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3-D Mapping Technologies for High Level Waste Tanks

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EXECUTIVE SUMMARY

This research investigated four techniques that could be applicable for mapping of solids remaining in radioactive waste tanks at the Savannah River Site: stereo vision, LIDAR, flash LIDAR, and Structure from Motion (SfM). Stereo vision is the least appropriate technique for the solids mapping application. Although the equipment cost is low and repackaging would be fairly simple, the algorithms to create a 3D image from stereo vision would require significant further development and may not even be applicable since stereo vision works by finding disparity in feature point locations from the images taken by the cameras. When minimal variation in visual texture exists for an area of interest, it becomes difficult for the software to detect correspondences for that object.

SfM appears to be appropriate for solids mapping in waste tanks. However, equipment development would be required for positioning and movement of the camera in the tank space to enable capturing a sequence of images of the scene. Since SfM requires the identification of distinctive features and associates those features to their corresponding instantiations in the other image frames, mockup testing would be required to determine the applicability of SfM technology for mapping of waste in tanks. There may be too few features to track between image frame sequences to employ the SfM technology since uniform appearance may exist when viewing the remaining solids in the interior of the waste tanks.

Although scanning LIDAR appears to be an adequate solution, the expense of the equipment ($80,000 - $120,000) and the need for further development to allow tank deployment may prohibit utilizing this technology. The development would include repackaging of equipment to permit deployment through the 4-inch access ports and to keep the equipment relatively uncontaminated to allow use in additional tanks.

3D flash LIDAR has a number of advantages over stereo vision, scanning LIDAR, and SfM, including full frame time-of-flight data (3D image) collected with a single laser pulse, high frame rates, direct calculation of range, blur-free images without motion distortion, no need for precision scanning mechanisms, ability to combine 3D flash LIDAR with 2D cameras for 2D texture over 3D depth, and no moving parts. The major disadvantage of the 3D flash LIDAR camera is the cost of approximately $150,000, not including the software development time and repackaging of the camera for deployment in the waste tanks.

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LIST OF ACRONYMS

3-D	Three Dimensional
DOE	Department of Energy
GPS	Global Postioning System
HLW	High Level Waste
LIDAR	Light Detection and Ranging
SfM	Structure from Motion
SLR	Single-Lens Reflex
SRNL	Savannah River National Laboratory
SRS	Savannah Rive Site

1.0 INTRODUCTION AND BACKGROUND

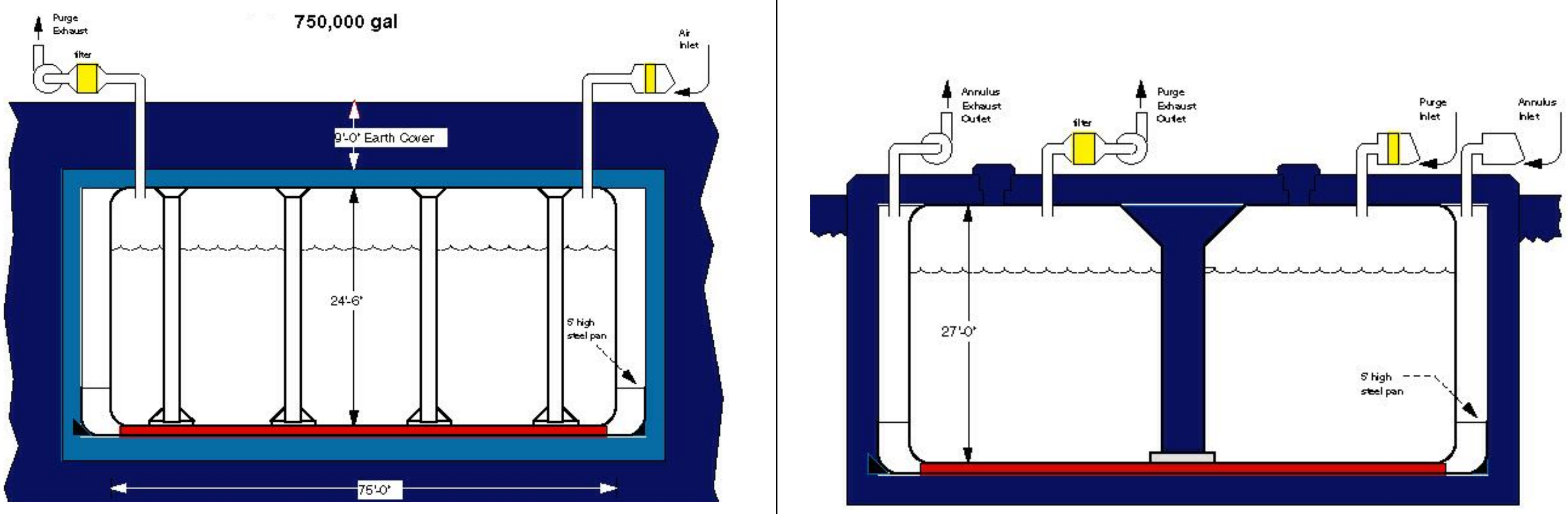
Four different types of tanks were constructed at the Savannah River Site (SRS) for the purpose of storing radioactive contaminated hazardous waste. The Department of Energy's (DOE's) objective for most of these tanks is to discontinue their use and close them. Closure of the tanks will require filling the tanks completely with a cementious material; however, this cannot be accomplished until nearly all of the waste is removed from the tanks. Radioactive contaminated sediment/sludge continues to exist in the bottom of the tanks even after repeated cycles of flushing. To ensure that the tanks are not closed with excessive amounts of contaminated material remaining, (it is necessary to be able to accurately determine the volume and concentrations of the remaining solids. The purpose of this research is to determine the technologies available to measure the remaining tanks solids once tank cleaning has reached the maximum extent possible (MEP) and map the solids in a 3 dimensional (3D) view to permit DOE to evaluate the quantity and distribution of the remaining solids.

The Savannah River National Laboratory (SRNL) performed this research with funding provided by SRS Essential Site Services.

