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Comparison of Point-Cloud Acquisition from Laser-Scanning and Photogrammetry Based on Field Experimentation

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Abstract: Laser scanning technology has been explored as a reliable and accurate method to generate point clouds for the purposes of 3D modelling, as-build model development, and object recognition. Despite the high cost of laser scanning equipment, the rapid scanning ability, automated data analysis and precision of this technology have enabled many cost effective applications in different fields such as construction progress tracking. Recently, photogrammetric techniques have been introduced as a more flexible and a cost-effective approach for creating point clouds, which would significantly reduce the cost of point cloud acquisition and therefore enable a broader range of applications in the construction industry. This paper presents a comparison of point-cloud generation using laser scanning and photogrammetry considering costs, portability, labour hours per collected information unit, and training expertise. The analysis was conducted in the context of point-cloud acquisition for the purposes of confirming as-built construction, and progress tracking of piping and ducting activities for an institutional construction project in Waterloo, ON. Laser scanning was performed using a FARO scanner, and photogrammetry utilized a hand-held digital camera on this project. The dialogue in this paper juxtaposes the two technologies, and seeks to identify the strengths and weaknesses of each when applied to progress tracking and as-built construction activities over the course of several months on a construction project. It was found that on one hand photogrammetry fits more a user profile for which money is an important issue, and on the other hand when training time and expertise are the issues then the laser scanning technology is preferable.

1. Introduction

There are a number of construction related applications which require accurate, reliable, and cost effective methods of acquiring point-clouds from construction sites. These applications range from object recognition, automated construction progress estimation, as-built model construction, BIM verification, quality control, and even automated payment calculations.

One of the two available methods of acquiring 3D point clouds is the terrestrial three dimensional laser scanning technology, also named LADAR (Laser Detection and Ranging). Automatic object recognition techniques from 3D laser scans have been developed for project management and quality control applications. Recent developments in object recognition techniques enable the retrieval of 3D computer-aided design (CAD) objects from laser-scanned data (Bosche and Haas, 2008; Bosche et al. 2008; Bosche et al., 2009). Bosche's new approach for the recognition of 3D CAD objects from point clouds obtained from 3D laser scans of the site has enabled a wide range of applications in the construction industry. Researchers are using the possibilities offered by the LADAR technology to monitor landsliding and any soil deformation measurement. Lijing and Zhengpeng (2008) show that the technology offers an advantage over traditional methods of surveying that overlook minor local deformations. LADAR technology has also proved to be valuable for construction managers to help them on many tasks such as material tracking, progress monitoring, quality control and facility/infrastructure management (Akinci and Anumba 2008). On the same aspect, Golparvar-Fard et al. (2009) note that such a tool allows managers to remotely explore the construction site and be used for contractor coordination purposes. Huber et al. (2010) are studying the laser scanning technology for analyzing surface flatness, quality assurance, floor plan modeling and recognition of building components. Qui and Wu (2008) are working on deformation and safety monitoring of tunnel structures using LADAR. All these examples show the large range of applications that covers the laser scanning technology today, and this variety of applications involves a need for reliable and cost effective method of point cloud acquisition of construction sites.

With the current advances in photogrammetric technology, it has become possible to assemble a low-cost system to work with any off-the-shelf high resolution camera and any off-the-shelf Software (SW), that handles camera calibration, interior and exterior orientation, bundle adjustment, image normalization, and epi-polar stereo matching. Photogrammetric SW has become able to generate a high density point cloud automatically as well. Although photogrammetry has been studied and applied for centuries, many of its core principles and methodologies have been developed over the last two centuries (American Society of Photogrammetry 1980). In particular, aerial photogrammetry was used extensively in the 20th century because of the importance of measuring topographies for a variety of reasons that range from strategic military to real estate and environment conservation considerations. Close range photogrammetry usually refers to that branch of photogrammetry wherein the distance between the object and the camera is less than 300 meters. Close range photogrammetry has been applied in a wide variety of disciplines including manufacturing, medical, sport, biology, zoology, preservation of cultural heritage sites, aerospace and forensic sciences. Within the civil engineering domain it has been used for structural monitoring (Fryer et al. 2007) and research initiatives are being conducted to determine its suitability to automated construction progress monitoring (El-Omary 2008; Ahmed et al. 2011). Using photogrammetric technology to acquire 3D point clouds has thus become quite feasible.

