A New Approach to Survey Using Unmanned Aerial Vehicles (UAV's)

Paul David Ramirez
Unmanned Ad-Hoc Industries, Inc.
519 E Oak Hill Dr, Spring, Texas 77386
Tel: 888-396-5924

Adam Hargraves
Unmanned Ad-Hoc Industries, Inc.
519 E Oak Hill Dr, Spring, Texas 77386
Tel: 888-396-5924

Presented April 11, 2016 at SPAR3D Conference, The Woodlands, Texas

Abstract

Analysis into the efficiency of using unmanned aerial vehicle's (UAV) to perform pipeline survey is provided using a case study project performed in June 2015. Utilizing advancements in unmanned aerial technology including intuitive mapping software like Pix4D®, Global Mapper® and others designed to accurately process photogrammetry and LiDAR data to render valuable deliveries such as geographically rectified 3-Dimensional point clouds, orthomosaic, digital terrain maps, and others; new process methods have consistently shown value efficiencies. Case study data is presented to demonstrate the high-level business case, improvements to conventional survey processes, and common pitfalls associated with the advancement in UAV and digital mapping technology. Future development applications will also be presented to illustrate the versatility of UAV's in the aerial survey data collection process.

Keywords: *unmanned aerial vehicle, UAV, pipeline, survey, right-of-way,* Pix4D®*, DTM, DSM, intelligent data collection, point cloud, orthomosaic, Unmanned Ad-Hoc Industries, Inc.*

INTRODUCTION

There are over 2 million miles of natural gas and petroleum pipelines stretched across the continental United States alone[2]. This critical infrastructure supplies immense quantities of energy sources to consumers; literally fueling our way of life. The continual need to support all phases of pipeline life-cycle provide a basis for industry to ensure its viability and survival of the very essence of the American lifestyle. Conventional methods of pipeline survey include an extensive network of ground crew personnel painstakingly covering hundreds of miles on foot to ensure accurate data is gathered and delivered to those that are charged with the maintenance and upkeep. However, as new technologies are introduced to scan vast stretches of sometimes unnavigable terrain, a more efficient way of performing the same route survey and providing higher fidelity information deliveries must be accounted for. The creation and implementation of an intelligent data collection (IDC) process methodology has potential to save thousands of man-hours surveying these pipelines utilizing state-of-the-art surveying technology. The IDC process combines both limited conventional survey methods as well as proven unmanned aerial vehicles and processing software to continue the evolution of smart sensing for industries including midstream oil and gas, energy, construction engineering and others. With ground truthed, repeatable accuracy to within 3 centimeters using Real-Time Kinematic (RTK) satellite navigation techniques enhanced by precise position data derived from satellite-based positioning systems (Global Navigation Satellite Systems, "GNSS"), the next evolution of field survey has great utility.

By combining RTK AND GNSS with conventional ground control methods, the application of remote sensing in the pipeline survey industry allows for remarkable levels of accuracy and efficiency. Class location studies, preliminary centerline surveys, road profiles, and their respective deliverables can now save a third of the time and associated costs.

Unmanned Ad-Hoc Industries, Inc. (UAI), an industry provider of remote data collection solutions based in Houston, Texas, performed extensive research and proof of concept testing in 2015 to validate the feasibility of advanced concepts in pipeline survey. The objective of proving that the same fidelity of survey information can be provided using UAV's as the data collection mechanism in place of conventional survey crews was accomplished using a minimized physical footprint on the survey site and post-processing of data to render accurate 3-dimensional models of the terrain and surrounding geological features and attributes.

BACKGROUND AND EVOLUTION

Data collection using remote sensors is not a new technique to improving the interpretation of the physical environment. For decades aerial surveyors have been performing similar aerial surveys using manned-aircraft and film. The type of raw data collected from these manned craft have provided construction firms with accurate information to understand the nuances of the terrain. However, as a result of the last decade of war in Iraq and Afghanistan, unmanned aircraft have come to replace manned aircraft in multiple aspects of intelligence, surveillance and reconnaissance (ISR). The technology and tools and techniques have been refined over these missions have often meant the difference between life and death on the battlefield. The benefit to utilizing this type of technology, now widely available to the commercial market, is mostly realized in the knowledge and expertise in the safe and effective employment of these tools. While manned aircraft have been performing traditional aerial surveys since the 1930's, various commercial applications and progressive market leaders have realized the value in using UAV's to replace conventional methods of aerial survey data collection.