1.1 Tank Types at SRS

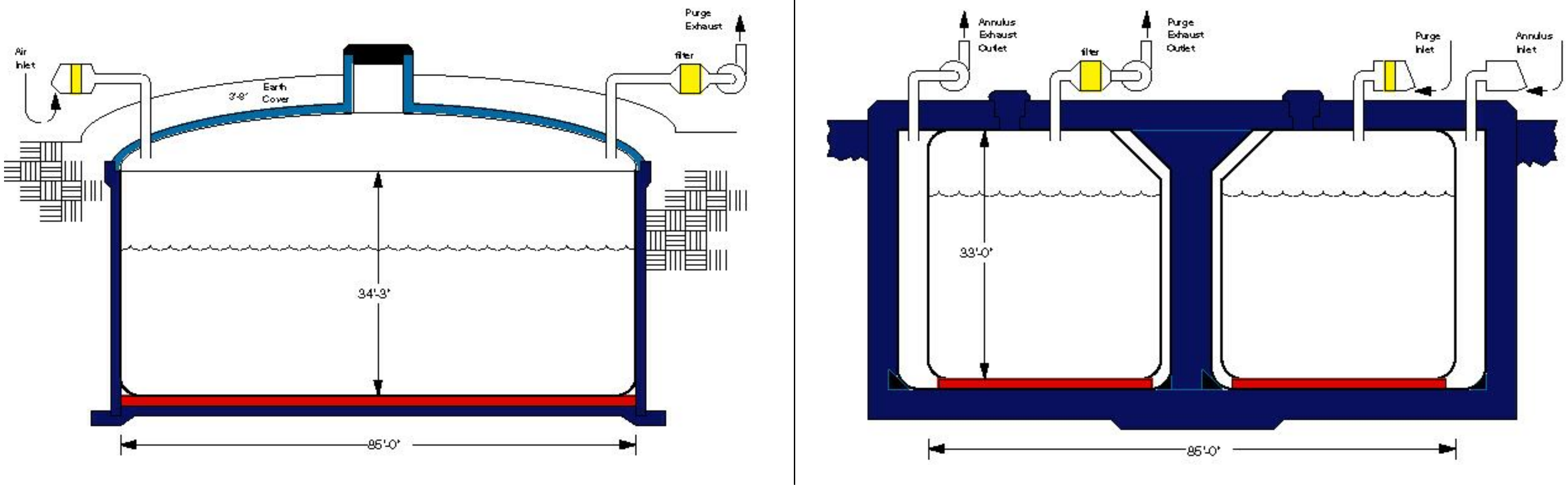
The tanks located at SRS are defined as Tank Types I, II, III and IV. These tanks are illustrated in Figure 1. The tanks were built between 1951 and 1981 and range in capacity from 750,000 gallons to 1,300,000 gallons.

Figure 1. SRS Tank types



Type I - 750.000 gal: Tanks 1 to 12 (1951–53)

Type II – 1,030,000 gal: Tanks 13 to 16 (1955-56)



Type III – 1,300.000 gal: Tanks 1 to 12 (1967–81)

Type IV – 1,300,000 gal: Tanks 13 to 16 (1958-62)

All tank types at the SRS consist of interior cooling coils as shown in Figure 2. These cooling coils were placed in the tanks to control the temperature of the liquid waste, therefore reducing the potential for a critical reaction occurring in the tanks. This "maze" of cooling coils not only increases the difficulty during clean-out of the tanks but also increases the difficulty of remotely measuring the solids remaining on the floor of the tanks.

Figure 2. Cooling coils located in the waste tank interior

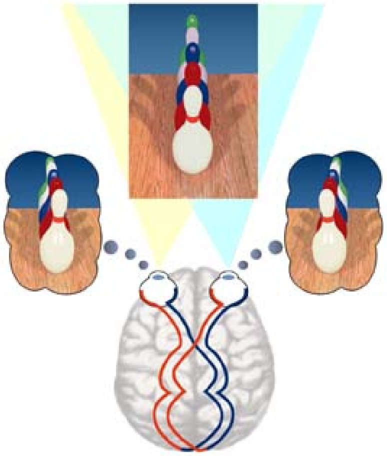
2.0 POTENTIAL TANK MAPPING TECHNIQUES

Research of available technologies for remotely generating a topographical map of the interior of a tank revealed that there isn't commercially available off-the-shelf equipment that can be procured for this application without further development. This development may include software and/or equipment modifications for remote deployment within the tank. Four techniques were identified as having potential application for 3D mapping of tank solids: (1) stereo vision, (2) light detection and ranging (LIDAR)/3D laser scanning, (3) flash LIDAR, and (4) Structure from Motion.

2.1 Stereo Vision[1]

A stereo vision system is a set of two or more cameras used to extract depth of a 3D scene as viewed from different vantage points and modeled after binocular vision in humans. Binocular vision is defined as vision from two eyes where the data being perceived from each is overlapped. The overlap from the two different views is used in biological vision to perceive depth. Stereoscopic vision is the use of binocular vision to perceive a three-dimensional structure. Figure 3 demonstrates how stereo vision is present in humans

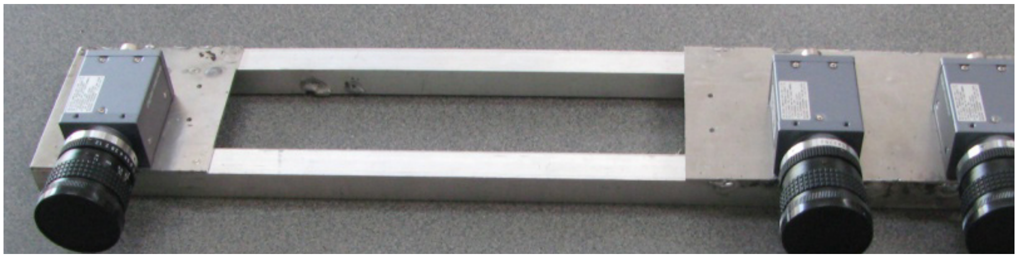
Figure 3. Example of binocular vision in humans



through the use of two eyes viewing a scene from different vantage points to extract depth. In humans, this is known as depth perception.

In a stereo vision system, cameras are horizontally aligned and separated by a distance known as the *baseline*. Figure 4 shows an example stereo vision system with three cameras mounted on a bar. Using the camera on the left and one of the cameras on the right will provide the two images necessary to extract a disparity map, which provides the data needed for 3D reconstruction.