As demonstrated in this paper, Photogrammetry can be used as a strong alternative to LADAR technology for generating point-clouds for various applications related to the construction industry. In this paper the background of the Photogrammetry technology is presented along with the state of the art research related to the construction industry. The two technologies are then compared on an industrial construction project and the advantages and disadvantages of each technology are evaluated. A number of recommendations on the use of these technologies on construction projects are also described which aim at improving the efficiency and effectiveness of the use of these technologies for construction related applications.

2. Point cloud Acquisition Technologies

The art and science of Photogrammetry, or Metrophotography as it was originally termed by its inventor Laussedat in 1851, was developed to be able to find the correct metrical representations of the object photographed from ordinary photographs. The history of close-range photogrammetry can be traced back to the late 1840s. But its bases have deeper roots in history (Ahmed and Haas 2010; Falco 2007; Al-Haytham 1038). Metric cameras were the main tools of photogrammetric data collection, because of the necessity of available camera calibration data; e.g., lens distortion and interior orientation parameters before starting computations. Calibration techniques were very complicated due to the use of complicated hardware devices, e.g., a large number of light collimators; each one is directed at a certain tilted angle across the diagonals of a certain platform, allowing only one ray to pass through each known collimator. By allowing light bundles to pass through the collimators and through camera lens to the image plan; the computation of deviations across image diagonals was possible, hence the characteristics of lens distortion could be computed. This task was mainly done by special experts and complicated optics computations were required. Many calibration techniques were developed through years of research and technology advances, and calibration became simpler and more systematic with time. Photogrammetry is still evolving, since the era of analog photogrammetric systems where stereo vision was generated physically using mechanical and opto-mechanical instruments. Analytical photogrammetry emerged with advances in computing machines where only point coordinates were taken physically on hard-copy images while the stereo models were formed computationally to produce direct 3D coordinates of real world objects. Later in digital photogrammetry, the digital images enabled the automation of measuring point coordinates to a great extent, and Photogrammetric Work Stations (PWS) became the standard, however, PWS were based on either special operating systems and/or special hardware. Now, due to dramatic development of computers, digital cameras and lenses, and software development tools, the PWS can be any computer, and photogrammetry technology has become more applicable to new engineering applications.

The terrestrial three dimensional laser scanning technology, also named LADAR (Laser Detection and Ranging), is an imaging technology expanding in use since the 90's, that is used as an efficient tool to acquire 3D point clouds. Laser scanners are based on two main technologies: (1) time-of-flight or pulse-based, and (2) phase-based (Jacobs 2008). Pulse-based scanners send a laser pulse in a narrow beam toward an object and then estimate the distance to the object based on the time the pulse takes to be reflected from the object back to the scanner. Phase-based scanners measure the distance to the object by calculating the phase shift in a continuously emitted and returned sinusoidal wave as the wave hits the object. Pulse-based scanners can be used for long-range applications up to 1 km, while phase-based scanners are better suited for low-range applications up to 50 m (Jacobs 2008). The development of this technology over the years enables users with a wide range of applications by accurately acquiring three dimensional data for a whole construction scene (Stone and Cheok 2001). The acquired data is represented by a point cloud where every point contains coordinate information regarding its position in the scene. The generated point cloud represents every object surface within visible range. The LADAR technology was considered by many as the top technology to capture project point clouds with accuracy and speed (Cheok 2000). These 3D point clouds can be considered as an end product or be used for further purposes such as the creation of as-built CAD models for progress tracking and quality control for instance.

Recent developments in object-based recognition techniques enable the retrieval of 3D computer-aided design (CAD) objects from laser-scanned data (Bosche & Haas 2008; Bosche et al. 2008; Bosche et al. 2009). In Bosche's method, the 3D model of the scanned environment is used as priori knowledge for recognizing objects from the scanned 3D point clouds. In this method, the 3D model is utilized to identify the relative position of the object to be recognized from the scanned point cloud. Therefore, the object recognition system has a-priori expectations of where to find each element, given that the 3D model and the scanned point cloud are correctly registered together.

