OASRTRS-14-H-UAF

Advanced Imaging of Transportation Infrastructure Using Unmanned Aircraft Systems

Final Report

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We wish to acknowledge the participants in this project.

For the University of Alaska Fairbanks (UAF) team, Dr. Keith W. Cunningham served as principal investigator and led the research. Flight operations by the unmanned aircraft systems (UAS) were supported by the Alaska Center for UAS Integration.

Rayjan Wilson and Bruce Crevensten of ArcticFire Development Corporation, a UAF business spinoff supported by this project, led the development of the open source ground control station.

Harris Corporation provided a variety of hardware and software to support the beyond-line-of-sight mission, which includes aircraft transponders, transponder radios, and software to provide the transponder location to air traffic controllers.

The technical advisory board consisted of:

Gary Shane – TCQ Consulting
Cheryl Seiwald – CR Inspection
Jacques Cloutier – Alyeska Pipeline
Frank Wuttig – Alyeska Pipeline
James Cieplak – Harris Corporation

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Executive Summary

The University of Alaska Fairbanks has been conducting research into unmanned aircraft systems (UAS) since 2000, with more missions and mission diversity than any other university. With the creation of the Alaska Center for Unmanned Aircraft Systems Integration, UAF was poised to lead the effort for UAS research in Alaska as well as leading the winning proposal to become one of the six Federal Aviation Administration (FAA) test sites for UAS research. This project with the US Department of Transportation (DOT) and with Alyeska as a partner provided global attention to research with how UAS can be safely and efficiently integrated into pipeline business and engineering operations.

Project goals include two items:

- First is a Decision Support System (DSS) that integrates UAS for a variety of pipeline management and engineering operations.
- Second is a set of best practices and operational examples on the safe integration of UAS for pipeline operators.

Our team focused on three areas of research to archive these goals. We call these the research scenarios:

<u>Scenario 1</u> is right of way monitoring. This tested the use of real-time video and high-resolution imaging with UAS. The video fed into a real-time secure web browser, capable of viewing on a variety of devices. This demonstrated how security officials in Fairbanks could monitor the video along with an engineer in Anchorage, from a PC, tablet, and a smart phone. The engineer interacted with the pilot flying the UAS to capture a high resolution image of specific engineering features and the security officer interacted with the pilot to loiter at a location while an encroachment or threat was evaluated. Year one demonstrated a hexacopter, operating at short range, with line-of-site piloting. Year two was a longer endurance mission, with more complex air space management, safety planning, and authorizations from the FAA.

<u>Scenario 2</u> was pipeline inspection, primarily for the generation of as-built survey data, using a photo modeling technology called structure from motion. We explored the survey accuracy of the 3D photo models and how they compare to traditional as-built surveys.

<u>Scenario 3</u> aligned with the function of the thermosiphons and keeping the soils stable. Unstable soils due to thaw are a growing concern, and a more efficient method of inspecting thermosiphons was the goal. Optimal time of year for the first flights was when temperatures are about zero degrees Fahrenheit.

Pump Stations # 7 & 9 were selected because of its proximity to Fairbanks, the nature of its operations, and logistics. Pump Station #7 was used to conduct a line-of-sight mission related to Scenarios 1-3. Pump Station #9 was used for the beyond-line-of-sight mission focused on Scenario 1 to test airspace management systems, video and data telemetry from the UAS, and other mission performance issues.

Glossary

ACUASI — Alaska Center for Unmanned Aircraft Systems Integration
ADS-B – Automatic Dependent Surveillance - Broadcast
ADS-B Xtend – Harris radio system to relay ADS-B information
As-builts – Survey data of features and facilities after construction
BLOS — Beyond Line of Sight
C2 — Command & Control
COA — Certificate of Authorization/Authority
CRADA — Cooperative Research and Development Agreement
CRSSI— Commercial Remote Sensing and Spatial Information
DSS — Decision Support Systems
EOC — Emergency Operations Center
FAA — Federal Aviation Administration
FMV — Full Motion Video
GCS — Ground Control Station
GIS — Geographic Information System
Hexacopter – UAS with six lifting rotors
IARC — International Arctic Research Center
Lidar —Light Detection and Ranging
NAS — National Airspace System
PHMSA — Pipeline and Hazardous Materials Safety Administration
PI – Principal Investigator
PS07 – Pump Station 07
PS09 – Pump Station 09
RangeVue – Harris software for monitoring airspace, specifically for UAS test ranges
Responder – UAS manufactured by ING Robotics with one lifting rotor (helicopter)
ROW — Right of Way
ScanEagle – UAS that is fixed wing
SfM — Structure from Motion
SNAP — Scenarios Network for Alaska & Arctic Planning
sUAS — Small Unmanned Aircraft System
Symphony – Harris software for managing air traffic and facilities
TAC — Technical Advisory Committee
TAPS — Trans Alaska Pipeline System
UAF — University of Alaska Fairbanks
UAF OIPC — UAF Office of Intellectual Property and Commercialization
UAS — Unmanned Aircraft System

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

1.1 Background

The Office of the Assistant Secretary for Research and Technology (OST) funded research at the University of Alaska Fairbanks (UAF) to study "Advanced Imaging of Transportation Infrastructure Using Unmanned Aircraft Systems." This is cooperative agreement OASRTRS-14-H-UAF.

The original project schedule was two years, from June 2014 to June 2016. However, a no-cost extension added an additional 90 days to accommodate turnover with the co-investigator and the ensuing project delays in the final and most complex unmanned aircraft system (UAS) mission.

1.2 Project Executive Summary

Pipeline operators are required to continuously monitor their infrastructure for safety and integrity. Federal regulations require surveillance patrols 26 times per year—patrols that may be on foot, in a vehicle, or from an aircraft.

Unmanned aircraft systems (UAS) are likely to be a technology integrated into this business, so the OST supported research by the University of Alaska Fairbanks to evaluate pipeline applications.

The research focused on:
- Right of Way Monitoring
- Close-Range Inspection
- Geotechnical Assessments
- Beyond-Line-of-Sight Flights

The research was conducted from the spring of 2014 to the autumn of 2016 near Fairbanks, Alaska. This location represents some of the most austere environments for UAS operations, not only environmentally, but also because of its very sparse communications infrastructure necessary for UAS data telemetry.