The IDC process is both qualitative and quantitative. The importance of quality in the ultimate product being delivered and interpreted cannot be understated, and its value is strongly rooted in the accuracy of the quantitative raw data collected at the sensor level; this point will be addressed in more detail in the next section which highlights the intelligent data collection process.

PROCESS: INTEGRATED DATA COLLECTION

Aerial Survey Ground Control

A minimum of three ground control points (GCP's) should be placed within the project terrain features for ideal geo-referencing. The points should be located throughout the terrain and not be located in a straight line to establish boundaries of the project. Typical best practices will provide a minimum of five GCP's, with four points towards the edges of a project and one in the middle. Each ground control point location is annotated through the use of RTK GPS survey equipment to attain centimeter accuracy at each point.

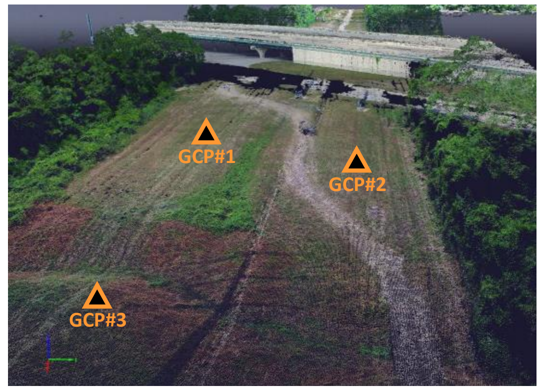

Fig. 1. 3D Point Cloud with Minimum GCP Profile

Survey Accuracy

With conventional UAV GPS systems alone, a survey project can attain a 3 meter accuracy without the use of GCPs, which will place the survey location in the correct area (relative accuracy), but may be off in any direction of up to 10 feet in the horizontal (x,y coordinate), and even more in the vertical (z coordinate) of the elevation data. With the use of RTK located GCP's, absolute accuracy is improved to 2-4 cm in the horizontal (x,y coordinates) and 2-6 cm in the vertical (z coordinate)[1]. The precision of these points is dependent on the ground sampling distance (GSD) of the aerial imagery. GSD is the distance between 2 consecutive pixel centers measured on the ground. The larger value of the image GSD, the lower the spatial resolution of the image and subsequent visible details. The GSD is directly correlated to the UAV flight height; the higher the altitude of the flight, the larger the GSD value. For example, a GSD of 5 cm means that one pixel in the image represents 5 cm on the ground. Through proper planning of flight altitudes based on the topography of the project area, coupled with the internal and external parameters of the aerial camera, a consistent GSD can be attained. In photogrammetry, the points marked with the RTK GPS location are a single pixel within the imagery. To capture that pixel accurately over many images, it must be a clear pixel captured by the UAV camera at an optimal height above ground. As a quality standard, a higher megapixel camera will provide higher resolution image clarity, however, more important considerations are the sensor size and capability to capture a more precise point over many images. Overall, the greater ability to visually locate a single point associated with an RTK GPS location, enables the software to more effectively triangulate the images to the specific location.