3. Experimental Program

In order to compare point cloud acquisition technologies, a real world case study was investigated in a new building inside the campus of the University of Waterloo. The E6-Building was being monitored during its construction progress. The experimental program was focused on the fifth floor of the building. One floor was large enough to provide a comprehensive basis for comparison of the available technologies, since it could be easily scaled up to include the entire project or even much larger projects. The following criteria were used for evaluation of these technologies in this paper: labour hours required for data collection and data processing, cost of equipment, portability, and training expertise.

Since the purpose of this paper is to compare the laser scanner technology with photogrammetry, the conducted experiment aimed at using both technologies to produce a point-cloud of a common area in the monitored building. Respective experts were given carte blanche to use their knowledge and expertise in order to produce the desired point-clouds. The numbers of scans and pictures, as well as their respective resolution were completely at the discretion the experts.

For the photogrammetric part; the complicated networks of different types and sizes of pipe-works was investigated using a low-cost consumer-grade camera, Canon XSi 450D with its basic zoom lens (kit lens). This is important to mention, because zoom lenses not only lower the imaging quality in general but also cause unstable interior orientation parameters of the camera at any chosen focal length. These parameters were changing even between images in some sequences; which certainly affected the final outputs. This study used the camera built-in flash and natural indoor daylight as main sources of light. Free positions for camera stations were arbitrarily chosen so that the taken images maintain a common overlapping area. The overlapping is necessary for reconstruction of 3D models to satisfy the co-planarity condition at each model point (Mikhail 2001). Satisfying this condition at five common points between any two images is required in the case of calibrated metric camera, however, for a non-metric camera, at least eight common points need to be identified between the two overlapping images to satisfy the necessary conditions (Ahmed 2007). For automatic epi-polar matching and image re-sampling; the tilted images are transformed to normalized images. An accurate 3D point cloud is automatically generated then processed to produce a 3D meshing surface. The surface is rendered using either the images, so that a virtual reality style surface is reconstructed with original texture, or by using color shades. See (Ahmed et al. 2011) for further details of output formats. The used calibration technique can be found with further details in (Ahmed and Haas 2010).

The laser scanner that was used in this paper was a FARO Laser Scanner LS 840 HE. This scanner is considered an advanced surveying and spatial imaging sensor that uses time-of-flight technology to determine the distance of objects from its mirror, and allows the collection of millions of points with a high spatial resolution. Table 1 shows the technical specifications of the laser scanner.

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Table 1: Technical Specifications of Laser Scanner

Range	0.6m to 40m
Resolution	0.6mm – 17 Bit Range / 9 Bit Intensity
Measurement Speed	120000 Hz
System Distance Error	+/-3mm at 20m
Laser power	20mW
Wavelength	785nm
Beam Divergence	0.025 mrad
Beam Diameter at exit	3mm, circular
Vertical Field of view	320°
Horizontal Field of view	360°
Weight	14.5kg
Ambient Temperature	+5° / +40°

Tables 2 and 3 summarize the specifications of respectively the used lens and camera.

Table 2: Technical specifications of the lens

Maximum format size	APS-C
Focal length	18-55mm 35mm equivalent focal length (29-88mm)
Diagonal angle of view	74° - 27°
Max. aperture/ Min aperture	F3.5-5.6 / F22-38
Lens Construction	11 elements/9 groups, 1 Aspherical element
No. of diaphragm blades	6
Minimum focus	0.25m
Maximum magnification	0.34x at 55mm
Auto Focus motor type	DC Micro Motor
Focus method	Extending front element
Image stabilization	4 stops, Single mode
Weight	200 g
Dimensions	68.5 mm diameter x 70 mm length

Table 3: Technical specifications of the camera

Sensor	12.2 million effective pixels, 22.2 x 14.8 mm CMOS sensor
Focus modes	AI Focus, One shot, AI Servo
Shutter speed	30 - 1/4000 sec
Drive modes	Single, Continuous: 3.5 fps, Self-timer 10 sec (2 sec with mirror lock-up)
Dimensions	129 x 98 x 62 mm (5.1 x 3.9 x 2.4 in)
Weight (no battery)	475 g (1.0 lb)

3.1 Labour hours for Data Collection and Data Processing

Photogrammetric data acquisition is mainly a photography process. No special arrangements are required, however, an overlap needs to be maintained between any two consecutive images so that one point-cloud can be generated using these two sequential images. Additional point-clouds can be generated as a by-product between any third or fourth overlapping images taken from the same or different viewing angles. A camera calibration process can either be conducted once per project or every few months to ensure the quality of camera and lens data. For a zoom-lens, it takes about one hour to conduct two calibration sessions using the two zoom focal ends.