At the beginning of the project, the following press release was circulated to provide a clear mission statement at the beginning of the project.

http://uafcornerstone.net/uaf-researcher-initiates-pipeline-research-using-unmanned-aircraft/

1.3 Team & Technical Advisory Committee (TAC)

The project principal investigator (PI) was Dr. Keith Cunningham. Dr. Cunningham is part of the Scenarios Network for Alaska & Arctic Planning (SNAP), which is a sub-entity of the International Arctic Research Center (IARC) at UAF. Dr. Cunningham's research focus is unmanned aircraft systems (UAS) to collect a variety of remote sensing data in Alaska. He has a strong interest in how remote sensing data create information that can be used in executive decision making and for policy-making. Dr. Cunningham is very active in the creation of intellectual property and commercialization of technology at UAF.

The project team included the Alaska Center for Unmanned Aircraft Systems Integration (ACUASI) with its director serving as co-investigator. Turnover with the director at ACUASI led to three different co-investigators on the project.

Assisting UAF with understanding the needs of the pipeline industry was the Technical Advisory Committee (TAC). Their guidance was related to industry needs, specific operational needs for Alyeska, and input to the broader decision support systems this project envisions.

The Technical Advisory Committee Members were:
- Gary Shane – TCQ Consulting
- Cheryl Seiwald – CR Inspection
- Frank Wuttig – Alyeska Pipeline
- Jacques Cloutier – Alyeska Pipeline
- Jim Cieplak – Harris Corporation

Providing guidance on pipeline surveillance monitoring and integrity management is Gary Shane. Mr. Shane retired from British Petroleum after 32 years as director of their Pipeline Management Office. Since then, Mr. Shane has researched how UAS can be utilized to perform integrity monitoring of pipeline corridors. Now he is the lead consultant of TCQ Consulting, and continues to pilot manned aircraft on regular integrity-inspection flights.

Providing expertise on the inspection of pipeline facilities is Cheryl Seiwald. Ms. Seiwald is owner and President of CR Inspection, the oldest pipeline inspection firm in the United States. The company's inspectors operate worldwide, providing third-party inspection of new construction and certifying inspection records for the Pipeline and Hazardous Materials Safety Administration.

Serving as advisor on geotechnical maters, particularly in Alaska, is Frank Wuttig. Mr. Wuttig is a geotechnical engineer with Alyeska and provides expertise related to unstable soils and slopes, thawing permafrost, and engineering solutions to mitigate geotechnical risks.

Serving as advisor on geospatial matters is Jacques Cloutier. Mr. Cloutier recently joined Alyeska and provides technical oversight of surveying operations. Prior to Alyeska, he worked in the remote sensing field, primarily in lidar data collection and processing in Alaska.

Subject matter expert on airspace management, particularly for the beyond line of sight mission planning, is James Cieplak. Mr. Cieplak is a Senior Manager at Harris Corporation and peforms business development and aviation systems engineering.

1.4 Project Contractors

The project subcontractors were:

- Atkinson Aeronautics/Atkinson Robotics & Technology Integration
- Northern Embedded Solutions

Atkinson Aeronautics and its business subsidiary, Atkinson Robotics & Technology Integration secured permissions from the Federal Aviation Administration to operate the unmanned aircraft systems (UAS) with a Certificate of Authority (COA). The COA was specific to the planned flight area, aircraft, and safety plan, which is described in detail later in this report. Atkinson also supported early planning for the beyond-line-of-sight UAS flights.

Northern Embedded performed a variety of systems engineering related to streaming video, video telemetry, and UAS piloting/operations. Later in the project, they developed the open-source code to support the full-motion video that is overlain on existing mapping data as the UAS flies a mission.

1.5 Harris CRADA

UAF and the Harris Corporation (http://harris.com/) entered into a Cooperative Research and Development Agreement (CRADA) to evaluate airspace management, command & control, and surveillance as part of the research project. The results were a Automatic Dependent Surveillance-Broadcast (ADS-B) transponder-equipped UAS during the BLOS mission that transmitted its position and was tracked in real time from a remote and austere location along the Alyeska pipeline.

Harris and UAF also partnered with the FAA Next Generation Institute on a command & control (C2) study for Alyeska pipeline, and links for this report are at: https://www.snap.uaf.edu/sites/default/files/files/NextGen%20Institute%20C2%20Study.pdf

1.6 Project Kickoff Meeting

The project kickoff meeting was held July 7, 2014. Attending the kickoff meeting were approximately 25 individuals from Alyeska, UAF, Alaska DOT, and Caesar Singh from OST. All members of the TAC attended, as well as the four project subcontractors. Slides from the kickoff meeting can be found here: https://www.snap.uaf.edu/sites/default/files/kickoff_presentations_2.zip

Chapter 2: Project Planning Process

2.1 Research Summary

Three types of imaging missions with unmanned aircraft systems (UAS or "drones") were the focal points of this research. However, other activities such as the development of Decision Support Systems (DSS) and especially commercialization of the Ground Control Station (GCS) emerged as particular success stories.

Primary scenarios for UAS flight operations included monitoring, inspection, and geotechnical engineering.

Monitoring pipeline rights-of-way risks is a federal requirement by PHMSA to patrol every pipeline right of way (ROW) 26 times per year. Flights with manned aircraft have proven to be the most economical approach, although land patrols are used over rough terrain and during periods of prolonged poor weather. A question addressed by the research was whether UAS could augment manned flights at a lower cost.

Inspection of new pipeline construction by a third party is a PHMSA safety requirement. Third-party inspection of new construction is designed to ensure the safety of plant and facilities used to transport crude and refined petroleum products. Our project determined that newly acquired high-resolution, birds-eye imagery from a UAS could be part of an evolving inspection regime.

Geotechnical Engineering of unstable soils, especially on permafrost and at river crossings presents a mitigation and maintenance challenge. Our research examined how imagery collected from a UAS could generate three-dimensional surface models similar to terrestrial lidar.