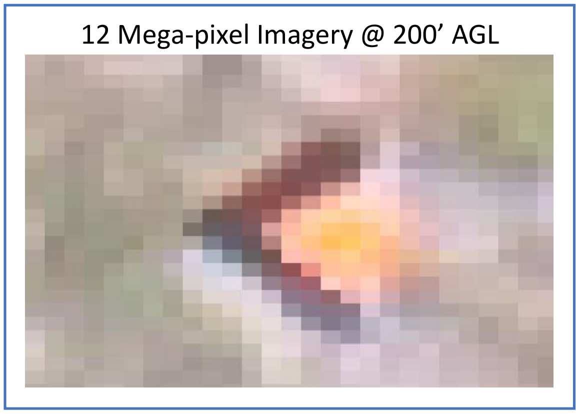

Fig. 2. Low Resolution Camera Imagery of GCP Taken from UAV

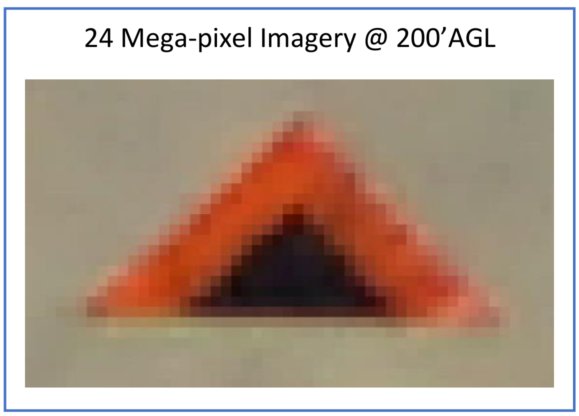

Fig. 3. High Resolution Camera Imagery of GCP Taken from UAV

UAV Data Collection

Unmanned Aerial Vehicle. Appropriate UAV selection relies on the technical scope of the survey project to be completed. Centimeter quality precision can be obtained through smaller commercial off the shelf (COTS) UAVs (DJI Phantom/Inspire, 3DR Solo, etc.) with the use of RTK geographically located GCPs. Typical COTS UAV's require more direct teleoperation to manually navigate the flight path while simultaneously operating the camera to capture aerial survey imagery. Direct manual teleoperation can prove challenging at times to create a uniformed collection of data and requires the operator to manage tasks that may interfere with his ability to maintain visual contact and adequate situational awareness of the aircraft and airspace at all times. Additionally, lower end COTS UAV's are usually limited to specific camera sensors which may not provide suitable resolution and image capture precision. In contrast, professional grade UAV's with programmable autopilot systems can be flown semi-autonomously, and in some cases fully autonomous. Greater autonomy enables more specific flight paths and automatically triggered camera specifications to create adequate overlap for successful survey project creation. By creating flight path and camera triggering parameters, the operator enhances his ability to maintain visual observation of the aircraft through each phase of flight and may augment operational procedures with the use of a secondary observer to relay aircraft performance telemetry information during the flight. Larger UAV systems (>25 lbs.) also provide a wider sensor selection which can greatly enhance the precision of the project, the amount of area covered within a finite flight time, and overall resolution of project orthomosaic and digital surface model deliveries.

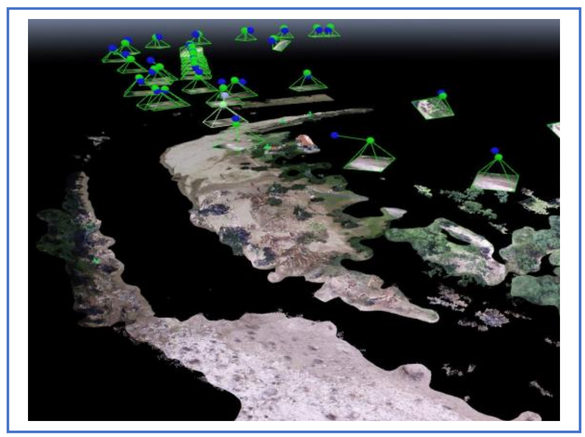

Fig. 4. Flight Path with No Autonomous Manual Operator Control

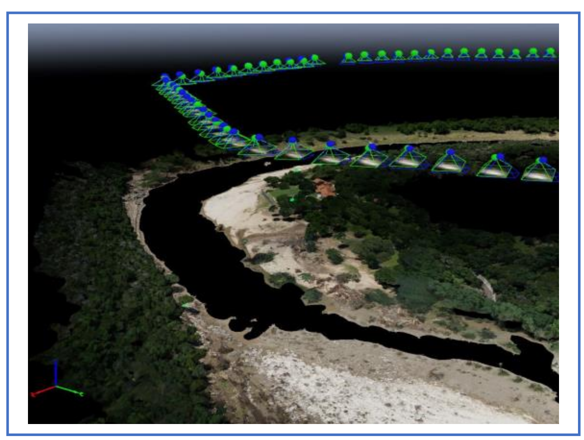

Fig. 5. Flight Path with Semi-Autonomous Operator Control

Camera/Sensor. UAV sensor and lens selection will impact the flight parameters required to cover the area to be flown. The flight altitude, aircraft speed, and coverage area are dependent on the sensor selected. UAI's typical UAV data collection process will utilize a 24-megapixel camera with a full frame sensor combined with a 10-18mm lens. By capturing aerial imagery with a wider full frame sensor it is possible to reduce the number of flight paths by increasing the physical terrain area covered in one image. The full frame sensor not only allows for greater coverage area, but provides higher fidelity in the imagery resolution; resulting in greater survey project accuracy.

Data Collection. To produce accurate high fidelity survey deliveries like 3D point cloud, digital elevation/terrain model, plan and profile drawings, and orthomosaics, optimal frontal and side overlap must be obtained in the imagery. By using high resolution camera sensors, the ability to cover larger areas of terrain in a single flight allows for greater project efficiencies.