To investigate the system, a large number of images were taken during different phases of project construction and pipe-works installations. Different types and sizes of pipe-works at different heights and orientations were monitored and accurately reconstructed using two photogrammetric techniques. The first technique produced automatically a dense point-cloud very-similar to the known output of laser scanners. The maximum output density was variable between different stereo-pairs because of using hand-held photography. No one fixed camera configurations or setups were applied through the whole data collection process. The camera orientation and settings were changing all the time just to maintain overlap and image quality as much as possible because of the indoor low light environment. Generally it is possible to generate between 200,000 to 1 million points per stereo-image pair. The system can even generate points more than number of overlapping pixels using sub-pixel interpolation, however, practically, 1/4 to 1/2 the possible density is found to be faster. Within a few seconds to a few minutes, a low to high 3D point cloud can be generated. It is always possible to generate different densities at different parts of the same stereo-model. This flexibility enables the representation of homogeneous surfaces with much less than the total number of points normally required. The second technique utilized a very effective photogrammetric approach which has the capability to directly produce 3D CAD elements interactively from the oriented images, especially cylinders of monitored pipes. This second approach overcomes the traditional need for post-processing of a scanner's point-cloud, which is not a trivial or standardized task and may require special algorithms (Bosche and Haas 2008) to detect the geometric elements within the point-cloud. However, some interaction and manual control is required.

The laser scanning process implies the deployment of the laser scanner station inside the building under construction due to its scanning range and precision. Once the area to scan has been determined, the user must plan the positions of the successive stations. This decision is made by considering different factors, such as scanning range, wanted precision and accuracy, and objects occlusions. When the scanning layout plan has been established, the last task to perform prior to mobilizing the scanning station is to determine the position of the registration targets. The user must position the targets in the scanning environment by making sure that at least three of those targets will be in common between the first scan and the next. This process will ensure the success of the registration step which assembles the set of scans into one unique point cloud that represents the scanned area. Once all those preliminary tasks have been performed, the user can mobilize the station. A power source, which is usually available on site, is required to enable the laser scanner. At this point, the scanning process can be performed. The scanning time depends on the chosen resolution for the acquired point cloud. Table 4 provides the scanning time for each choice of resolution.

Table 4: Laser Scanner Resolution Specific Characterizations

Resolution	Scanning Time (min)	Number of points in the generated point cloud (Millions)	Eye Safety Distance (m)
1/10	1.11	7	0.3
1/8	1.74	11	0.7
1/5	4.44	28	1.0
¼	6.94	44	1.3
½	27.78	175	2.5
1	111.11	700	4.9

When the point cloud has been acquired and saved in the database, the station can be shutdown, moved to the next location of the scanning layout plan, and set up again for the next scan. Table 5 provides the average estimated time spent on every task constituting the data collection and processing of both laser scanning technology and photogrammetry from the average of 150 observations. After the acquisition of every individual point cloud representing the pieces of the scanned scene, the user has to assemble those point clouds into one sole point cloud representing the entire area. A point-cloud processing software is provided with the scanner and is used to register the point clouds. The target registration is designed to merge the point clouds into one. To do so, 3 common points must be found between two different point clouds to be able to merge them together.

