal resolution of 6m x 6m.	The aircraft will be able to fly a pre-programmed flight path autonomously.	Overlay heat map onto Copper map	Aircraft must be able to maintain steady, level flight at density and altitude conditions found on the top of Copper Mountain with wind gusts up to 20 knot
3	Snow depth measured to within better than ±10cm with a horizontal resolution of 6m x 6m.			Aircraft must be stable in 25 knots winds at density and altitude conditions found at the top of Copper Mountain with gust up to 30 knots

IV. High Level Functional Requirements

1) **Sensor and snow-depth accuracy.** The product shall meet the following requirements for the quality of data collected:
    a) The snow depth shall be measured accurate to ±10 cm.
    b) The snow depth data shall be presented as a grid with spatial resolution no coarser than 6m x 6m.
    c) Each snow depth measurement shall be associated with a GPS position accurate to 3m in lateral directions.
    d) The altitude must be measured and recorded by the aircraft with sufficient accuracy in order for the sensor package to meet the snow depth resolution requirements.
    e) These accuracy requirements must be met in areas clear of foliage.
    f) The sensor package must meet these requirements at an altitude of no more than 400 ft above ground level in order to comply with Federal Aviation Regulation (FAR) FAR107.51.
2) **Endurance.** The aircraft will have sufficient endurance such that data for a 0.3 km^2 area can be gathered with a maximum of two flights.
3) **Aircraft operating condition and capabilities.**
    a) The aircraft shall have a service ceiling not less than 14000 feet density altitude to accommodate variance in atmospheric pressure.
    b) The aircraft shall maintain its attitude and altitude that allows the sensor package to retrieve accurate snow depth data within the 10 cm requirement.
    c) The entire system must be operable by Copper Mountain staff with a maximum of 40 hours of training, not including the necessary training to obtain a FAR107 FAA remote pilot certificate.
    d) The aircraft must meet FAR107 requirements for operation in the national airspace system:
        (i) The maximum takeoff weight must not exceed 55 pounds according to FAR107.3.
        (ii) The aircraft will be equipped with anti-collision lighting visible at at least a 3 statute mile distance to enable operations during periods of civil twilight (FAR107.29).
    e) The aircraft shall be able to achieve a climb rate and climb angle that allows it to enable maneuvering over steep terrain at the take off altitude.

f) The aircraft shall traverse the survey area in steady winds not to exceed 25 knots at a groundspeed that allows it complete the data collection process without needing to land.
g) The aircraft shall be able to takeoff and land on top of Copper Mountain: the aircraft shall be capable of takeoff and landing within a snow-covered uneven area of 20m x 20m.
h) The aircraft shall carry the weight of the sensor package plus all other subsystems needed for successful data collection as required by the senor package.
i) The aircraft shall be able to operate between a temperature range that allows the sensor package and aircraft systems to operate at needed capacity.
j) The aircraft's electronics system must provide the necessary wattage and voltage for the sensor package to operate for the duration of the data collection period.
k) The aircraft shall be controlled with a telemetry and command system capable of controlling the aircraft at a range of 0.5 km from the control station.

4) **Data visualization and storage.** The product shall meet the following requirements for processing the collected data:
   a) The sensor data shall be stored on the aircraft and collected upon landing. The data shall be saved to a common and easy to interface with storage device, such as an SD card or USB FLASH drive which can be used to transfer the data to the resort's computers.
   b) A heatmap shall be produced with a color code to indicate the snow depth.
   c) This heatmap shall be able to be superimposed onto ARCGIS software which is already used by the resort's ski patrol.
   d) Each set of data must be able to be saved to a file which can be re-examined at a later time by the ski patrol.
5) **Cost.** The aircraft, sensor package, all supporting hardware, and spare parts, must be designed and fabricated for no more than 5000 USD.