Overlap

Sufficient imagery collection overlap is a critical variable regardless of image megapixel count or sensor size. Ideal flight mission planning will consider optimal overlap with a minimum of 80% frontal overlap and 70% side overlap between images. With the change in terrain features, these values can change drastically to lower or higher values. If the terrain slopes down, the aircraft is essentially flying at a higher altitude from the ground which increases the amount of coverage in an image, providing higher image overlap values. If the terrain elevation increases from the initial take off point, the image overlap values will decrease. Tall objects such as trees, buildings, power lines, etc. will also decrease overlap values. Proper flight planning may include multiple flights depending on terrain and vertical object changes throughout the survey project area.

UAV Flight Mode

As previously explained, flight parameters with more autonomous flight modes where the autopilot is pre-programmed for optimum flight paths, reduces human operator input and produces greater efficiencies in flight paths. While a project can be created using autonomous or manual flight modes, the use of greater autonomy creates a much more uniformed collection of imagery, which increases the precision of data collected (less storage space and resources on the program to render a point cloud) and ensures a more precise rendering of the imagery. Autonomous flight modes allow the imagery to stay in a more consistent pattern, allowing the rendering software a more linear correlation between images; resulting in denser, more accurate point cloud creation.

Fig. 6. 3D Point Cloud of Pipeline Right-of-Way, 80 Percent Overlap

INFORMATION SYSTEMS

For the scope of the project as described in this case study, multiple software information systems were utilized.

UAV Mission Planner

In the data collection phase, the Mission Planner software allowed the UAV operator to plan semi-autonomous flight paths for optimum aerial imagery capture along 8 miles of a densely populated urban pipeline right-of-way corridor located in Houston, Texas.

Raw Aerial Imagery Conversion

In the post-processing phase, the UAI data analyst team converted high-resolution image files to X, Y, Z values using Pix4D® Advanced Photogrammetry Software. Additional Pix4D® processing outputs included 3D Point Cloud (used for project overview and high level presentation), imagery orthomosaic (allowed project team to generate X, Y, Z alignment data and import .kml file to third-party Google Earth mapping application).

XYZ Alignment

Using conventional engineering expertise, the UAV aerial survey alignment data was imported into Trimble Business Center, Bluesky, and Civil 3D and compared with baseline survey data which was performed using conventional survey methods. Alignment sheet production was also completed using these software resources.

Product Delivery

Reduced budgets and proliferation of various data types require creative solutions to allow the end user to have near real time access to project outputs. This case study demonstrated collaborative data management using open access secured server storage applications like Dropbox and Google Drive for simple project planning, and data transfer between stakeholders. More importantly, with respect to the service provider to end user relationship, big data management via a secured access portal (Data Halo[3]) was utilized and demonstrated customized value. The advantage of a data management solution like Data Halo[3] provided the end user direct access to aerial survey digital data and permitted scaling of data sets for export to various industry standard systems.

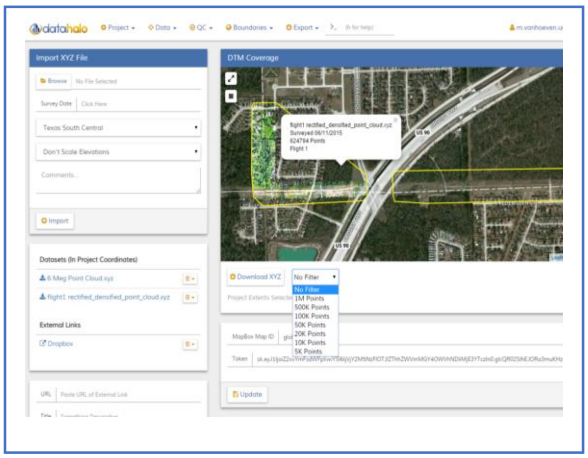

Fig. 7. Data Halo User Interface, the Link between Field and Office

SURVEY OUTPUTS AND DELIVERIES

It is important to note that in order to provide survey output deliveries that meet or exceed the industry standard, certain conventional survey competencies are integral to an integrated approach. While advanced processing utility of Pix4D® a revolutionary tool to expedite the accurate dissemination of aerial survey data, the critical need to provide a valuable addition in the form of time and cost efficiencies to the market cannot be understated. In this regard, both UAV and survey engineering expertise play a role to output not only traditional survey deliverables as well as new 3-dimensional digital modeling and orthography.