Figure 4. Stereo system, with 18" baseline, using 1 color and 2 monochrome cameras

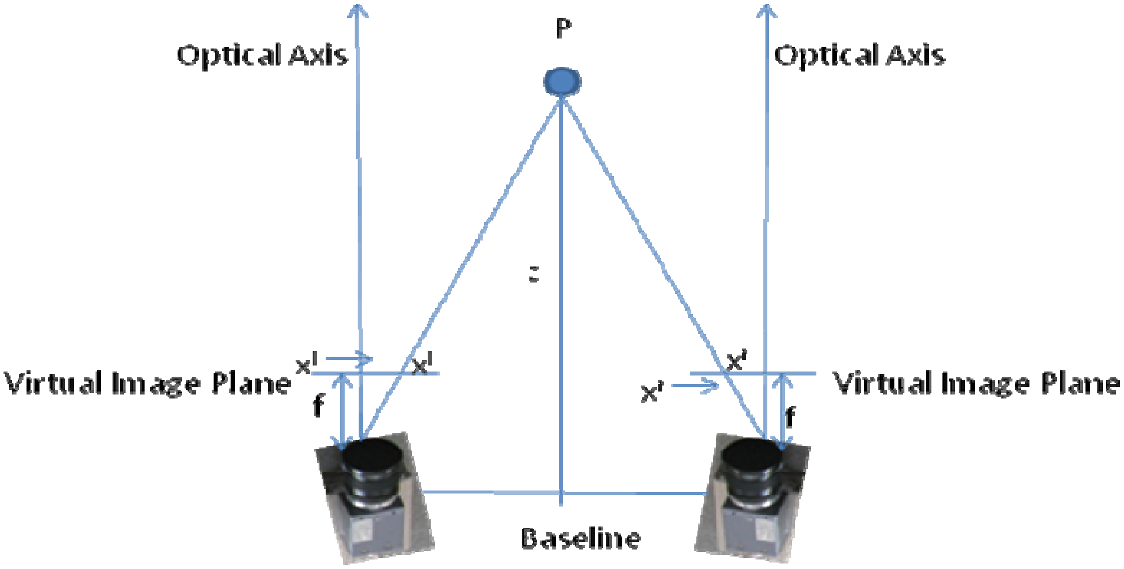


Stereo ranging is illustrated with the simple arrangement that is shown in Figure 5. In this ideal system, the optical axes of the two cameras are perfectly parallel, both image planes are coplanar, and no lens distortion is present. Since scene point *P* projects onto both image planes, its 3D coordinates can be recovered. In this case, the distance *Z* (also called the range or depth) can be found using Equation 1:

Equation 1.

$$Z = \frac{Bf}{d}$$

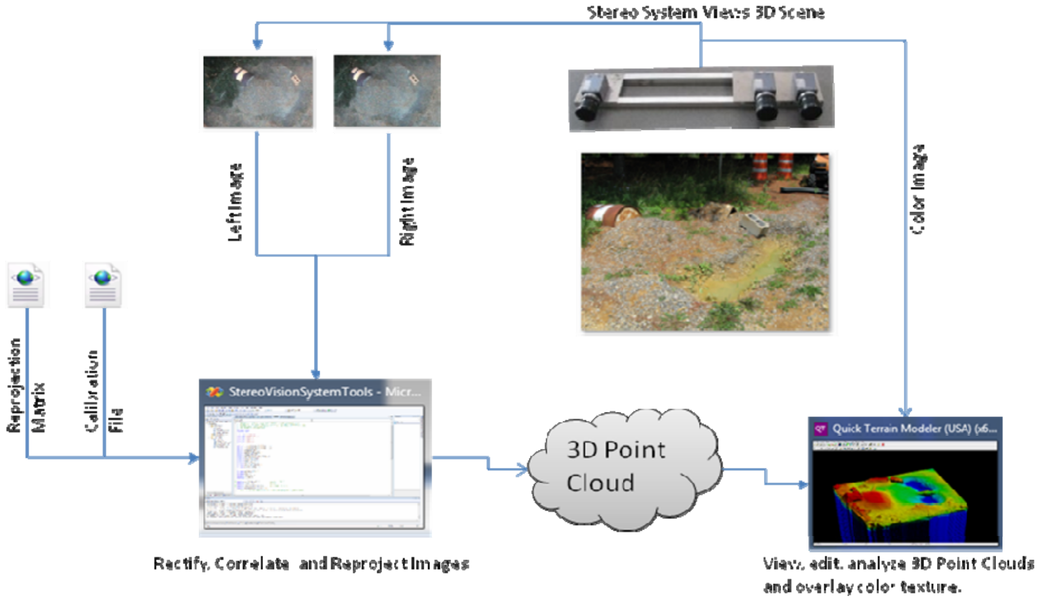
Figure 5. Simple geometry for stereo ranging



In equation 1, f is the focal length, B is the baseline, and d is the disparity which is defined by $d = x^l - x^r$ (Refer to Figure 5).

Figure 6 illustrates the work flow for processing a stereo image. The stereo system sends a left and right image of the 3D scene being viewed to a stereo vision system software program. The software rectifies the images, correlates the pixels, and reprojects the two dimensional (2D) points to a 3D point cloud. A point cloud is simply a set of x, y, z coordinates extracted from the x, y pixel coordinates and the disparity associated with each point. In addition, the color image taken by the stereo camera can be then be overlaid onto of the point cloud creating a texture map.

Figure 6. Stereo vision system flow diagram



The stereo vision system described previously was used to take images of a test site that was built at the Virginia Polytechnic Institute's Unmanned Systems Laboratory to replicate actual terrain. The test site is shown below in Figure 7, which consists of several objects (a barrel and a cinder block) and areas with elevated and lowered terrain. The system was placed on a fork lift and was lifted 16 feet above the site. A 3D point cloud of the terrain is shown in Figure 8, and a wire mesh model is shown in Figure 9 with a color map overlaid based on distance of the points from the stereo system.