A. CONOPS

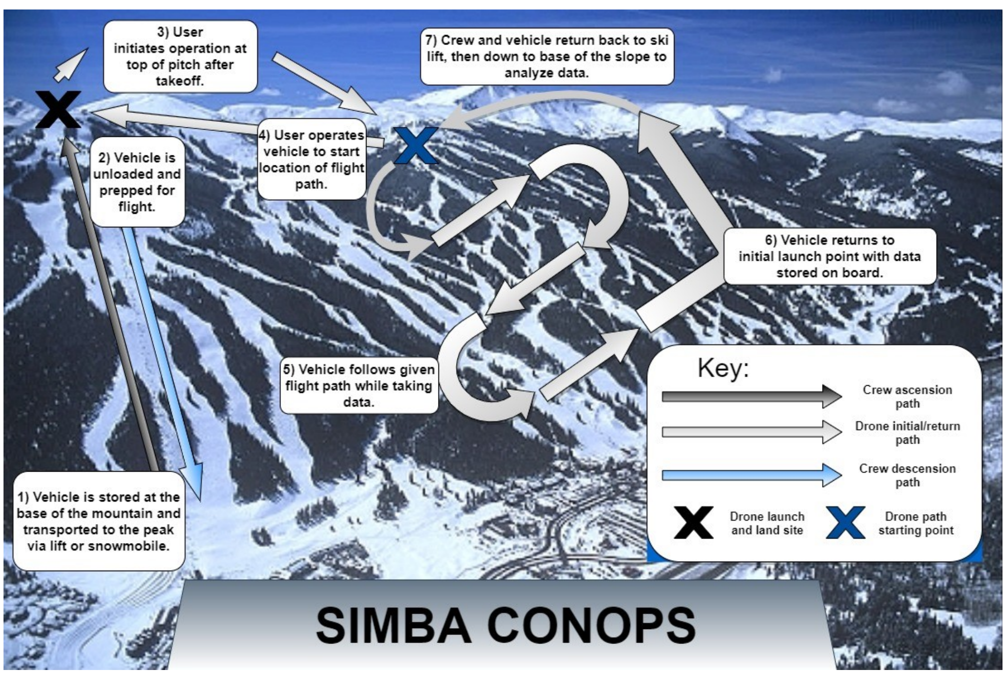

Fig. 1 Concept of Operation for project SIMBA

B. Functional Block Diagram

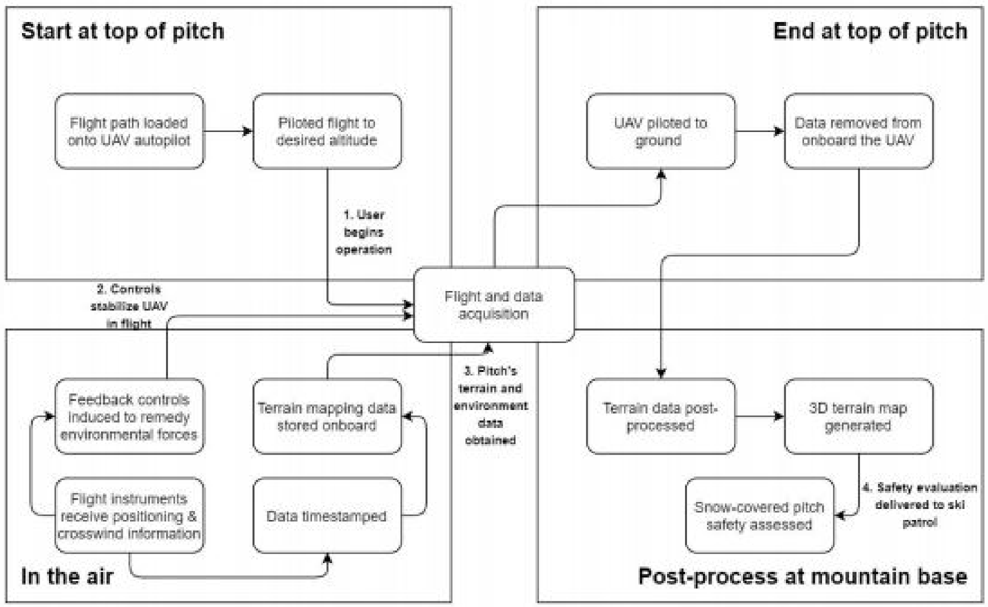

Fig. 2 Basic Functional Block Diagram

V. Critical Project Elements

A. Selection of Sensor Package

Sensor package on the vehicle must measure snow depth on varying terrain to an accuracy of at least $\pm 10cm$. The data must be stored on board the vehicle until the end of the mission. Selecting a sensor package that achieves the desired accuracy while staying within the budget is the first critical design choice as all subsequent design choices depend on which sensor package is selected.

B. Data Processing Software

The post-processing software must produce a visual representation of the measured snow depth. Without post-processing the raw data will be not be useful for the client. The software must be able to compare snow depth from different days and present this information visually as a heat map. It must also be accessible to the customer and the team for preliminary map generation. Software validation, testing, and familiarity can be performed early and without the need for team generated data via existing online data.