Conventional Survey Deliverables

- Preliminary survey plan and profile
- Class location study documentation
- Plats
- Route Maps

Integrated Data Collection Survey Deliverables

- 3D point cloud and virtual fly-through
- Digital Surface Model (DSM)
- Digital Terrain Model (DTM)
- Digital volumetric computations
- Aerial photography (HD and multi-spectral)

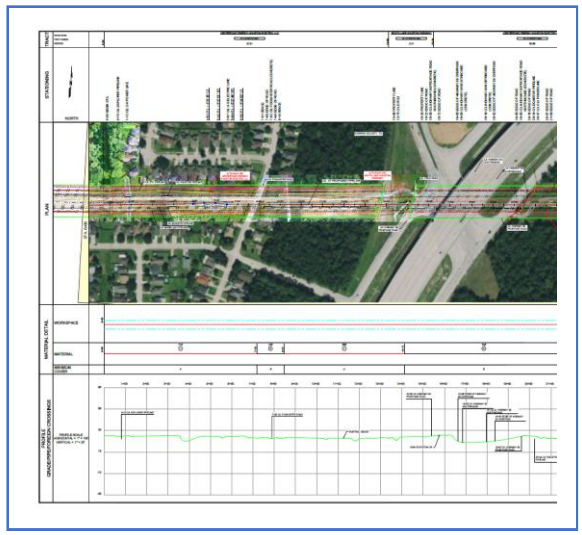

Fig. 8. Alignment Sheet Produced from UAV Aerial Photogrammetry

BENEFIT AND IMPACT

The advantage to utilizing new technology like UAV's to complete the preliminary phases of a pipeline survey begins with the ability to use the xyz values from the point cloud, as shown in ***Figure 6***, and add to it feature and attribute values to allow for the successful delivery of electronic data into a client's Pipeline Open Data Standard (PODS). This recent integration of remote sensing and traditional pipeline survey methodology is not only allowing for increased efficiency, but subsequent increased safety and accuracy ratings.

Other value additions include time savings with respect to pre survey permission in which aircraft may be flown in public use airspace to collect survey imagery data without intruding on private property. This expedited data acquisition and delivery of current geo-referenced aerial imagery is measurable and promotes early design and alignment sheet production within at least 24 hours following commencement of data collection.

Case Study Efficiencies-Time in Field

The following metrics are provided to demonstrate time savings that were realized during the case study survey project conducted over an 8-mile preliminary survey in a densely populated, congested pipeline right-of-way in Houston, Texas.

An overall efficiency of 66% was demonstrated by conducting the identical data collections with both a traditional survey crew and an integrated aerial UAV survey crew. Decrease in field man hours directly correlates to a reduction in crew exposure to potential health, safety and environmental hazards.

Position	Units	Days	Hrs/Day	Total Field Man Hours
Supervisor	1	22	10	**220**
2-Man Survey Crew	3	22	10	**1320**

Fig. 9. Time in Field: Traditional Survey Crew; Total hours: 1,540

Position	Units	Days	Hrs/Day	Total Field Man Hours
3-Man UAV Crew	1	2	10	**90**
2-Man Survey Crew	1	22	10	**440**

Fig. 10. Time in Field: Integrated Aerial Survey Crew, Total hours: 530

Commercial Risk Reduction

As the cost of change increases exponentially as a project moves from the project development phase to the construction phase, the ability to mitigate or influence cost decreases during the same transition. The utilization of efficient survey technology aims to support construction and engineering firms to get ahead of the problem up front with constructability reviews and feedback to clients and engineers during critical phases of a project's development.

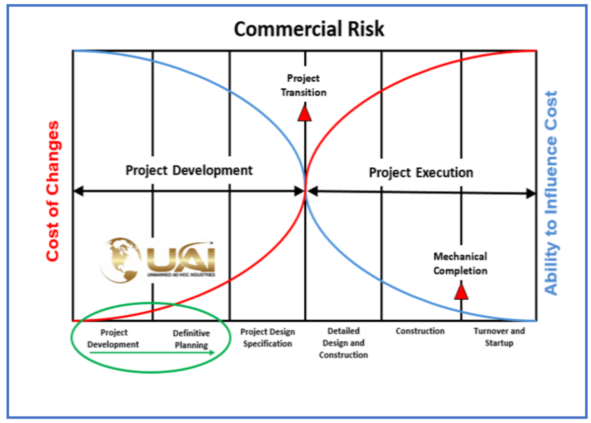

Fig. 11. Commercial Project Risk Matrix

APPLICATIONS

Pipeline Construction

Right-of-Way concerns of building and constructing today's pipeline routes, the value of providing new pipeline Route Terrain models, and the impact they have on engineering and construction are very well known. Preliminary easement flyovers to establish baselines prior to construction bid preparation, pre-construction, construction and post-construction have significant value. By supplying visual proof of right-of-way down to 3 cm, a record of compliance to assist all parties is essential (regulators, pipeline companies and landowners).

