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ABSTRACT

This paper presents the evaluation Montana Tech completed for the Western Energy Company Rosebud Mine relating to the benefits of survey data collected using novel technologies over traditional methods for topographic surveys. These technologies include Unmanned Aircraft Systems (UAS), photogrammetry, and laser scanning/LIDAR. Utilizing these technologies, large areas such as reclamation areas and cast blasts can be surveyed in a timely manner for use by the mining operation. The areas that were evaluated were the improvements in the safety of employees and the time required to collect data. In addition, there is also a potential cost savings for the operation, all while not affecting the accuracy of the data that is collected.

PROJECT BACKGROUND

Accurate topographic survey data is critical to successful surface mining operations. It is used for mine planning and design as well as permit compliance. Currently, employees typically collect survey data using GPS equipment or total stations. These methods can be dangerous, as they require employees to work near large operating mobile equipment, edge of high walls, and on piles of stacked steep-sloped loose material. Aerial and satellite photographs, performed by a contractor, can be used to obtain some of this information, but it is expensive and may not be attainable during overcast conditions.

Montana Tech, along with the Rosebud Mine, conducted research on the accuracy, cost, and other benefits of survey data collected using novel technologies. Some of the methods studied include, but are not limited to, Unmanned Aerial Systems (UAS) or Vehicles (UAV), photogrammetry, and laser scanning. These methods were evaluated to determine if these technologies provide mining companies with a safer, cost effective, and accurate method to collect data for surface mining operations.

The project scope was to evaluate various surveying techniques to determine which techniques would be applicable for the Rosebud Mine and complete a trade-off study comparing the new techniques with currently used methods. The trade-off study included an analysis of the technological differences between the methods, safety and legal considerations for the new techniques, operational limits, and the costs associated with each technique. Working with the Rosebud Mine team, techniques were selected for field trial and accuracy comparison.

This paper presents a literature review of applicable technical papers and a summary of the Federal Aviation Administration regulations for UAS, followed by a study comparing conventional GPS topographic surveys with UAS based systems and laser scanning systems. The comparison of the various methods was broken into the following four categories: operator safety analysis, time comparison, survey accuracy, and cost analysis. After all of these portions of comparison were completed a recommendation was provided based on the evaluation that was performed.

LITERATURE REVIEW

The literature review focused on technical papers on the topics of laser scanning and photogrammetry and the use of these with tripod, vehicular and UAS mounts. The research included the limitations and beneficial attributes of the various systems, as well as one paper comparing the accuracy of UAS photogrammetry to network real time kinematic (RTK) global Position System (GPS) surveys.

Laser Scanning

Laser scanning is one of the technologies currently being used to replace the conventional survey methods. These systems utilize narrow lasers to record individual points of the features of the area being mapped. These units do not require any ground control points, as long as the position of the equipment being utilized is known when the measurements are taken.

The time required to perform these scans and the resulting level of detail is largely dictated by scan design. In order to cover larger areas at greater densities, and with minimal point spacing, larger periods of times must be set aside for data acquisition (Gatzoubaros, 2009).

Photogrammetry

Photogrammetry uses overlapping photographs to depict the area to be mapped. The photographs taken using this method are then post processed to determine elevations and other features of the surface. These features can then be extracted to produce models of the area (Abu-Achempong, et al., 2013).

In terms of viability for use of the system in mining operations, aspects point towards photogrammetric systems being more practical for use in mines when compared to scanners (Gatzoubaros, 2009). While photogrammetry has been used in exploration and mining projects for many years, recent improvements in the data collection and processing systems have made this method readily available for use at an operating mine.

Unmanned Aerial Systems/Vehicles

Historically, laser scanning and photogrammetry data collection required large cameras and scanning systems that required airplanes to use over mining operations. With the introduction of lighter data collection devices and the commercialization of unmanned aerial systems, the mining industry has an opportunity to embrace this technology and improve the safety and efficiency of its data collection.

The ability to take the images with a camera located above the ground allows images to be taken more orthogonal to the surface of interest, and in turn improve the geometry needed to produce good terrain models (Tannant, Radmanovic, & Jiang, 2006). Another benefit from obtaining points from above is the elimination of any void spaces that would be present if data collection was performed from the ground surface.