Decision Support Systems are tools used to transform data. Our project collected data during the three UAS scenarios, and used DSS to convert the data into useful information for making decisions about pipeline infrastructure.

Ground Control Stations (GCS) are tools that a UAS pilot/operator uses to fly the aircraft and, more importantly, to collect data in a specific fashion such that it can be turned quickly into information via the DSS. Most of the GCS on the market today were determined to be specific to a UAS vendor and aircraft, and therefore proprietary, closed systems that could not be adapted for broader science and research purposes. Our effort with GCS led to development of a flexible and easy-to-use system based on open-source programming that a software engineer from the broad developer community could readily adapt for a specific UAS data collection need and for the needs of a particular DSS.

2.2 FAA Coordination

UAF leads one of the six test sites for the Federal Aviation Administration (FAA). As such, the working relationship with the FAA requires rigorous compliance with all regulations involving the National Airspace System (NAS). Part of this compliance is the need for special flight permissions from the FAA for any UAS operations, called Certificate of Authorization (COA). The COA waives certain flight regulations that would otherwise forbid UAS flights.

Applications for several COA were made for this project, and only a few were authorized. The first was for flight operations beginning in late summer 2014, utilizing direct and visual line-of-sight by the pilot and observers. The first COA operational summary specified the aircraft (UAF Ptarmigan hexacopter), the geographic location (70 nautical miles north and south of Alyeska Pump Station 07), and the altitude above the pipeline structure (200 feet). This first COA can be found at: https://www.snap.uaf.edu/sites/default/files/files/2014-WSA-101_Ptarmigan_Alyeska.pdf

The second COA was to be for beyond-line-of-sight (BLOS) operations with flights planned for 2015, but issues with the mission approval delayed the mission until 2016. The second BLOS COA specified a fixed-wing aircraft with a longer range, and with an operational altitude above 400 feet.

During the course of this project, the regulatory environment for UAS operations changed significantly. Ultimately, UAF received a blanket COA because of its status as an FAA test site. This COA permits nationwide UAS operations provided they are less than 200 feet altitude, line of sight, and not near airports and dense urban areas. This blanket COA is located at:
https://www.snap.uaf.edu/sites/default/files/files/FAA%207711-1%20UAS%20COA%202015%20AHQ-105%20200%20Ft%20TEST%20SITE%20-Univ%20of%20Alaska-Fairbanks%5B1%5D%20%282%29.pdf

In the spring of 2015, the FAA began issuing to commercial UAS operators exemptions similar to the blanket test site COA. These exemptions fall under Section 333 of Public Law 112-95. In Fairbanks, two companies have received Section 333 exemptions, while several thousand exemptions nationwide have been granted by the FAA at the time of this report. It is fair to say that UAS regulations are now enabling commercial operations, and that this is no longer a domain strictly for research institutions.

In the summer of 2016, an additional FAA exemption called the Part 107 allowed even broader commercial activity. This regulation loosened rules concerning pilot training, further allowing sUAS to become more broadly integrated into the nascent

commercial UAS industry.
https://www.faa.gov/uas/getting_started/fly_for_work_business/

2.3 Decision Support System

This research project also looked at whether decisions concerning overall pipeline operations, safety, and cost performance could be improved through the use of a Decision Support System (DSS). In this aspect of the research, the UAS airframe and sensors were of lesser significance.

Case studies of existing decision support systems integrating remote sensing from UAS for pipeline inspection, monitoring and engineering were sought. It was hoped that useful examples of prior DSS would provide a start for our research and point to some directions for additional development. We conducted a literature review as well as an online survey to provide this guidance.

2.4 Literature Review

A review of the pipeline industry's application of UAS technology was completed in August 2014. We found at the time only a modest amount of academic research and publications, with just over 20 peer-reviewed publications located. This included findings from research at the Pipeline Research Council International and the Transportation Research Board (TRB). The TRB provides access to the Transportation Research Information Services (TRIS) Database and the Organization for Economic Cooperation and Development's (OECD) Joint Transport Research Centre's International Transport Research Documentation (ITRD) Database.

2.5 Pipeline Operator Survey

In the summer of 2014, an industry survey was developed and mailing lists for survey invitations generated with assistance from TCQ, CR Inspection, and the Pipeline Research Council International (PRCI). The survey comprised three sections, one dealing with UAS for pipeline right-of-way surveillance, the second pertaining to facilities inspection with UAS, and the third relative to geotechnical engineering with UAS-derived mapping products.

The survey generated a 17% response rate, which is slightly above average for external surveys. Of the 258 individuals identified as pipeline operators and potential users of UAS technology, 44 responses were received. While the team hoped for a greater rate of response, this may have been impacted by a plunge in oil prices prior to the survey and resulting changes within the oil and gas industry.

In January 2015, the responses cited an uncertain regulatory environment as the largest barrier to UAS operations by pipeline operators. Since this time, the FAA has added clarity to the commercial operation of UAS, though BLOS operations are still strictly limited, to case-by-case demonstrations.

Chapter 3: Ground Control Station for UAS

3.1 GCS Background

Existing commercial ground control systems (GCS) for unmanned aircraft fall into two types, either a propriety system (usually for the military) or a civilian system. Civilian systems tend to be developed with a "one-size-fits-all" approach, and few have entered the market.

The result in these cases is a user interface designed for an expert technician, engineer, or pilot. Unfortunately, the interface does not integrate well into a Decision Support System for other users such as researchers, scientists, and pipeline operators.

More importantly, the software code used to develop the GCS is not in the public domain. The code can therefore be maintained only by the system's owners, often with considerable inflexibility and issues with bug fixes. An open source GCS with multiple third-party developers, similar to the Linux operating system, appears to be a more ideal solution for this rapidly evolving technology.

Researchers at UAF believe that a more open GCS would enable collaboration among a broader range of users than just the UAS experts. The broader community would include those processing the data and decision-makers dealing with the information from the prior data processing steps.