Figure 7. Test site used to build 3D model

Figure 8. Ungridded point cloud with height coloration overlay

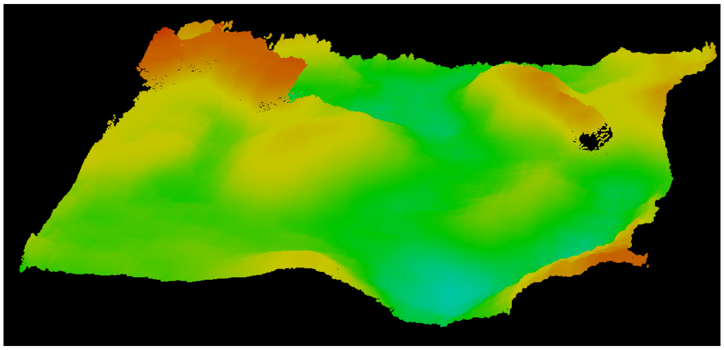


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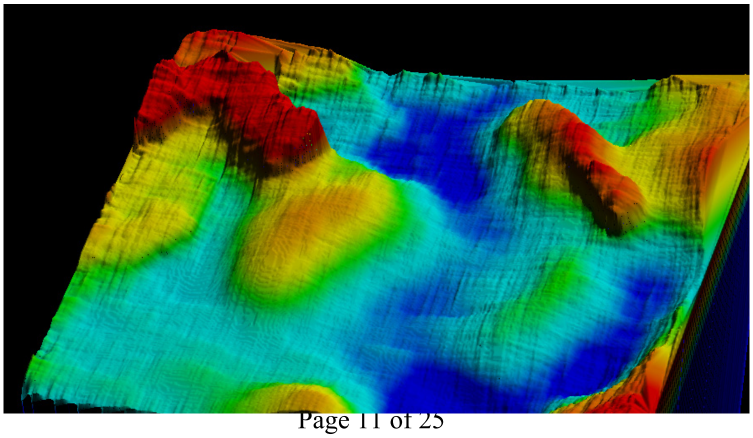
Figure 9. Wire mesh gridded surface model with height coloration overlay



Using the same stereo system, images were taken of a modified test site (see Figure 10) where a bridge and a pipe were added and placed on objects above the ground. The 3D model created used a higher resolution camera. From the point cloud generated and shown in Figure 11, it can be observed that the model has significantly more points than the version created using lower resolution cameras. The number of points in the point cloud increased from 255,640 to 1,444,064 with the higher resolution cameras. Looking at the point cloud shown in Figure 11 and the gridded surface in Figure 12, the objects appear much smoother and have a more defined shape than those generated by the lower resolution stereo system. The reason for this is that there are more points per area (higher density of points) in the point cloud generated by the high resolution system. The trade off is the amount of time taken to generate the model. With higher resolution cameras, the number of disparities searched must be increased which adds to the search time in addition to the increased number of pixels in the image.

Figure 10. Modified test site

Figure 11. Ungridded point cloud with height of terrain indicated using a color map

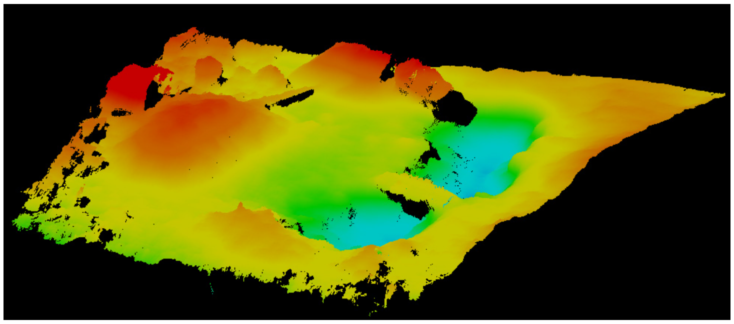
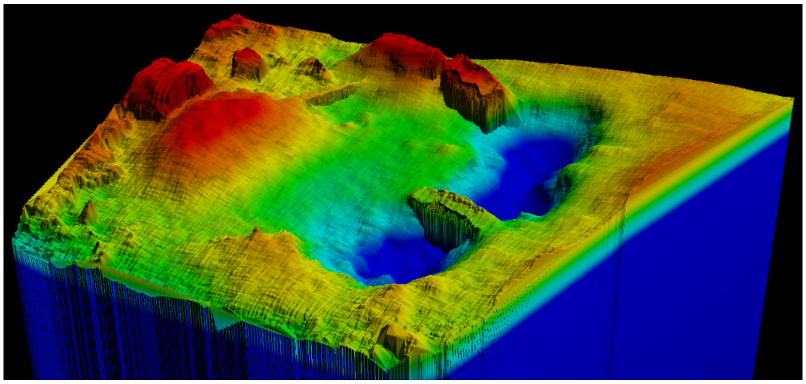


Figure 12. Wire mesh gridded surface model of sample terrain site with color map corresponding to height overlaid



The benefits of using stereo vision for measuring and mapping the remaining solids in waste tanks are low equipment costs (cameras) and the ability to package the cameras to permit placement of the equipment through the 4-inch access ports of the tanks. However, as mentioned previously, stereo vision works by finding disparity in feature point locations from the images taken by the cameras. When minimal variation in visual texture exists for an area of interest, it becomes difficult for the software to detect correspondences for that object. Objects having a uniform appearance in the horizontal direction are difficult for a stereo system to analyze. This uniform appearance may exist in the interior of the waste tanks when viewing the solids remaining in the tanks.

2.2 LIDAR/3D Laser Scanning[2]

Light detection and ranging (LIDAR) or 3D laser scanning is a technique for determining range and/or other information about a remote object or scene by transmitting a laser pulse, detecting the reflected signal, and measuring the time delay between the original pulse and the reflection. This information is collected and processed to produce a 3D image.

3D laser scanners yield a dense point cloud in which each point is represented by a coordinate in 3D space (x, y, z relative to the scanner's position). With this data, the 3D shape of any object or the geometry of any scene can be quickly determined. The most important advantage of the laser scanning method is that a very high point density can be achieved, and the shape of the surveyed object or scene can in principle be measured in three dimensions at a very high level of detail and accuracy.

Laser scanners for terrestrial applications have developed successfully over the last few years. Laser scanners consist normally of a range measurement system in combination with a deflection for the laser beam. The deflection system points the laser beam in the direction to be measured, the laser beam is emitted, and the reflected laser light is detected. The accuracy of distance measurements depends mainly on the intensity of the reflected laser light and therefore on the reflectivity of the object surface. LIDAR distance measurements can be determined by Equation 2.

Equation 2.

$$\text{Distance} = (\text{Speed of Light} \times \text{Time of Flight}) \div 2$$

Laser distance measurement can be used in a two mode application where the first pulse measures the range to the first object encountered (e.g., tree foliage), and the last pulse measures the range to the last object (e.g., the ground beneath the tree). By acquiring first-pulse and last-pulse data simultaneously, LIDAR can measure both tree heights and the topography of the ground beneath in a single pass.

The LIDAR signal and the measurements can be affected by the following:

(1) Reflectivity of the object. Highly reflective objects may saturate some laser detectors while the return signal from low-reflectivity objects may occasionally be too weak to register as valid.
(2) Interaction with dust and vapor particles. Such interaction can scatter the laser beam and the return signal; however, using last-pulse measurement can reduce or eliminate this interference.

LIDAR measurements are unaffected by the angle to the target, background noise, and temperature variations; however, the electronics will have temperature limitations, pressure, or vacuum variations. Since LIDAR is an active illumination technique, it does not depend on ambient illumination (i.e., measurements can be made with no illumination).