Table 5: Labour Hours for Data Collection and Processing

Laser scanning		Photogrammetry	
Activity	**Time**	**Activity**	**Time**
Data acquisition training	2h	Data acquisition Training	1h
Software training	1 week	Software training	4 weeks
Calibration	N/A	Camera calibration	1 hour (once per project or every few months)
Establishing the layout plan to scan	10min	Establishing the layout plan to photograph	10min
Setting up the station	10min	No station	
Putting up the targets	3min	Putting up the targets (not always needed)	3min
Point-cloud acquisition	10min	Picture acquisition	10sec
Moving the station to next location	5min	Moving between two shoots	5 sec
Merging 2 scans together (data processing)	5min	Data processing of 2 pictures	10 min

The photogrammetric data acquisition approach is very systematic, keeping in mind a few basic rules to ensure a quality output. On the field, overlapping images with good quality takes fraction of second per image; however, there is the overlapping photography mandate of shooting large numbers of images with small separation distances especially in case of medium field of view and low optics quality. Two photography techniques can be applied to overcome these limitations. The first is the careful use of tilted images, and the second is lowering the camera close to the ground. Ideally, a high quality lens of wide to super-wide angle will provide a complete coverage with minimum number of images. A trade-off between camera and lens specs versus quality, coverage and price which vary from one application to another and from project to another. There is no special eye-safety or special health precautions required for dealing with the camera during data collection. Camera calibration needs to be conducted once per project or once every few months for long time projects. With a growing experience, the photogrammetric data acquisition becomes faster and faster. However, data processing is still longer for photogrammetry no matter how much experience the user has.

Data analysis and processing is more time consuming than data collection. The user needs to interactively select settings and make decisions all the time, especially in cases of low quality optics where the output quality may change from one image to another. These decisions for example could be statistical for blunder detection and removal or even to raise the project quality or geometrical by adding or even removing some match points or control points if any. Another kind of decisions is the selection of suitable computational depth of field and optimal density versus time and required accuracy. Additional kind of decisions could be removing one image or pair from processing or adding one image or pair to processing. Also, each image may have an overlap with multiple images at the same time, the data redundancy provide the advantage of generating more point-clouds from the very same data sets, however, the excess of data may sometimes cause confusion. Loosing images in intermediate parts within the long strips or blocks of several strips of images needs careful office processing to avoid the need to return to the field.

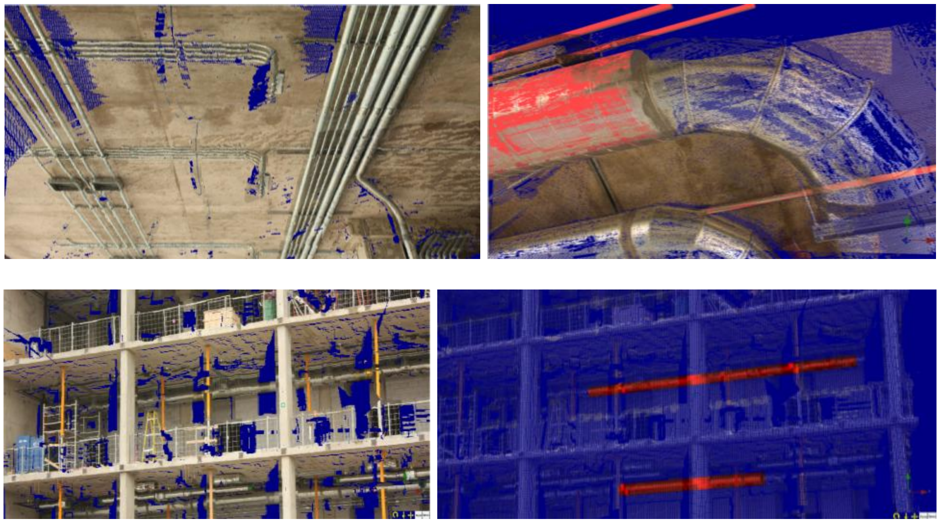

Figure 1: Photogrammetry: fusion of several interior point clouds (up-left), generation of CAD pipes and fusion to point-clouds (up-right), 1st technique output: Point-cloud (down-left) VS 2nd technique output: CAD pipe-objects (down-right)

Figure 1 and 2 show examples of outputs from both photogrammetry and laser scanning technology. From experience, it was established that the number of scans required to model an entire building floor is 12, whereas 150 to 200 pictures are required when using photogrammetry.