In keeping with the goal of leveraging research to foster commercialization and small business opportunities, this research project supported two software developers at UAF (Rayjan Wilson and Bruce Crevensten), who, together with the PI, saw the possibility of bringing a commercial open-source GCS to the UAS community. The team worked with the UAF Office of Intellectual Property and Commercialization (UAF OIPC) to make a small business a possible outcome of the research, leading to the creation and spin-off of a business called ArcticFire Development Corporation. http://www.nanooktechventures.com/single-post/2014/06/02/UAF-Inventors-and-NTV-Launch-Drone-Startup

3.2 GCS Architecture

The design of GCS architecture has two important factors: platform and connectivity. The GCS from ArticFire Development is designed with HTML5 and JavaScript and operates with broadly supported web browsers on common types of computing platforms, i.e. phone, laptop, and tablet. Moreover, based on our extensive experience with UAS operations in Alaska's austere environment, we have designed the GCS to have no reliance on internet connectivity, such as from a 4G cellular telecommunications network. It is notable that the places in the world best suited for UAS operation are in austere environments without internet infrastructure.

Another goal of the GCS aligns well with the goals of the DSS. We've designed the GCS to support user-specific interaction with data collected from the UAS to enable other professionals to collect data for their specific needs. This includes integrated workflows from mission planning, data collection, and other specifics related to each project. These missions can then be saved as GCS applications that can be further customized by the user.

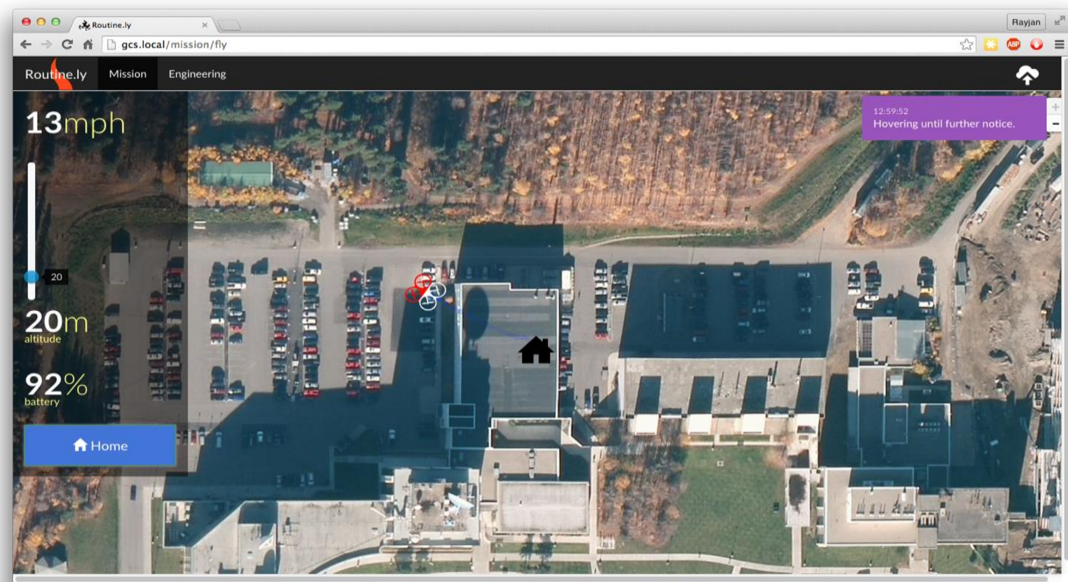

Figure 1 - Screen capture of the GCS software interface

ArcticFire Development also created a hardware component for the GCS. This includes a field computer and radio control system as well as operational testing of the GCS software interface that controls the UAS autopilot.

The software source code is being published as open source in order to grow the community of users and enlist their support. The open source code is published on Github, which is a software developer's forum. The link to the source code is here:

https://github.com/arctic-fire-development/dapper-gcs/commits/paths

The hardware includes an updated CPU based on a smaller Intel Edison board which has on-board wifi. Integrated with the Edison board is the radio telemetry hardware for communication with the UAS and a GPS so the system knows where it is operating. The power supply is also now cleanly integrated.   All of this integration is in a "wearable" size as shown in Figure3.

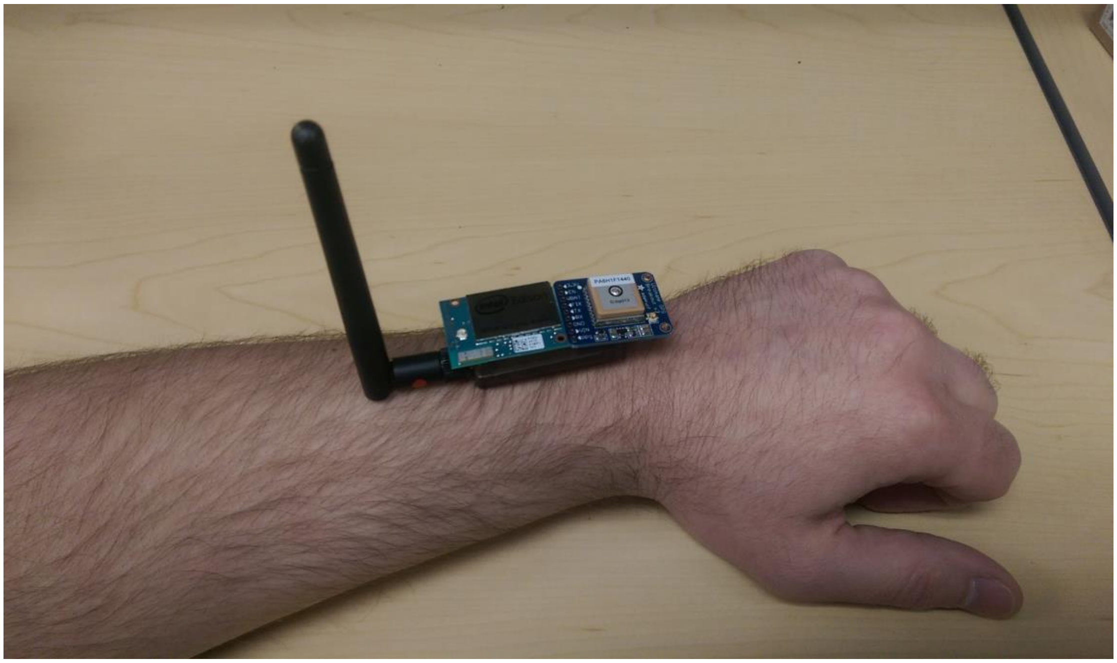

Figure 2 - GCS server and radio link without its enclosure

The PI continues to hold discussions with Alaska investors and entrepreneurs, including Launch Alaska (http://www.launchalaska.com/launch-program/). Launch Alaska comprises two startup companies in Alaska engaged in the UAS industry for which the PI provides business mentoring.