Limitations that have been observed with UAS measurements include the movements with the shadows of structures during UAS measurements that have caused significant errors (R. Heikkila, 2013). In addition to comparing UAS data to traditional data, it is common that the surface of the UAS is slightly higher. This is possibly due to the thickness of ground control targets, tendency of measuring too low with GPS (for example, having the survey rod penetrating ground surface), vegetation, and number of survey points (Siebert & Teizer, 2013).

FAA UAS REGULATIONS

The Federal Aviation Administration (FAA) is tasked with ensuring the United States airspace is safe and efficient. With the rapid introduction of unmanned systems, the FAA has had to expand existing regulations and work to develop new procedures for maintaining public safety. Until recently, the FAA relied upon existing rules that required operators to apply for a Section 333 Exemption and obtain pilot certificates. (Federal Aviation Administration, 2015). With the rapid adoption of UAS technology, this lengthy process was difficult to negotiate and was intended for larger aircraft.

On August 29, 2016, the new rules governing the use of small unmanned aircraft (Part 107) went into effect and simplified the process of qualifying to operate a UAS for civil use (non-recreational). Part 107 has significantly reduced the requirements to qualify to use UAS, however there are still some limitations that must be understood (Federal Aviation Administration, 2016). These limitations include:

- Aircraft must weigh less than 55 lbs. (25 kg),
- Visual line-of-sight only without aiding devices,
- Daytime only operation,
- Must yield right of way to other aircraft,
- Use of a Visual Observer (VO) will be optional,
- Maximum groundspeed of 100 mph,
- Maximum altitude of 400 feet above ground level (AGL),
- Minimum weather visibility of 3 miles from control station,
- Preflight inspection required, and
- Person may not operate a UAS if he/she has reason to suspect any physical or mental condition that would interfere with the safe operation of a small UAS.

In addition to the operational limitations there are also Operator Certification and Responsibilities that the pilot, considered the "operator", must adhere to. Some of these requirements include:

- Passing an initial aeronautical knowledge test or hold a part 61 pilot certificate,
- Obtaining a remote pilot airman certificate with a small UAS rating,
- Making available, upon request by FAA, the small UAS for inspection or testing and all documents/records required to be kept under the proposed rule,
- Reporting any accident to the FAA within 10 days that results in injury or property damage, and
- Conducting preflight inspection including specific aircraft and control station system checks, to ensure the small UAS is safe for operation.

SAFETY ANALYSIS

As with any new technique or equipment to be used in the mining industry, survey equipment should be subjected to a thorough analysis to ensure it does not create any new hazards for the workforce or public and hopefully, reduce the hazards currently encountered. This study focused on the hazards that a mine surveyor is exposed to while performing surveying duties using traditional GPS surveying, UAS based surveying systems, and vehicle or tripod mounted laser scanning systems.

Accident Statistics

No data was found on statistics related specifically to surveyor injuries from the Mine Safety & Health Administration (MSHA), however the United States Department of Labor's Occupational Safety & Health Administration (OSHA) does track this data across industries. The review of this data found that there were 44 incidents since the year 2000 (United States Department of Labor, 2016). Of these 44 incidents, 32 were fatalities that involved surveyors or other employees performing survey tasks. Within these 32 fatalities, 23 involved vehicles or equipment striking the employee. Of the remaining 12 non-fatal incidents, 8 were related to falls, 3 involved vehicles or equipment, and 1 was a heat related incident (United States Department of Labor, 2016).

Tasks Analyzed

Each of the methods of data collection has their own inherent risks associated with performing the tasks. To evaluate the various methods, a list of tasks that the employees would complete on a day to day basis was developed encompassing all of the methods of data collection. Some of the tasks included in the assessment are: walking and driving around large mobile equipment, near highwalls, and on steep sloped material; employee exposure to wildlife (snakes, ticks, etc.); slips, trips, & falls; mounting & dismounting vehicles; and heat and/or cold exposure.

Risk Assessment Matrix

When assessing each of the tasks, the relative probability/likelihood of occurrence and the severity of the risk were identified. Risks were given numerical rankings for the probability ranging from 1 for rare or unlikely occurrence through 4 for frequent or certain to happen. Each risk was also assigned a severity ranking from 1 for minor injury/first aid through 4 for a catastrophic event/fatality. Table 1 shows the Risk Assessment Matrix of probability versus severity rankings where the product is the relative level of risk for the task with lower values representing lower-risk tasks (Occupational health and safety management systems, 2012).