3.2 Equipment Cost

The tested camera and lens currently cost together about $600 CAD. Concerning the laser scanner, the equipment cost is a consequent issue. The scanner itself without any additional equipment cost $83,000 CAD 3 years ago. The additional package including the software licence, tripod, scanner battery and case, and a 3-day training session, make the total cost reach $112,000 CAD.

Figure 2: Laser scanning: point cloud (left), fusion of several interior point clouds (right)

3.3 Portability

The portability of the laser scanning equipment is an important inconvenience. The technical sheet indicates that the laser scanner weighs 14.5kg, which does not include the additional equipment that are required, such as laptop, targets, extension cord, and what is needed to establish the eye safety distance perimeter around the scanner location. Carrying all these equipments is very time-consuming if they are not stored directly on site, and even then at every change of laser scanner location the whole station must be relocated. Ultimately, the relocation of the station (which is represented by step 5 followed by step 2 in the following table), is as time-consuming as the scanning step in the whole data acquisition process, with 10 minutes each. Table 6 shows the distribution of time consumption mostly due to the laser scanner equipment portability: tasks 2 to 5 are the ones repeated at every relocation stage. These estimates were made from the average of 150 observations.

Table 6: Time Allocation for Laser Scanner Equipment Portability

Step number	Activity	Time spent
1	Establishing the scanning layout plan	10min
2	Setting up the station	10min
3	Putting up the targets	3min
4	Point-cloud acquisition	10min
5	Moving the station to next location	5min

Photogrammetric data acquisition is almost one repeated step which is shooting overlapping images. Cameras are portable by nature. One can even shoot an image for a remote surface using a zoom-lens without moving if required. Shooting a single image takes usually takes a few seconds. No tripod or equipments were used during data collection other than the camera.

3.4 Training & Expertise

The use of a laser scanner requires training on both on-site point-cloud acquisition and point-cloud data processing. A 3-day training session is offered at the purchase of the equipment to deal with data acquisition. However, a certain experience is required when it comes to identifying the laser scanner setup locations as well as the target locations to ensure that the acquired point-cloud can be related to other point-clouds. The user's experience is handy when it comes to being sure that such a problem will not occur. That experience is built up with time: a few weeks making those mistakes can provide that experience. An additional week of training is needed for the user to acquire all the necessary experience to deal with point-cloud data processing by merging all the different point-clouds into one. That experience will include dealing with registration problems such as low-resolution target and target occlusion that are the major problems in the point-cloud creation process.

The experience in photogrammetric is a different process and takes relatively more time; it accumulates through iterative processes comprising of practical applications and revision of theoretical bases in related disciplines, e.g., stereo-vision, optics, photography, math and geometry among others. For example, the best utilization of any specific camera needs understanding of the physics behind the large number of camera settings at one level, in another level, the geometry of image acquisition has effect on the final output because in the core of any photogrammetric engine there are a number of geometrical constraints that must be satisfied, the error propagation through the several built-in computation modules has theoretical correlation with relative relationships between images, and consequently on the final output. Quality of the images is important as well because all computations are based on image data; understanding the photography process, camera settings and digital camera advantages and limitations is fundamental. Understanding of selecting the suitable lens among large number of alternatives is also required. The understanding of at least the basics of inherent formulations of photogrammetric sensor modeling is among the requirements; such requirements assumes that the photogrammetrist has a special expertise for best data analysis, the longer the experience the faster and better the output. So to summarize the needed training in order to use the basics of the photogrammetry technology, the user needs some theoretical knowledge of about 20 hours spent studying, some data acquisition training of an hour, and software training for a minimum of 4 weeks.

3.5 Constraints

There are a number of constraints associated with using these technologies on a construction site. The first package of constraints concerns the weather conditions during which the laser scanner is being used. The ambient temperature must be comprised between 5°C and 40°C and the humidity non condensing. The most important constraint of all is the eye safety distance concerning the laser beam: depending on the purpose of the laser scanner use (as-built data collection or progressing tracking data collection), a certain resolution is to be chosen prior to the scanning process. This choice will involve a different eye safety distance requirement. Establishing a safety perimeter around the laser scanner on the construction site can be challenging, keeping in mind that construction workers might be on site while scanning, which involves restricting their working area for the time of a scan collection. Another constraint is the target positions. For a point cloud to be useful, it has to be referenced into a known space coordinate system, which involves placing targets on scene that can be seen from another point cloud acquisition location. Point-clouds are usually acquired in streak on site before any data processing is done, which means that if a point-cloud in the middle of the streak cannot be related to the others, a long time will be spent on manually merging those clouds into one common coordinate system. Thus, those targets sometimes have to be placed in difficult-access location and not to be removed until the two point-clouds have been acquired. The last practical constraint concerns the energy alimentation of the station which can be problematic at the early stages of construction. The scene lighting is not a constraint for a laser scanning acquisition that relies on a laser beam travelling time such as the FARO LS 840.