3.3 GCS Commercialization

The PI, working with the UAF OIPC, has created an investor prospectus. The management team of ArcticFire believes that the opportunity with the open source GCS could be a significant business with job creation potential, and has located it in the economically disadvantaged interior of Alaska.

The investor prospectus is attached as Appendix C.

ArcticFire continues to support the commercialization of the open source Ground Control Station. The company has recently moved the maintenance of the source code away from UAF, and new commercial partners are now maintaining it. These commercialization partners are:
Alaska Aircraft Proving Ground (www.alaskauav.com),
Aquilo (www.aquiloalaska.com), and
CalCam (www.calcam-ap.com)

The Harris Corporation provided extensive project support and also has an interest in the open-source GCS. The PI is already working with Harris Corporation via a CRADA (Cooperative Research And Development Agreement).
https://www.youtube.com/watch?v=7l1IU30h8IA&feature=youtu.be

Researchers have conducted outreach with additional universities to encourage ongoing development and support for the GCS. These include the University of Nevada Reno and the Missouri University of Science & Technology, where we conducted a GCS programming workshop in September.

Chapter 4: Right of Way Integrity Monitoring

4.1 Line-of-Sight Flight Operations

Mission Flown: November 4-5, 2014

Flight planning was initiated with the Federal Aviation Administration (FAA) in May 2014, and an approved Certificate of Authorization (COA) was received on October 21, 2014, three months later than planned.

Planning documents were readied, including the Mission Plan, Job Hazard Analysis, and a Statement of Airworthiness. These and other supporting documents are aggregated in Appendix A.

The mission was performed on November 4 and 5, 2014. The high temperature was 0 °F. A steady wind of 15 knots contributed to harsh operating conditions, with wind chills of -15 °F. The aircraft performed adequately and remained stable in the wind gusts. However, the low temperatures did reduce battery life significantly. Some electronic components experienced thermal issues that affected image stability and the video from the aircraft.

Figure 3 - Student & hexacopter at PS07

The primary goal of the mission was to test the basic concepts of the decision support system (DSS). Other goals included testing the UAS in austere and cold weather, and assessing the imaging camera's dual-mode imaging capability, which would permit real-time video streaming and the collection of high-resolution imagery.

The DSS was developed to provide real-time surveillance of pipeline infrastructure with multi-party audio and video communications from multiple locations. The trial demonstrated the basics of real-time DSS operations, with livestreaming video from the UAS relayed to Alyeska Pipeline emergency operations centers (EOC) in Fairbanks and Anchorage. Observers at the EOC were able to collaboratively view and discuss the real-time video and request that the UAS pilot hover the aircraft, pan the camera, and collect high-resolution still imagery, all on demand. The video broadcast could also be viewed via web browser from any location with internet connectivity, including from cell phones.

One of the important lessons learned with UAS operation at this time of the year is the poor solar lighting and high reflectance of the stainless steel on the pipeline, all contributing to poor image quality.

4.2 Beyond-Line-of-Sight (BLOS) Flight Operations

Mission Flown: September 25-26, 2016

The BLOS demonstration was originally planned for the summer of 2015, however, project planning affected the mission date. The Mission Plan, Job Hazard Analysis, and other documents for the BLOS project have been aggregated in Appendix B.

Table 1 - The table of planned BLOS activities and actions

Task	Plan	Action
Task 1 – Command & Control Planning	a. Develop command and control (C2) plan b. Radio and data infrastructure along TAPS corridor c. Evaluate radio view-shed models for mission sites d. Integrate FAA air traffic radar data with the GCS e. Evaluate UAS transponders	a. Longer range radio/data telemetry – developed a tracking directional antenna. b. Explored cellular data coverage c. Selected alternate flight location at PS09 d. Separated air traffic control computer from GCS e. ADS-B transponder to UAS
Task 2 – Selection of Aircraft & Sensor	a. Determine suitable UAS, evaluating both fixed and rotary wing aircraft b. Understand the sensor and data telemetry requirements for streaming video c. Determine how streaming video can be shared with DSS end users	a. Selected ScanEagle first, then AeroMapper, then Responder, then ScanEagle, then Responder b. ScanEagle had camera-point metadata integrated while other aircraft did not c. No camera metadata prohibited FMV for real-time DSS
Task 3 – Airspace Management Planning	a. Integrate the transponder with UAS and telemetry b. Implement the FAA radar airspace management on GCS c. Share airspace management data with the DSS d. Identify strengths, weaknesses, and other considerations for each component	a. ADS-B provided by Harris Corp. b. FAA air traffic radar software using RangeVue Symphony c. Camera metadata prevented FMV with live DSS –post-mission FMV demonstrated. d. Multiple systems requiring integration created a fragile project plan.
Task 4 – Mission Execution	a. Develop the UAS mission plan b. Coordinate safety and security planning with Alyeska c. File FAA documentation required for the days of operation	a. Adjusted plan against constraints. b. Met safety training required for operating on TAPS ROW c. Several mission delays due to aircraft changes, COA delays, and weather

	d. Perform the BLOS mission, collect data, share information via the DSS e. Evaluate C2 and airspace management operations	d. Lack of camera metadata prevented real-time FMV DSS. e. C2 & airspace management with Harris support was flawless.

Key to the BLOS mission is integration of the Automatic Dependent Surveillance-Broadcast (ADS-B) transponder with the UAS. The ADS-B transponder was coordinated with Harris Corporation and they also provided the ADS-B Xtend radio repeaters as well as the RangeVue™/Symphony™ software to track the UAS, which was flying well below the FAA's airspace management radar.