Pipeline Inspection & Leak Detection

Pipeline intrusions and breaks result in tremendous waste hazards both for the environment and the client. The ability for timely and accurate detection of the impacts of these events are critical to minimizing catastrophic damage to natural ecosystems as well as loss in product and revenue, not to mention regulatory compliance. Using advanced sensing methods such as infrared thermographic, multi-spectral, and hyper-spectral provide a unique methodology to detect indications of natural gas and petrochemical substances and gases.

Quick Reaction Capability

Quick reaction inspections detect and report immediate impacts of pipeline events. This immediate and real-time collection of data allows pipeline owners, operators, and land owners to make the best decision based on timely and accurate truth-information. The data gathering and analytics in an on-call standby sense gives pipeline operators piece of mind to respond to pipeline intrusion triggers at a moment's notice. Easily deployed aerial data collection UAV's enable a fast response to pipeline events that can cause havoc with each passing hour.

Well Pad Site and General Construction Survey

In today's expanding information age, the need for up-to-date detailed information to facilitate planning, verification, and present information on any given project is reaching new heights. Building Information Modeling (BIM) is reaching new levels through the use of UAV's which are serving the construction industry from the ground up. From verification of subcontractor work to informing and updating stakeholders with 3D modeling, UAVs provide an immediate value addition to the project life cycle. With one flight over a project area, multiple useful products are importable into software suites such as AutoDesk and ArcGIS.

CONCLUSIONS AND FUTURE DEVELOPMENT

As the adoption of intelligent data collection becomes more widely accepted, these state-of-the-art surveying applications such as; HD Aerial Photography, HD 4K Aerial video, elevation data, digital terrain models (DTMs), and Geo-rectified Orthomosaic images of sites will likely become the mapping standard. Capabilities that can also be realized such as providing an ability to import the high definition images into prolific online software interfaces like Google Earth and other mapping programs, will continue to promote the utilization well after the data collection and product delivery phases.

Intelligent deliverables like this provide a digital baseline of what the condition of the area was in before, during and after a project. Pipeline contractors now have real time imagery of their project sites, thus providing situational awareness needed to better manage, whether it be in the field or in the office.

As with most emerging technologies, it is essential to continually ascend the education curve, especially the value in having real-time access to:

- 3D representation of the earth's surface
- Digital Elevation models used for visualization
- Volumetric computations
- Pipeline route studies
- Terrain analysis
- DTM of Route
- DSM's of Route
- Engineering Design Mapping and Geographic Information Services

It is clear that with integrated survey data sets, a true capture of the existing conditions can be obtained; and at a higher level of efficiency than conventional ground methods. With this information, a true baseline of site conditions will be created, which not only allows a present site picture to be assessed, but more importantly provides future ability to track potential site degradation through subsequent scans.

While project site construction laser scanning is still relatively new technology, further development of process and delivery mechanisms are necessary in many industry applications. A clear differentiator is the ability for the survey crew to provide added value to the end user in actionable survey data that can be immediately disseminated as information used in decision making. In this regard, the necessity for accessible data management applications serve a critical function. While UAI has presented the current pipeline case to highlight an efficient and accurate use for UAV's in pipeline survey, there are a myriad of other uses that either augment or replace current survey methods as the technology continues to evolve.

REFERENCES

[1] *Accuracy of Pix4Dmapper Outputs*. (2015, November 24). Retrieved from Pix4D Support Site: https://support.pix4d.com/hc/en-us/articles/202558889-Accuracy-of-Pix4Dmapper-Outputs#gsc.tab=0

[2] Transportation, U. D. (2013, January 23). *PHMSA General Pipeline FAQ's*. Retrieved from PHMSA Pipeline and Hazardous Materials Safety Administration: http://phmsa.dot.gov/portal/site/PHMSA/menuitem.6f23687cf7b00b0f22e4c6962d9c8789/?vgnextoid=a62924cc45ea4110VgnVCM1000009ed07898RCRD&vgnextchannel=f7280665b91ac010VgnVCM1000008049a8c0RCRD&vgnextfmt=print#QA_6

[3] VanHoeven, M. (2015, N/A N/A). *DataHalo*. Retrieved from DataHalo: http://www.data-halo.com/