Terrestrial laser scanners may be categorized by the principle of the distance measurement system. The distance measurement system correlates to both the range and the resulting accuracy of the system. Three different techniques for range measurements are used with laser scanners:

(1) Time-of-flight measurement. (Refer to Equation 2). This technique is the most popular measurement system for laser scanners and allows measurement of distances up to several hundred meters.
(2) Phase measurement. To determine the distance measured, the phase differences between the transmitted signal and the reflected signal are compared. The range is restricted to a maximum of one hundred meters. Accuracy of the measured distances within several millimeters is possible. The measurement speed is also much higher and can be up to 100 times faster than time-of flight laser scanners.
(3) Optical triangulation. This distance measurement principle is illustrated in Figure 13. Close range laser scanners with ranges up to few meters are available. Accuracies down to some micrometers can be achieved with this technology. Table 1 provides a list of laser scanners, based on this measurement principle.

The techniques mostly used in terrestrial surveying are the time-of-flight and the phase-measurement techniques.

Figure 13. Laser measurement principle using optical triangulation

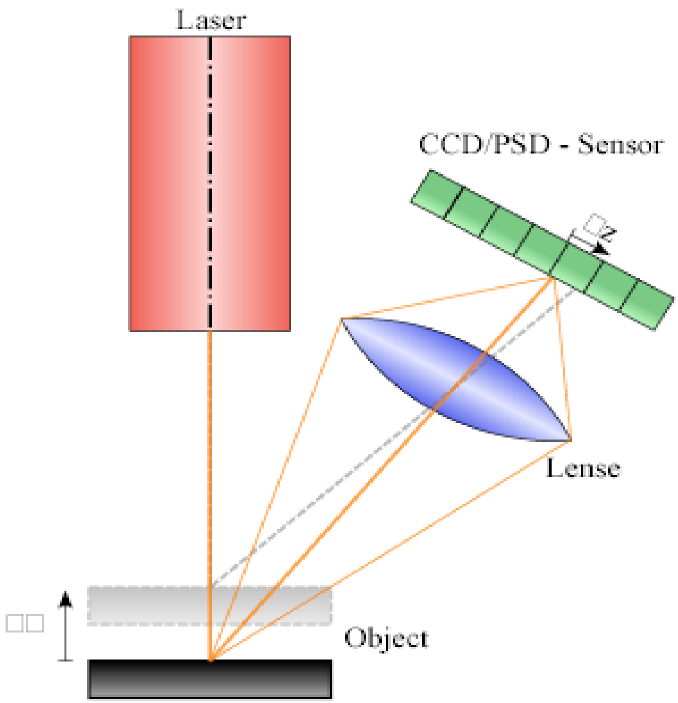


Table 1. Laser Scanner Measurement Principle – Range and Accuracy

Measurement Technique	**Range (meters)**	**Accuracy (mm)**	**Manufacturer(s)**
Time-of-Flight	< 1000	< 20	Callidus, Leica, Mensi, Optech , Riegl
Phase Measurement	< 100	< 10	IQSun, VisImage, Leica, Zoller+Fröhlich
Optical Triangulation	< 5	< 1	Mensi, Minolta

Technical specifications that should be reviewed prior to selection of a laser scanner include the scanning speed (i.e., sampling rate of the system), field of view (i.e., camera view, profiling, imaging), spatial resolution (i.e., number of points scanned in field of view), and accuracies of range measurement system. Terrestrial laser scanning systems offered by several different manufacturers are shown in Figure 14.

Figure 14. Manufacturers of terrestrial laser scanning equipment

Optech ILRIS 3D

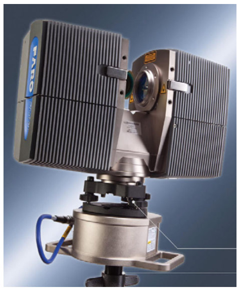
Minolta VIVID 910

Leice HDS 4500

Riegl LMS-Z210i

IQ Sun 880

Trimble (Mensi) GS200



FARO Photon 120

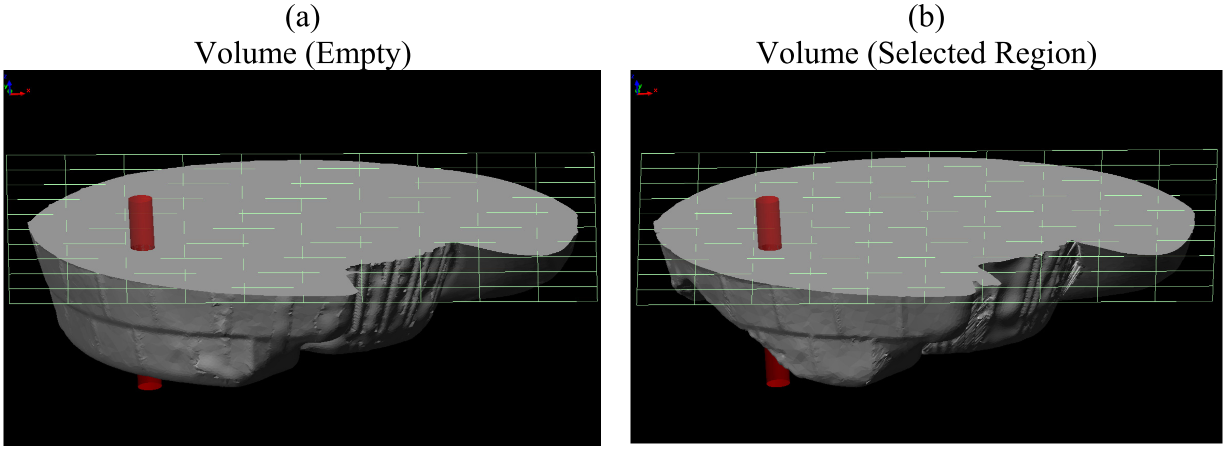
Once the 3D data set for an object or terrain scene is obtained, software is required to analyze the data for creation of the 3D image. Several manufacturers of LIDAR equipment have developed software that is compatible with their equipment. In addition, several companies, such as Quick Terrain Modeler from Applied Imagery, have developed software to generate a 3D point cloud and terrain visualization which is adaptable to LIDAR equipment from many different vendors. The software can provide the user with options such as mensuration, statistical analysis of features, terrain slope analysis, point interrogation, volume calculations, line of sight measurements, cross sectional details, etc.