The graphic below shows the location of the actual flight at Pump Station 09. On the left is an aeronautical chart showing a 5 nm geofence in amber with a small blue circle in the center which is the UAS location. Aircraft coming within this 5 nm geofence safety area will be highlighted and an alert provide to the UAS pilot. Also inside the amber circle is another small blue circle around PS09 and a small green vector. The imagery on the right is a zoom-in with the blue circle around PS09 and a vector showing the helicopter. Note how the green vector does not connect to PS09, with the vector only beginning once the helicopter climbs altitude and is picked up by the FAA tracking radar.

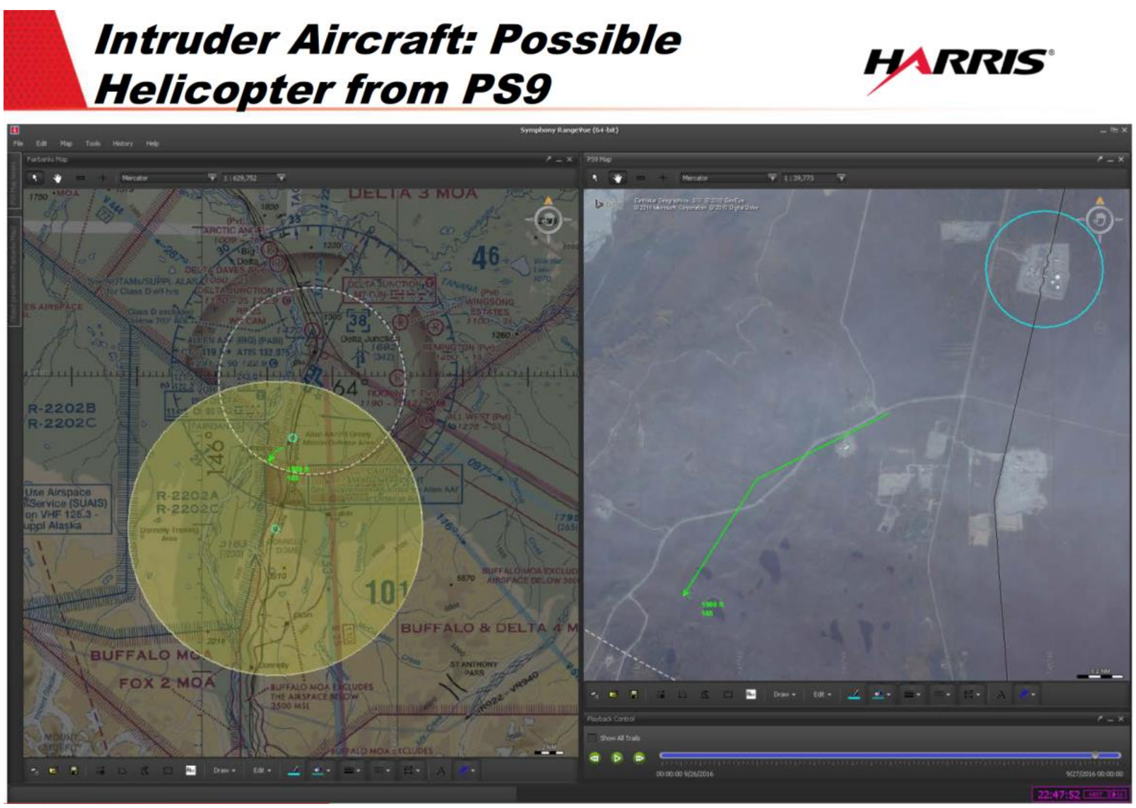

Figure 4 - RangeVue™ software showing UAS and manned aircraft

Chapter 5: Construction Inspection

5.1 First Inspection Mission – Annotation of Stills & Video

Mission Flown: November 4-5, 2014

Coincident with the first Line of Sight Mission (Scenario A1), two imaging tasks were performed for the construction inspection scenario. The first was the streaming of live, high-definition video and the simultaneous display on web browsers at the emergency operations centers (EOC) for Alyeska in Fairbanks and Anchorage on November 4-5, 2014. Still imagery was also collected on the same flights.

The video and stills were used to create a data dictionary of terms used by inspectors to standardize comment on the videos and stills. With the assistance of the Harris Jagwire™ software, we were able to note "mission chat" in the streaming video metadata with key words. This chat and keywords were stored for query and future analysis.

5.2 Second Inspection Mission – Annotation of Full Motion Video

Mission Flown: June 10, 2016

We developed the situation awareness and decision support system that utilizes full motion video (FMV). Starting in March 2016, we integrated the GPS with the unmanned aircraft, and with the camera gimbal's orientation system that provides both azimuth and tilt look angles. Combined with the GPS aircraft position, compass heading, and the camera-point orientation, we were able to integrate with the live streaming video as a real-time overlay on a base map with as-built survey data of the Alyeska pipeline.

The video is located at https://vimeo.com/170234385.

During the playback of the video, you can observe several things:

- Left image pane is the live streaming video. The right image pane is the base map as a preloaded orthomosaic with other GIS data superimposed.

- On base map to the right is a purple trapezoid that represents the bounding coordinates of the oblique-looking video. Following the trapezoid is the flight path of the unmanned aircraft system.

- Annotations can be made in the streaming video or on the orthomosaic/GIS layer. Notes and measurements marked in the video have their positions recorded on the orthomosaic in real-world survey coordinates.

- Observe the parked car (1:00 minute mark). That represents an encroachment in the pipeline right of way that is then marked for a security team to investigate. The coordinates of the parked car are recorded (at 1:00 minute in the video), a note is entered (1:25 minute), and the distance from the pipeline is also recorded (1:35 minute).

- Notice the as-built GIS layer superimposed (2:45 minute mark). Red dots are the vertical support members. They are displayed as overlays on the base map, and their calculated positions are also displayed in the oblique video. As the aircraft flies and the video pans, the GIS as-built layer is updated in both views. This enables querying of the GIS data for additional analysis of the as-builts.