In terms of the photogrammetry technology, the accuracy of the generated point-cloud varies with the variations of camera relative positions to each other, and to the reconstructed surface, the quality of the lens had some impacts on the final output, for example less number of images could be taken with higher quality wide angle lenses. The depth of the field, (Min-Max) distance from the camera was affected by the size of Air-conditions ducts and influenced the accuracy to some extent, in the meantime, its reflective materials and its holding frames affected the imaging process due to three main factors: (1) its closeness from the camera itself made a random dispersion of light, (2) its size compared to the other pipe-works exaggerated the depth of field compared to camera distance, and (3) there were rare to minimum control points that could be distinguished under the applied configuration because the ducts were like an irregular mirror surface, resulting in positioning the camera very close to the ducts when acquiring pictures; about half the area of each image had no control points or good feature suitable for stereo-matching and orientation process, fortunately the severe effect was on parts covered by these ducts only when the images taken from close distance. It is recommended in similar cases to follow the following: (1) shooting the images from a larger distance, (2) using a lens of wider angle, (3) using higher resolution camera to compensate for the larger distance effect, and (4) using a polarizing filter to minimize the mirror effect of reflecting surfaces. Also, shooting tilted images instead of parallel images with respect to the object surface needs the consideration of the geometrical effect due to perspective projection; that is as the angle of tilt increases the coverage dramatically increases but the accuracy in the meantime changes dramatically from one side to another, this can be exploited sometimes as an advantage by selecting the suitable overlapping to gain wider coverage and high accuracy. Fortunately, using another photogrammetric technique enabled the production of as-built ducts directly from the images independent of point-cloud generation. All those previously stated constraints affect the data processing. The main issue when processing the data is to be able to find common points between pictures, so if one constraint is not respected, then the overall image quality is affected, thus reducing the chances of finding those needed common points. Another issue considering data processing addresses the computational performances of the lab installation, a minimum of 4Go of RAM is recommended to obtain a point-cloud output within a reasonable amount of time.

4. Conclusions and Recommendations

In conclusion, laser scanning technology has a few key advantages over photogrammetry that make it preferable in some situations: (1) a lower training time, (2) its resolution up to 700 million points, (3) it can scan actively into dark and shadowed areas and (4) a lower processing time to obtain a point-cloud. However, the laser scanning technology also has some disadvantages that could potentially shift the balance in favour of photogrammetry: (1) a high purchasing cost, (2) a bad portability and (3) constraining environmental and weather conditions recommendations.

The use of the photogrammetric point-cloud generation approach may include simple data collection with the following advantages: (1) lower cost, (2) cameras can work from an unstable platform using affordable lenses with anti-shake image stabilization technology, (3) cameras can image almost any tiny size textured objects using suitable lenses for the task, (4) cameras can scan objects at any distance ranging, from centimetres to hundreds of meters, (5) no eye safety or health issues, (6) can work at all temperatures, does not require any interference with workers or machines, (7) imaging can be repeated as many times as required, (8) seamless upgrading of the system capability over time as technologies advance and as budgets allow. The disadvantages of photogrammetry are: (1) the need for a long experience and training because of the several decisions to be made during data processing which vary from one case to another and from one expert to another and affect the final output accuracy and (2) the relatively long data processing time no matter how much experience the user has.

In conclusion, when cost is the main issue, the user might want to choose photogrammetry as the technology to utilize in order to produce point-clouds. However, when training time and expertise are problematic, then the laser scanning technology seems more indicated.

In the future, a better analysis of the overhead associated with relating and managing scan data needs to be conducted.

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