Table 1. Risk Assessment Matrix.

		PROBABILITY / LIKELIHOOD of occurrence or exposure for selected unit of time or			
SEVERITY of injury or illness consequence		*Frequent/Certain* Likely to occur repeatedly 4 Ex: occurs daily	*Likely / Probably* Likely to occur Several Times 3 Ex: occurs weekly	*Occasional/Possible* Likely to occur sometimes 2 Ex: occurs monthly	*Rarely / Unlikely* Not likely to occur 1 Ex: occurs yearly
Catastrophic Imminent and immediate danger of death or permanent disability	4	16 Extreme	12 Extreme	8 High	4 Moderate
Critical Permanent partial or temporary disability	3	12 Extreme	9 High	6 Moderate	3 Low
Marginal Hospitalized minor injury, reversible illness	2	8 High	6 Moderate	4 Low	2 Negligible
Minor First aid or minor medical treatment	1	4 Moderate	3 Low	2 Negligible	1 Negligible
Risk Severity	Negligible	Low	Moderate	High	Extreme
Ratings	1-2	3-4	4-6	8-9	12-16

Table 2 displays the resulting probability (upper number) and severity (lower number) values for each task and the resulting relative risk level. After a value was determined for each of the tasks, they were totaled for each of the data collection methods to indicate a relative level of risk for each method. As shown in the table, the UAS method receives the lowest risk rating as the operator can determine their control location and avoid many of the risks encountered by other methods.

TIME COMPARISON

Due to changing conditions at the mine site, it was difficult to arrange for the various surveying systems to survey the same area at the same time. In order to analyze the time required to complete a survey with each, however, two systems were able to be compared by analyzing two data sets of similar pit lengths located on the mine site. These systems were a fixed wing UAS and a laser scanner that was vehicle mounted.

Time data was collected during a demonstration flight of the UAS and compared to the time required for the mine site personnel to survey a similar dimensioned pit length with their current laser scanning system. Table 3 displays the results of the time study at the Rosebud Mine. With a labor cost of $40.00 per hour (Costmine: Mine Cost Estimating, 2015), the cost per acre surveyed is significantly less when using UAS.

Table 2. Risk Assessment for Various Data Collection Methods.

	GPS		UAS		Vehicle Mounted Scanning		Tripod Mounted Scanning	
Walking around Large Mobile Equipment	P = 1 S = 4	R = 4	P = 1 S = 1	R = 1	P = 1 S = 1	R = 1	P = 1 S = 4	R = 4
Driving around Large Mobile Equipment	P = 1 S = 4	R = 4	P = 1 S = 4	R = 4	P = 1 S = 4	R = 4	P = 1 S = 4	R = 4
Walking Near Highwall Crest	P = 1 S = 4	R = 4	P = 1 S = 1	R = 1	P = 1 S = 1	R = 1	P = 1 S = 4	R = 4
Driving Near Highwall Crest	P = 1 S = 4	R = 4	P = 1 S = 1	R = 1	P = 1 S = 4	R = 4	P = 1 S = 4	R = 4
Walking Near Highwall Toe	P = 1 S = 4	R = 4	P = 1 S = 1	R = 1	P = 1 S = 1	R = 1	P = 1 S = 4	R = 4
Driving Near Highwall Toe	P = 1 S = 4	R = 4	P = 1 S = 1	R = 1	P = 1 S = 4	R = 4	P = 1 S = 4	R = 4
Walking On/Around Steep Sloped Loose Material	P = 2 S = 2	R = 4	P = 1 S = 1	R = 1	P = 1 S = 1	R = 1	P = 2 S = 2	R = 4
Exposure to Wildlife (snakes, ticks, etc.)	P = 3 S = 2	R = 6	P = 3 S = 2	R = 6	P = 1 S = 2	R = 2	P = 2 S = 2	R = 4
Slips, Trips, & Falls	P = 4 S = 1	R = 4	P = 2 S = 1	R = 2	P = 1 S = 1	R = 1	P = 2 S = 1	R = 2
Mounting/Dismounting Vehicle	P = 1 S = 1	R = 1	P = 1 S = 1	R = 1	P = 3 S = 2	R = 6	P = 1 S = 1	R = 1
Exposure of other personnel in event of Equipment Failure	P = 0 S = 0	R = 0	P = 1 S = 2	R = 2	P = 0 S = 0	R = 0	P = 0 S = 0	R = 0
Heat Exhaustion/ Cold Stress	P = 3 S = 2	R = 6	P = 2 S = 2	R = 4	P = 1 S = 2	R = 2	P = 2 S = 2	R = 4
Data Collection Method Total	**45**		**25**		**27**		**39**	