- The next feature is the clipping of the streaming video and direct overlay on the base map (3:09 minute). Since the base map may be several years old, the overlay of the live or playback data allows the most recent imagery to be overlain for analysis. Note that these video clips are oblique (not ortho-corrected) with only a four-point "rectification" to pin it on top of the base map. That is why the pipeline at the furthest boundary of the trapezoid shows the slightly incorrect location.

This demonstration of the FMV could lead to other future research opportunities for saving the metadata from the GPS, compass, and camera gimbal orientation. Previously this technology was in the realm of military UAS surveillance applications, but we have created a less complex solution with source code in the public domain that has potential for low-cost commercial UAS.

Chapter 6: Geotechnical Engineering

6.1 Slope Modelling – Comparison of UAS Data to Lidar

Mission Flown: May 27, 2015 (partial findings due to crash)

This mission evaluated how UAS aircraft could be used to measure slope stability along transportation corridors. Two UAS missions were flown on May 27, 2015, collecting imagery able to generate three-dimensional surface models using Structure from Motion (SfM) photogrammetry techniques.

The goal was to determine if the improved imaging perspective from a UAS with oblique imaging could yield better surface models of the slope than traditional terrestrial lidar scans. This was evaluated on the same day we captured lidar scans from the ground, with the scanner pointed towards and slightly up the slope.

The task plan was detailed and included the following steps:

Task 1 – Survey Targeting & Control.

a. Establish a survey control and validation plan
b. Plan UAS data collection and SfM data processing
c. Gather prior terrestrial lidar scans

Task 2 – Collect UAS data at the area of interest.

a. Establish a survey control and validation network for UAS assessment
b. Perform the UAS mission with optical data collection
c. Collect supplemental terrestrial lidar scans at the site

Task 3 – Comparisons of UAS SfM to terrestrial lidar collected at the site.

a. Evaluate coverage and identify data gaps of each data source
b. Compare accuracy of the digital surface models to control points
c. Compare resolution – both level of detail and variability of the resolution
d. Identify strengths, weaknesses, and other considerations for each technique

6.2 First flight

The aircraft, an ING Responder, flew approximately ¼ mile from the launch/recovery area to the slope to be studied. FAA rules require a minimum of 500 feet standoff from the road at the bottom of the slope because passing vehicles are regarded as “non-participants” in the mission. Coupled with a maximum altitude of 400 feet, the camera was gimballed at a 45-degree side-looking angle.

The first flight collected a strip of imagery that was stitched into a useful surface model; however, the distance from the slope to the camera yielded a model of only decimeter resolution. The lidar scans were sub-millimeter resolution.

6.3 Second Flight

During the second flight, the aircraft began flying erratically with shaking visible by ground observers. Video telemetry was very poor because of the vibration. The aircraft was commanded to "return to launch," which initiated an automated protocol. As the helicopter approached, the communication link with the aircraft was lost, and the UAS attempted to proceed on autopilot. The aircraft did not land, but rather flew through a tree before crashing. Subsequent flights with this aircraft were canceled due to unknown reasons for the vibration and failure of the autopilot.

6.4 Results

Even with no data collection from the second flight, the limited and coarse data from the first flight did indicate benefits from the airborne look angle of the camera. The side-oblique-looking, bird's-eye view provides an orthogonal imaging plane to the slope. This improves imaging for surface model creation when compared to terrestrial laser scans that are essentially looking up-slope, which creates shadows (voids) in the lidar scan data.

Also, the stand-off from the road and its traffic means that lane closure permits are not necessary to collect the data, compared to traditional survey and laser scanning techniques performed from the road shoulder. Safer data collection means that data could be collected more frequently and on-demand, because prior DOT approvals for lane closures and flaggers are not necessary.

This is an area of traffic safety research that deserves further investigation and adoption by state DOT as an acceptable survey method.

Chapter 7: Conclusion

7.1 Findings and Outputs

Anticipated findings were confirmed and new findings discovered. These findings contributed to a refocusing of the research during the project and an effort launched toward rapid commercialization of the project outcomes.

A need for future research emerged concerning optimization of both training and operational costs. Successful integration of the technology into the pipeline market would demand fewer supporting personnel than are now used for flight operations and data analysis. Until the UAS could operate autonomously in conjunction with the automated sensing of intrusions along a pipeline, operational cost will be set by the number of support specialists piloting the aircraft, operating sensors, monitoring airspace, and analyzing the data.

Another finding we tested was the need for a robust radio telemetry system to carry pilot commands and real-time data such as video for analysis. Radio telemetry is a backbone of communications infrastructure, one that is only now maturing in the United States and likely to be based on existing cellular data networks. In locations across rural America, and especially Alaska, such coverage can be poor to non-existent. Therefore, supplemental communications systems will be required for future command and control applications, especially when UAS are operating at low altitudes beneath the view sheds of radio networks.

Promising findings related to commercialization of the project outputs centered on the ground control station (GCS). Using open source programming, researchers created a GCS that works with open source UAS autopilots. Unlike others currently marketed, this GCS can be customized for specialized applications such as the persistent surveillance of critical infrastructure locations, e.g., pipeline river crossings. We anticipate the future of UAS operations most likely will involve specialized applications that follow a planned script for the majority of flights and data collection.

7.2 Products and Outcomes

Several products were developed and their outcomes tested.

First among these was three-dimensional modeling of infrastructure from highly overlapping images collected from UAS. This type of photogrammetry—called structure from motion—is now a commercially mature technology in use by many markets around the world, though it was not at the start of the project. For pipeline operators, the results are “as-built” image-models with fine details suitable for inspection.

The second area of product development is an open source video integration with the UAS to generate full motion video. FMV utilizes metadata from the aircraft position/orientation/speed with the camera-gimbal pointing data to overlay the streaming FMV on top of an existing base map. Other users will be able to modify the FMV open source code for custom cameras and for later applications involving change detection. This is a step needed for future automated image analysis and change detection.

Operating a UAS beyond line of sight, typically defined as less than a half-mile from the pilot, will be an area of vigorous research. That’s due to the need to safely integrate the UAS into the National Airspace System, where manned aircraft fly. Our project successfully tested an aircraft transponder that operates below air traffic radar to show its location to air traffic controllers and even to other aircraft. This outcome was demonstrated with our commercial research partner, Harris Corporation.