Representatives from Faro, Inc. developed a scaled mockup of the waste tank internals to test the viability of using LIDAR equipment in creating a 3D model of the simulated tank solids.[3] Figure 15 illustrates the crude but effective test setup of the tank cooling coils.

Initially, a 3D point cloud of the test setup was developed using the Faro LIDAR equipment and Polyworks software. A model was created of the empty pool, and a volume calculation of the empty space (i.e., void) was performed as shown in Figure 16 (a). Soil was then placed into the pool to simulate the remaining solids in a waste tank, and the volume of the void was then modeled and calculated (see Figure 16 (b)). To determine the volume of the soil placed in the pool, the difference was calculated with an approximate error of 1.8%. This test indicated that LIDAR equipment is viable for measurement of remaining tank solids.

Figure 16. Test mockup of the HLW tank cooling coils with sediment

Figure 15. Volume determination of the solids placed in the test mockup

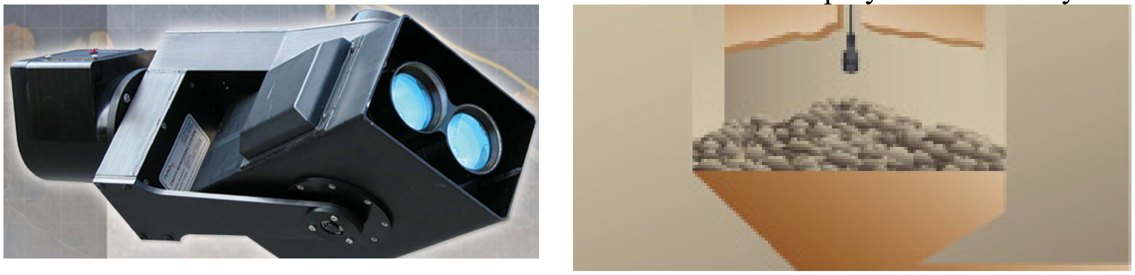

(a)
Volume (Empty)

(b)
Volume (Selected Region)

Although LIDAR appears to be an adequate solution, the expense of the equipment ($80,000 to $120,000) and the need for further development to allow tank deployment may prohibit utilizing this technology. The development would include repackaging of equipment to permit deployment through the 4-inch access ports and to keep the equipment relatively uncontaminated to allow use in additional tanks.

Most of the LIDAR equipment that has been researched would require major modifications to permit deployment through a 4-inch access port; however, one vendor has marketed a device that may fit with significantly fewer repackaging modifications. This device is known as the Cavity Monitoring System (CMS) and is illustrated in Figure 17. The CMS has a range resolution of ±1 mm with a horizontal range of 360° and a vertical range of 300°, which is adequate for tank mapping applications. The cost may still be prohibited at approximately $80,000.

Figure 17. Cavity Monitoring System



(a)
CMS

(b)
CMS shown deployed into a cavity

2.3 Flash LIDAR[4, 5]

Flash LIDAR is a 3D imaging technique that captures an entire scene with a single laser pulse. Rather than sending out pulses of a tightly collimated light beam, that is then mechanically scanned over an object or scene, with flash LIDAR you flood the scene with a diffuse laser light and use a focal plane array (FPA) as your detector to acquire a frame of 3D data each time the laser is fired. The detector concept is similar to the FPA in a 2D digital camera, and the flash is like the flash of a camera.

Advanced Scientific Concepts (ASC), Inc., a producer of 3D flash LIDAR systems, describes 3D flash LIDAR as follows[6]. 3D flash LIDAR cameras operate and appear very much like 2D digital cameras. 3D FPAs have rows and columns of pixels, also similar to 2D digital cameras but with the additional capability of having the 3D "depth" and intensity. Each pixel records the time the camera’s laser flash pulse takes to travel into the scene and bounce back to the camera’s focal plane (sensor). A short duration, large area light source (the pulsed laser) illuminates the objects in front of the focal plane as the laser photons are "back scattered" towards the camera receiver by the objects in front of the camera lens. This photonic energy is collected by the array of smart pixels, where each pixel samples the incoming photon stream and "images" depth (3D) and location (2D), as well as reflective intensity. Each pixel has independent triggers and counters to record the time-of-flight of the laser light pulse to the object(s). The physical range of the objects in front of the camera is calculated and a 3D point cloud frame is generated at video rates (currently possible up to 60 frames/second).

Currently, twenty or forty-four analog samples are captured for each pixel per pulse allowing for accurate pulse profiling. Because of the physics involved with the velocity of light, the accurate range data is a direct and simple calculation (as opposed to stereo vision camera systems whose range is interpolated based on lens disparity). The 16,384 data points per single flash (frame) that ASC cameras capture allows for high-rate dynamic scene capture and 3D videos that LIDAR scanners are unable to accomplish. The absence of moving or other mechanical parts to add weight or are subject to wear, make ASC cameras small, light and durable, without being subject to motion distortion. Figure 18 illustrates the compact size of a flash LIDAR camera.

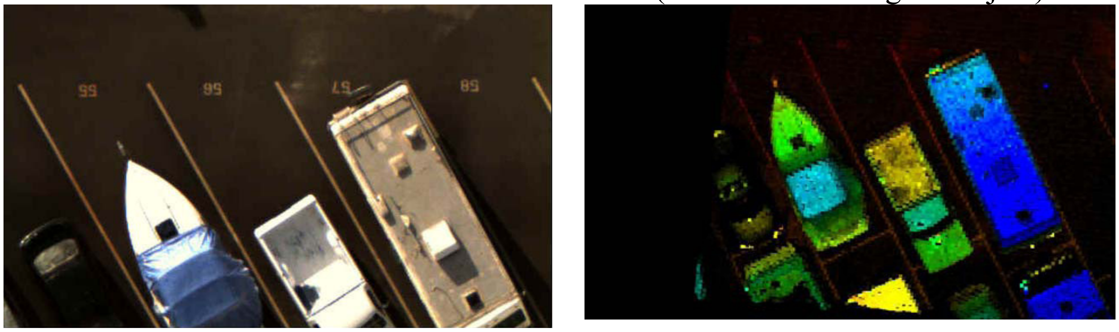
Figure 18. 3D flash LIDAR camera

3D flash LIDAR has a number of advantages over conventional point (single pixel) scanner cameras and stereovision camera systems, including:

- Smaller and lighter than point scanning systems
- Full frame time-of-flight data (3D image) collected with a single laser pulse
- Full frame rates (high) achievable with area array technology
- Unambiguous direct calculation of range
- Blur-free images without motion distortion
- Co-registration of range and intensity for each pixel
- Pixels are perfectly registered within a frame
- No need for precision scanning mechanisms
- Combination of 3D flash LIDAR with 2D cameras for 2D texture over 3D depth
- No moving parts