C. Aircraft Design

The aircraft must be able to provide the sensor package both with the flight time and stability necessary such that useful and accurate data can be collected. The aircraft will be operating in cold and harsh weather conditions with winds up to 18 m/s. The aircraft must be able to takeoff and land in a 20m x 20m area with uneven terrain and be serviceable by experienced heavy mechanics and residential/commercial electricians. Aerodynamic testing can be performed via the departments wind tunnels or simulated using CFD software. Real world testing is limited by FAA regulations and accessible testing sites.

D. Positioning and Navigation

The aircraft will have autonomous flight capabilities which will require accurate 3D spacial location. The sensor package/aircraft must also be able to locate itself in 3D space so the sensor package and post-processing software can calculate and show accurate snow depths.

VI. Team Skills and Interests

Team Members	Associated skills/interests	Critical Project Elements
Kevin Yevak	*Skills:* Soldering, Machine Shop, Materials *Interests:* Control systems, Guidance, Navigation and Autonomy	C,D
Aidan Sesnic	*Skills:*Aircraft design and Stability, Manufacturing, Piloting, FAA regulatory compliance, CAD, Embedded systems	A, C, D
Jordan Walters	*Skills:* Aircraft layout and Design, Propulsion, Manufacturing *Interests:* Aerodynamics, CFD, CAD and FEM	C, D
Max Fidler	*Skills:*Manufacturing, Electronics design, Organization, Communication	B, C, D
Stephen Peng	*Skills:* Manufacturing, Aircraft Design, CAD, Communication *Interests:* Photogrammetry, Data Handling, Positioning and Navigation	A,C,D
Travis Griffin	*Skills:* Aircraft Design, Leadership and Management, Communication *Interests:* Photogrammetry, Lidar, Aircraft Design	A,C
Adam Gourmos	*Skills:*Software (Python, MATLAB, Linux, C ++), Instrument Design, CAD Modeling, Electronics, Manufacturing	A,C
Saad Syed	*Skills:* Manufacturing, Sensor Integration, Photography, Aerodynamics *Interests:* Aircraft Design & Performance, Photogrammetry, Systems	A,B,C
Devon Ricken	Electronic design, Electronic and Structural Manufacturing, Software Design	A,D
Lucas Dickinson	*Skills:* Software (MATLAB, Python) and Manufacturing *Interests:* Testing, Manufacturing, Sensor Integration, Software, and Autonomy	A, B, D
Sean Yoo	*Skills:*Electronic Design, CAD Modeling, and Structural Manufacturing	A,C,D
Brett Papenfuss	*Skills:* Programming and electronic communications *Interests:* Aircraft Design, aerodynamics, and propulsion	A, B

VII. Resources

Critical Project Elements	Resource/Source
Selection of Sensor Package	Outside expertise from Dr. Sunberg or Dr. Thayer
Data Processing Software	Need access to ArcGIS desktop
Aircraft Design	Need large area for testing
Positioning and Navigation	Access to electronics equipment for element integration

References

[1] Avanzi, F.; Bianchi, A.; Cina, A.; De Michele, C.; Maschio, P.; Pagliari, D.; Pinto, L.; Piras, M.; Rossi, L. Measuring the snowpack depth with Unmanned Aerial System photogrammetry: comparison with manual probing and a 3D laser scanning over a sample plot. Cryosphere Discuss. 2017.

[2] Lievens, H., Demuzere, M., Marshall, H.-P., Reichle, R.H., Brucker, L., Brangers, I., de Rosnay, P., Dumont, M., Girotto, M., Immerzeel, W.W., Jonas, T., Kim, E.J., Koch, I., Marty, C., Saloranta, T., Schöber J., and De Lannoy, G.J.M., Snow Depth Variability in the Northern Hemisphere Mountains observed from Space, Nature Communications, 10, 2019 https://ees.kuleuven.be/project/c-snow/

[3] Traffic Products, Inc: Snow Depth https://trafficproducts.net/snow-depth-sensor

[4] COPPER MOUNTAIN SKI PATROL DAILY WEATHER AND AVALANCHE FORECAST RECORD. Measurements taken Nov 22 2019-April 4 2020.

[5] Deems, J. S., Painter, T. H.,; Finnegan, D. C. (2013). Lidar measurement of snow depth: A review. Journal of Glaciology, 59(215), 467-479. doi:10.3189/2013jog12j154