P = Probability of Occurrence	R = Resulting Relative Risk Level	Relative Risk	Negligible	Low	Moderate	High	Extreme
S = Severity of Consequence		Ratings	1-2	3-4	4-6	8-9	12-16

Table 3. Recorded Times: Scanner vs UAS Time Comparison.

	Field Work Time (hrs)	Persons Required	Processing Time (hrs)	Persons Required	Manhours Required	Labor Cost ($)	Total Time Required (hrs)	Area Surveyed (acres)	Cost per Acre Surveyed ($/Acre)
UAS	0.87	2	3.29	0	1.74	69.67	4.73	255.00	0.27
Laser Scan	0.80	1	0.42	1	1.22	48.83	1.22	40.95	1.19

Unfortunately, site conditions only allowed for approximately 3,500 linear feet of pit to be surveyed with the mobile scanner while the UAS was able to survey the entire area (4,000 linear feet). Eight setups were required to complete the mobile scan with the average time between each of the setups of 5.4 minutes. If site dimensions had allowed for full pit survey, another setup would have been required. Adding this additional setup, Table 4 shows the adjusted times for the laser scan system to collect and process the data in an approximately equal pit length, and an adjusted total area.

Table 4. Adjusted Times: Scanner vs UAS Time Comparison.

	Field Work Time (hrs)	Persons Required	Processing Time (hrs)	Persons Required	Manhours Required	Labor Cost ($)	Total Time Required (hrs)	Area Surveyed (acres)	Cost per Acre Surveyed ($/Acre)
UAS	0.87	2	3.29	0	1.74	69.67	4.73	255.00	0.27
Laser Scan	*0.89*	1	*0.47*	1	*1.36*	*54.35*	*1.36*	*46.07*	*1.18*

As shown in Tables 3 and 4 the man-hours required is greater for the UAS. This is in large part due to the large area that was surveyed using the UAS, as the flight time was 34 minutes (0.57 hours). The total surface area of data collected using the UAS was over six times greater than that collected using the mobile scanner (255 acres versus 41 acres). Note that if the NPRM is implemented as proposed, the second person currently required for UAS operation would become "optional" reducing the man-hour requirement substantially.

For comparison based on the total area surveyed, time adjustments were used to calculate the time required to survey approximately the same area using the laser scanner. This would require approximately 50 setups, so the field work time and processing time were each adjusted as shown in Table 5.

Table 5. Adjusted Times: Laser Scan vs UAS Area Comparison.

	Field Work Time (hrs)	Persons Required	Processing Time (hrs)	Persons Required	Manhours Required	Labor Cost ($)	Total Time Required (hrs)	Area Surveyed (acres)	Cost per Acre Surveyed ($/Acre)
UAS	0.87	2	3.29	0	1.74	69.67	4.73	255.00	0.27
Laser Scan	*4.30*	1	*2.60*	1	*6.90*	*276.04*	*6.90*	*255.96*	*1.08*

As shown in Table 5, in order to complete an equivalent total area with the laser scanner that was surveyed using the UAS, approximately four times the man-hours are required.

SURVEY ACCURACY ANALYSIS

Unfortunately, due to different coordinate systems, none of the UAS or laser scanning demonstrations completed at the Rosebud Mine were able to be correlated with a conventional GPS survey. Fortunately, staff from North American Coal's Falkirk Mine in North Dakota had recently completed a similar comparison using their fixed wing UAS versus GPS and were willing to provide the data for a statistical comparison (Obrigewitch & Burke, 2016). Three-dimensional topographic surfaces were created using the appropriate software and imported into the Maptek I-Site Studio software for comparison.

With the two surfaces in I-Site Studio, a 20-feet grid was created within the common regions to identify the elevations of common coordinates from both surveys. Approximately 2,400 points were created as shown in Figure 1.