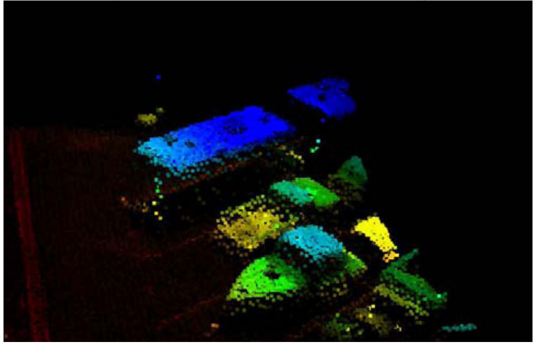
The major disadvantage of the 3D flash LIDAR camera is the cost of approximately $150,000, not including the software development time and repackaging for use in the waste

Figure 19. Flash LIDAR imaging



(a)
2D image of parking lot

(b)
3D image at 1000 ft.
(color denotes range to object)



(c)
3D image rotated (note depth of truck bed and height of boat cover is visible

tanks. Figure 19 illustrates a single laser pulse 3D raw-data image taken with the camera shown in Figure 18[7]. The image is color coded for range. Range was determined using a range algorithm developed by ASC, Inc. Shading resulted from amplitude processing of the data. This technology would easily be adaptable to tank mapping.

3.0 STRUCTURE FROM MOTION[8]

SRNL is managing a project for the Defense Threat Reduction Agency in which an Unmanned Aerial Vehicle (UAV) is being utilized as the platform for one of its mission. One of the objectives for the mission is to create a 3D map of the urban terrain of an area of interest. The technique used is referred to as Structure from Motion (SfM), which is a process for creating 3D images by analyzing the motion of an object over time. A single-lens reflex (SLR) camera is used for capturing a sequence of images synchronized with GPS coordinates to develop a 3D terrain map. The requirements for this imaging are to obtain relatively high resolution images with a 90% overlap factor so that the algorithm can successfully track feature points to obtain the 3D terrain geometry. The UAV system was capable of defining a flight path and generating trigger points for the camera based on a percent overlap factor for the images. The GPS data was recorded when an image was captured. Figure 20 shows a sample raw nadir image and the 3D rendering using the full sequence of images.

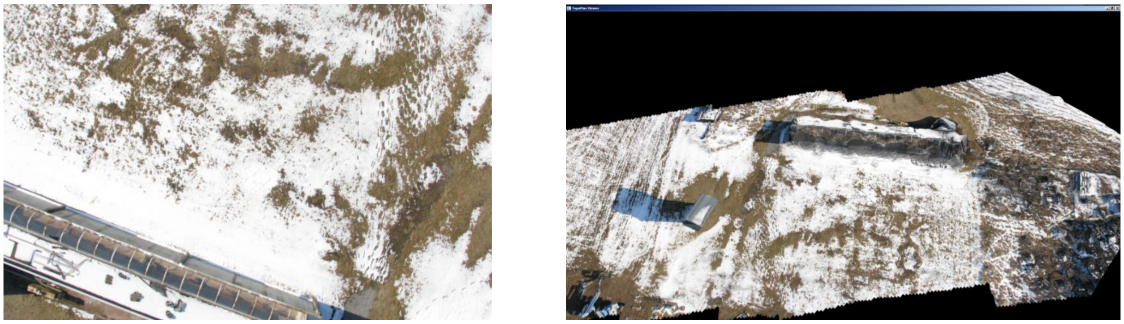


Figure 20. Imaging Results using SfM

Nadir image

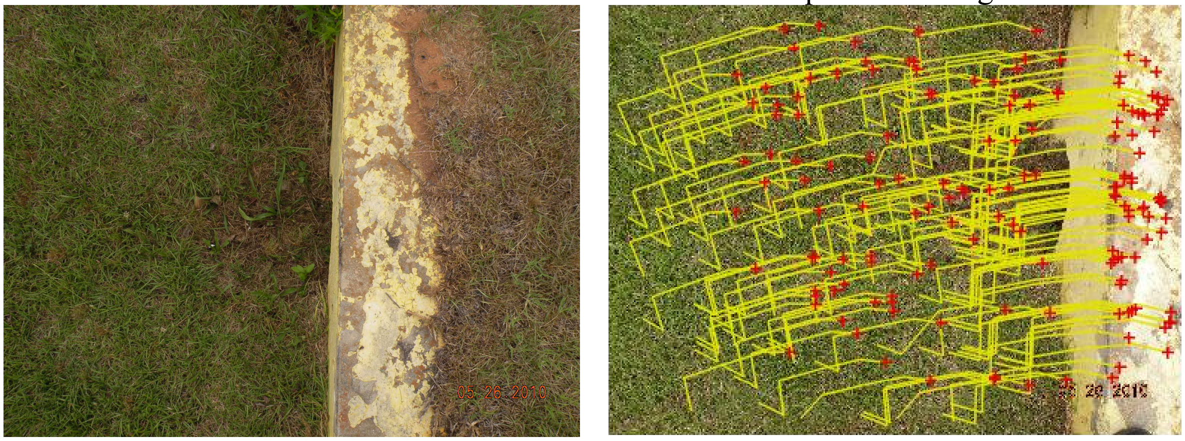
3D rendering

Several simplifying assumptions are made when constructing a 3D model from 2D imagery to formulate the SfM task. One key assumption is that objects in a scene are rigid and only the camera is allowed to move in the environment. A software algorithm is required to pre-process the camera's images to consistently extract, locate and label 2D features in the scene. Such 2D features could include salient points in the image, corners of objects, lines along their edges or curves around their contours. In each frame, the features are detected and associated to their corresponding instantiations in the other frames. The locations of the 2D features in the images depend on 1) their coordinates in 3D space, 2) the relative 3D motion between the camera and the scene and 3) the camera's internal geometry. It should be noted, however, that matching and detecting feature points is a difficult computer vision problem for practical implementation.