Chapter 8: Post Project Activities

8.1 Outreach

Much of this outreach was intended to support the commercialization of the project's research, especially the ground control station.

Date	Event	Note
9-16-2014	Alaska UAS Users' Meeting - Participant	
10-28-2014	Pipeline Week - Participant	
1-11-2015	Transportation Research Board – Presentation "Optical and infrared imaging with UAS to monitor permafrost thaw & soil stability"	[1]
2-9-2015	Alaska Forum on Environment - Class "Drones in Alaska"	
2-16-2015	Alaska Surveying & Mapping Conference - Presentation "Drones for the Trans Alaska Pipeline System"	
3-9-2015	Osher Lifelong Learning Institute "Drones in Alaska"	
3-24-2015	Arctic Technology Conference - Paper "UAS for Geotechnical Monitoring of Pipelines in the Arctic"	[2]
3-25-2015	Fairbanks West Valley High School – Class "Drone Day"	
4-28-2015	Commercial Remote Sensing & Spatial Information - Participant	
5-6-2015	Association for Unmanned Vehicle Systems International "Real Time Situation Awareness for Alaskan Pipelines" "Emerging Commercial Markets: UAS for Oil & Gas"	 [3] [4]
7-27-2015	NASA UAS Traffic Management - Participant	
9-15-2015	Pipeline Week - Participant	
9-28-2015	American Society of Photogrammetry & Remote Sensing "Multidisciplinary UAS Research & Applications"	[5] [6]
10-19-2015	Pipeline Research Council International - Participant	
12-2-2015	Commercial Remote Sensing & Spatial Information - Participant	
1-10-2016	Transportation Research Board - Participant	
1-20-2016	Helicopter Safety Advisory Council - Presentation "UAS for Pipeline ROW Integrity Monitoring"	
4-13-2016	American Society of Photogrammetry & Remote Sensing "UAS in the Oil & Gas Industry"	[7]
5-4-2016	Association for Unmanned Vehicle Systems International "Beyond Line of Sight UAS Operations in Alaska"	
7-17-2016	American Society of Civil Engineers - Pipelines - Participant	
9-7-2016	InterDrone - Participant	
9-12-2016	Missouri University of Science & Technology - Workshop "Autonomous Command and Control"	[8]

[1] http://www.abj50.org/subcommittees/sensing-technologies/
[2] https://www.onepetro.org/download/conference-paper/OTC-25582-MS?id=conference-paper%2FOTC-25582-MS
[3] http://www.auvsishow.org/auvsi2015/public/SessionDetails.aspx?FromPage=Sessions.aspx&SessionID=1007&nav=true&Role=U%27
[4] http://www.auvsishow.org/auvsi2015/public/SessionDetails.aspx?FromPage=Sessions.aspx&SessionID=1051&nav=true&Role=U%27
[5] http://www.asprs.org/a/publications/proceedings/UASReno2015/Cunningham.pdf
[6] https://www.youtube.com/watch?v=IqWf365TW7I
[7] http://www.asprs.org/a/publications/proceedings/IGTF2016/IGTF2016-000387.PDF
[8] http://rtd2016.mst.edu

8.2 Post Project Initiatives

This research has resulted in follow-on activities with continued UAS research and the commercialization of the ground control station.

Data collection has expanded to incorporate not only imagery (now ubiquitous), but also in-situ sampling. In-situ collection of aerosol data can include "sniffing" for methane leaks. Some sampling methods require weather and aerosol data, such as smoke and particulates, taken at differing altitudes. This points to the evolution of remote sensing into a real-time dynamic system that links data with spatial and temporal dimensions in a manner now possible only with low-flying UAS.

Several proposal opportunities for research and commercialization have been identified, largely to develop tools for data collection and surveillance.

Our largest post-project initiative is cultivating the community of UAS software developers now using the open source GCS. The first tier of developers includes other universities adopting the code for research and scientific purposes. UAS operators with aircraft whose autopilot the GCS supports represent the next tier. Finally, we envision an important segment of the community to be the manufacturers of aircraft and sensors. This group will want to build more tightly integrated systems that still can be repurposed by their users.

8.3 Spin-off Opportunities

Several opportunities to leverage this research have occurred. Some of these have been requests for proposals and others have been more associated with the good will this research has created with a variety of commercial and industry partners.

<u>Harris</u>: The Cooperative Research and Development Agreement (CRADA) with Harris Corporation was originally created with Exelis, which was acquired by Harris in the spring of 2015. This CRADA permitted the contractual participation of Harris in a variety of research phases, particularly those related to the BLOS operations.

<u>PRCI</u>: The Pipeline Research Council International participated with UAF in sharing lessons related to the UAS research, and UAF submitted a proposal to PRCI for further research, though the proposal was declined.

<u>AFDC</u>: ArcticFire Development Corporation was a UAF commercial spinoff assisted by the UAF Office of Intellectual Property and Commercialization. Funding for the ground control station support the creation of AFDC, though the company dissolved

in the spring of 2015 after publishing the GCS source code in the public domain under open source licensing.

AFRL: The US Air Force Research Laboratory awarded a $150,000 research project to develop a UAS-based microclimate data recorder that relies heavily on the GCS open source code.

DHS: The Department of Homeland Security issued a broad agency announcement for UAS technology, particularly focused on the command and control of UAS via a common GCS architecture. That proposal was led by Atkinson Robotics and Technology Integration Corporation which supported UAF on this project as a sub-contractor.

Appendix A – LOS Mission Plan

LOS Mission Plan: This document can be downloaded from the corresponding link on this page.

https://www.snap.uaf.edu/sites/default/files/LOS%20Mission%20Plan.pdf

Appendix B – BLOS Mission Plan

BLOS Mission Plan: This document can be downloaded from the corresponding link on this page.

https://www.snap.uaf.edu/sites/default/files/BLOS%20Mission%20PLan.pdf

Appendix C – GCS Prospectus

GCS Prospectus: This document can be downloaded from the corresponding link on this page.

https://www.snap.uaf.edu/sites/default/files/GCS%20Prospectus.pdf