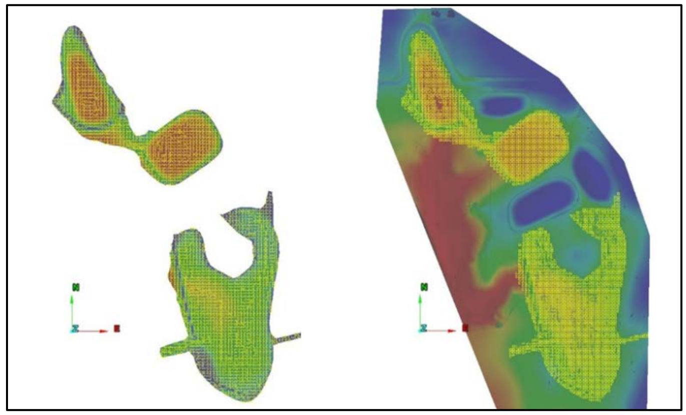

Figure 1. GPS Survey (left) and UAS Survey (right) with common 6 meter grids.

Once the points were created, the coordinates of each were brought into the statistical analysis software package Minitab for comparison. Minitab was used to create a random sample of 500 pairs (shown in Figure 2) of survey elevations for analysis using a Paired T-Test of the difference in mean elevation between the two survey methods.

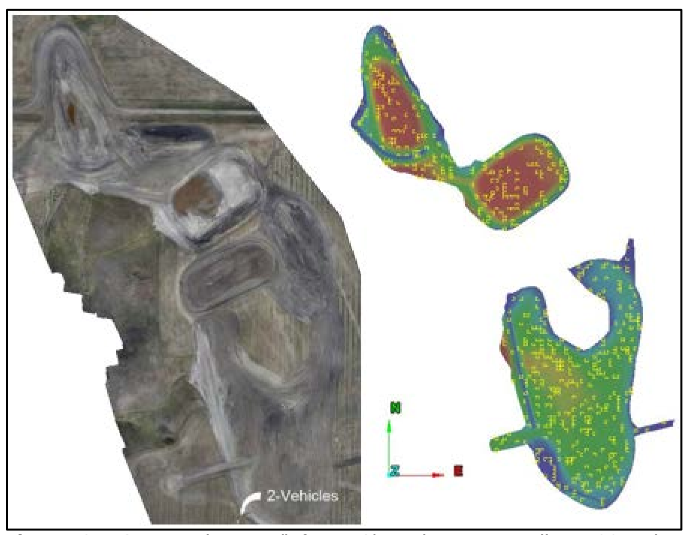

Figure 2. Surveyed Area (left, UAS) and corresponding 500 point sample used (right, GPS).

The paired T-Test shown in Table 6 was designed to test the difference in mean elevations modeled using the GPS survey data and the surface produced using a UAS platform with photogrammetry. If the survey methodologies produced exactly the same surface triangulations, it would be expected to see a mean difference of 0.00 feet and a relatively high p-value. In this case, however, we see a mean difference in elevation of 0.22 feet and a very low p-value (0.000) indicating that there is a statistically significant difference in the mean elevations of the two survey methods.

Table 6. Paired T-Test for GPS Survey Elevations minus UAS Survey Elevations.

Paired T for GPS Survey Elevations - UAS Survey Elevations				
(Values in Feet)				
	N	Mean	StDev	SE Mean
GPS Survey Elevations	500	1,955.97	5.41	0.24
UAS Survey Elevations	500	1,955.75	5.59	0.25
Difference	500	0.22	0.53	0.02
90% CI for mean difference: (0.1847, 0.2627)				
T-Test of mean difference = 0 (vs ≠ 0): T-Value = 9.46 P-Value = 0.000				

While the researchers agree there is a minor difference in mean elevation between the two models and that it may be of concern for other survey applications, it is not large enough to be considered practically significant when compared to the inherent variability in GPS surveys for mining operation topographic surveys. The techniques used for GPS surveying of large areas typically involve a vehicle or backpack mounted GPS system where sinking into soft ground, suspension travel, or even operator posture could result in an elevation difference similar to the variation observed in this study. Also, over time the variation will cancel out as the original topography, pit topography, and reclamation topography are all surveyed using the same system.