SRNL has been granted two licenses to use software developed by 2d3, Inc. called TopoMap. This software is use for generating 3D images from a sequence of 2D camera images. For a stream of video images or multiple still images, TopoMap analyzes the frames of imagery for identification of hundreds or possibly thousands of distinctive points that appear in areas of high contrast or high texture. The quality of a camera solution is, to an extent, dependant on the quality of the 2D feature tracks. TopoMap uses a large set of hundreds or thousands of automatically identified feature tracks and statistical analysis to identify the primary motion within a sequence and discard tracks with inconsistent motion. The software then reconstructs a 3D model using only the imagery. TopoMap determines the relationships among all the frames, connects them, and builds the model. In the process, the application software also produces an image referred to as a mosaic, which is a compilation of images blended into a single image that is used to texture the model. The result is a 3D model with texture that can be viewed using TopoMap Viewer or exported to a variety of 3D formats for use in other software applications.

For a quick test of applicability to waste tank mapping, a digital camera was used to take a sequence of images of an outdoor scene with a drop in elevation. An image of this scene is shown in Figure 21. A point cloud was generated from the sequence of 2D images. As illustrated in Figure 22, the point cloud, generated from the TopoMap software, shows the drop in elevation that is not apparent from the image of Figure 21. Further analysis using TopoMap would enable the creation of a mosaic for adding texture to the 3D point cloud for producing a 3D image.

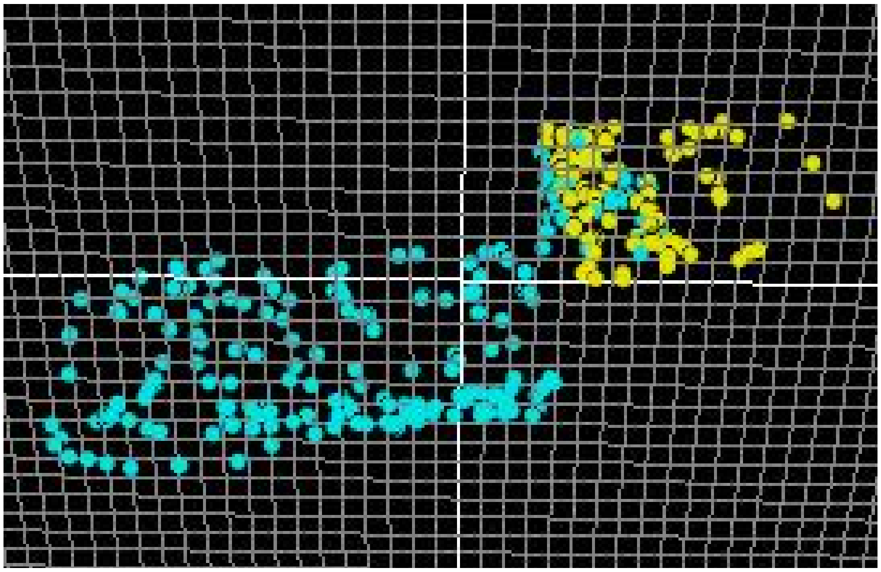
Figure 21. Outdoor scene with elevation change



(a)
2d image of terrain

(b)
Tracking of distinctive features from a sequence of images

Figure 22. 3d point cloud generated from the 2d sequence of images



If GPS data is available when the images are recorded, TopoMap can use the data to scale and geo-locate the 3D model to real world coordinates, permitting the determination of the exact latitude and longitude of any point, to permit measurement of objects and distances on the 3D model.

The benefits of using SfM for measuring and mapping the remaining solids at the bottom of the waste tanks are low cost of equipment (high resolution SLR camera) and the ability to package the camera for deployment through the 4-inch access ports. Additional development would be required for movement of the camera in the tank space to enable capturing a sequence of images of the scene. Although the TopoMap software development was expensive, it can be made available to SRNL for investigating its use in creating tank mapping models. However, as mentioned previously, SfM requires the identification of distinctive features and associates these features to their corresponding instantiations in the other image frames. When minimal variation in visual texture exists for a scene, it may be difficult for the software to construct a 3D model of the scene. Mockup testing would be required to determine the applicability of the SfM technology for developing a 3D model of the remaining solids in the tank There may be an inadequate number of features to track between image frame sequences to employ the SfM technology since uniform appearance may exist when viewing the remaining solids in the interior of the waste tanks.

4.0 CONCLUSION

Each of the techniques investigated has some advantages and some disadvantages.

Stereo vision is the least appropriate technique for the solids mapping application. Although the equipment cost is low and repackaging would be fairly simple, the algorithms to create a 3D image from stereo vision would require significant further development and may not even be applicable since stereo vision works by finding disparity in feature point locations from the images taken by the cameras. When minimal variation in visual texture exists for an area of interest, it becomes difficult for the software to detect correspondences for that object.

SfM appears to be appropriate for solids mapping in waste tanks. However, equipment development would be required for positioning and movement of the camera in the tank space to enable capturing a sequence of images of the scene. Since SfM requires the identification of distinctive features and associates those features to their corresponding instantiations in the other image frames, mockup testing would be required to determine the applicability of SfM technology for mapping of waste in tanks. There may be too few features to track between image frame sequences to employ the SfM technology since uniform appearance may exist when viewing the remaining solids in the interior of the waste tanks.

Although scanning LIDAR appears to be an adequate solution, the expense of the equipment ($80,000 - $120,000) and the need for further development to allow tank deployment may prohibit utilizing this technology. The development would include repackaging of equipment to permit deployment through the 4-inch access ports and to keep the equipment relatively uncontaminated to allow use in additional tanks.

3D flash LIDAR has a number of advantages over stereo vision, scanning LIDAR, and SfM, including full frame time-of-flight data (3D image) collected with a single laser pulse, high frame rates, direct calculation of range, blur-free images without motion distortion, no need for precision scanning mechanisms, ability to combine 3D flash LIDAR with 2D cameras for 2D texture over 3D depth, and no moving parts. The major disadvantage of the 3D flash LIDAR camera is the cost of approximately $150,000, not including the software development time and repackaging of the camera for deployment in the waste tanks.

5.0 RECOMMENDATIONS

The SfM technology option should be further investigated since this is the least expensive option available for accurately mapping the remaining solids within the waste tanks. The TopoMap software from 2d3, Inc. has been procured by SRNL and is available for use. Additional development and mockup testing are required to verify that the SfM technology will be successful when deployed in the waste tanks to generate 3D maps of the remaining solids. Testing of the stereo vision technology indicates that this is not a good option for tank mapping at this time since much further algorithm development is required to generate accurate 3D images.

If high investment in equipment is not a deterrent, then procurement of the LIDAR scanning or flash LIDAR equipment would definitely provide accurate 3D mapping models of the waste tank internals. Additional development in the deployment and repackaging of the equipment would be required to implement this technology.

6.0 REFERENCES

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