SURVEY COVERAGE

The main advantage of applying the use of a UAS to post cast blast surveys is the complete coverage that is obtainable from the UAS versus the mobile scanner. The main limitation when using the mobile scanner or GPS is safe access to the area following the cast blast. There is limited line of site in the post blast area and that in turn leads to holes in the data. With the use of the UAS there is no line of sight issues and the entire area is able to be captured. An example data set from both the laser scanner and UAS is shown in Figure 3 (note the two examples are different cast blasts, however they are representative of typical results).

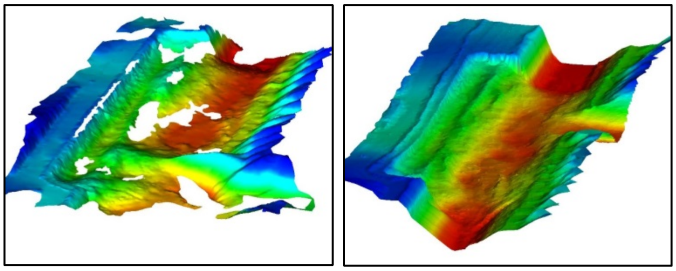

Figure 3. Data Sets from Laser Scanning (left) and UAS (right).

POTENTIAL COST SAVINGS

Another potential benefit of implementing the UAS technology is the cost savings from the mine eliminating aerial topographic surveys performed by a contractor. These topographic surveys would be performed by mine employees. The aerial surveys are costly and the results are frequently not available for use at the mine site for weeks or months.

UAS Costs

Every surveying system has varying operating and maintenance costs but for this study these costs for UAS were assumed to be similar for costs currently incurred by the mine for their current systems used for surveying. One vendor and another mining operation (North American Coal, Falkirk Mine) provided the estimated costs for two fixed wing UAS shown in Table 7.

Table 7. Cost Estimates for two UAS Systems.

	Vendor 1	Vendor 2
Equipment	$50,000	$85,000
Training and Software Licensing	$4,000	$3,500
Processing Computer	$10,000	$10,000
Sport Pilot License	$10,000	$10,000
Total	$74,000	$108,500

As shown in Table 7 the total cost including training, a computer designated for only data from the system, and acquiring a license for implementing an UAS on the mine site can range from $74,000 to over $100,000 depending on the vendor's pricing.

Aerial Topography

Assuming that there is an approximate annual cost of $40,000 to the mine for contracted aerial topographic surveys and photos and that this is the only cost savings achieved by the mine, Table 8 displays the cumulative net present value (MARR = 15%) of replacing aerial surveys with a site operated UAS. The UAS would be operated by mine employees as part of their regular duties and would not require any additional costs as the operating and maintenance costs would be offset by the reduced use of other systems. In addition, the equipment lives are assumed to be similar to current systems. Table 8 shows that Vendor 1 ($74,000) has a two-year payback and Vendor 2 ($108,500) has a three to four-year payback.

Table 8. Net Present Value of Annual Cost Savings.

NPV @ 15.0%	
Year 0	$40,000
Year 1	$74,783
Year 2	$105,028
Year 3	$131,329
Year 4	$154,199
Year 5	$174,086

CONCLUSIONS

After evaluating the various methods of survey data collection in terms of user safety, data accuracy, operational efficiency, and cost; the UAS appear to have an advantage over other systems when performing topographic surveys of large reclamation sites and areas with difficult access or safety concerns. These technologies reduce the risks that employees are exposed to on a day-to-day basis using the other equipment and do not require substantially more time. With the proper processing software (dependent on the system vendor) photogrammetric UAS can be as accurate as traditional GPS surveys. In addition to the safety and accuracy, there is the opportunity to replace contracted aerial surveys and pay back the initial capital investment of purchasing an UAS within a few years.

RECOMMENDATIONS

Moving forward, it is recommended that continuous monitoring of FAA regulations be performed, and an internal check be performed for potential operators who would already qualify as a pilot in command. Also, continued vendor demonstrations should be performed, if possible, to find the system that contains features that fit the site best and gain an understanding of how the systems operate and can work with the local mine survey grid. These steps need to also ensure that user safety, data accuracy, operational efficiency, and cost are not compromised with the systems.

Standard procedures also need to be developed in regards to the use of the UAS in the field, so as to properly utilize the new asset. As stated previously, a dedicated computer should be purchased for data processing and storage of the vast quantity of data that is generated, along with a dedicated data backup system. Regardless of the novel survey technology selected, standard file structures and naming conventions should be developed to ensure the large quantity of data is accessible when needed and easily retrievable.

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