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MOBILE LASER SCANNING FOR INDOOR MODELLING

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ABSTRACT:

The process of capturing and modelling buildings has gained increased focus in recent years with the rise of Building Information Modelling (BIM). At the heart of BIM is a process change for the construction and facilities management industries whereby a BIM aids more collaborative working through better information exchange, and as a part of the process Geomatic/Land Surveyors are not immune from the changes. Terrestrial laser scanning has been proscribed as the preferred method for rapidly capturing buildings for BIM geometry. This is a process change from a traditional measured building survey just with a total station and is aided by the increasing acceptance of point cloud data being integrated with parametric building models in BIM tools such as Autodesk Revit or Bentley Architecture. Pilot projects carried out previously by the authors to investigate the geometry capture and modelling of BIM confirmed the view of others that the process of data capture with static laser scan setups is slow and very involved requiring at least two people for efficiency. Indoor Mobile Mapping Systems (IMMS) present a possible solution to these issues especially in time saved. Therefore this paper investigates their application as a capture device for BIM geometry creation over traditional static methods through a fit-for-purpose test.

1. INTRODUCTION

1.1 Motivation

Recent years have seen an increase in demand for detailed and accurate indoor models. These models are, for example, derived according to the OGC standard CityGML LoD4 or national Building Information Modelling (BIM) standards. To obtain sufficient level of detail and accuracy the modelling process needs to be based on reliable measurement data. The data source of choice for high-quality models are point clouds acquired through laser scanning (Budroni and Boehm, 2010; Rusu et al., 2008).

To date the tool of choice for data collection to derive such models is a static terrestrial laser scanner. In the traditional surveying workflow the instrument is placed on a tripod on several pre-determined stations. Tie points are physically marked using artificial targets. These tie points provide a common reference frame, so that data from separate stations can be registered. The process is typically combined with total station measurements to obtain control information for the tie points, measure the position of the stations or a combination of both. All collected data (tie points, station data) is then entered into a network adjustment in a post-processing step to obtain optimal results.

While this procedure is expected to provide the best accuracy for the resulting point cloud it has some obvious draw-backs. The manual placement of the laser scanner on multiple stations interrupts the scanning and thus reduces the scanning rate (points per second). The placement of tie points requires additional manual effort. The combination with a second instrument increases cost and again manual effort. Furthermore the surveying process requires skilled personnel, e.g. to pick optimal stations, good network design for marker placement, etc.

In contrast, for large-scale outdoor point cloud acquisition mobile laser scanning (MLS) is now commonplace. A typical mobile LiDAR system consists of one or more laser scanners mounted on vehicle. The trajectory of the vehicle is determined using GPS and a high-grade IMU. Often a wheel rotation sensor is added to obtain odometry data. Such systems have been commercially available for several years and can achieve an accuracy of a few tens of millimetres (Barber et al., 2007; Haala et al., 2008). Their advantage is the rapid acquisition of large volumes and coverage of large areas in a small amount of time. This high data acquisition rate can be achieved since the data collection is uninterrupted and the mobile platform is continuously moving forward covering more ground.

Unfortunately this type of system cannot be directly used for indoor applications. This is largely due to their reliance on GPS which obviously is not available indoors. Also the high cost of these systems often due to the high-grade IMU is prohibitive for building surveys.

1.2 Indoor Mobile Mapping Systems

Indoor Mobile Mapping Systems (IMMS) present a possible solution to these issues especially in time saved. IMMS are much like the vehicle based mobile mapping systems used for rapidly capturing linear assets by combining sensors onto a kinematic platform. However the key difference is in positioning. Mobile mappers on vehicles primarily make use of GNSS; a system that is unobtainable indoors. Therefore other methods are necessary indoors of which Simultaneous Location and Mapping (SLAM) is the most prominent.

Given the time intensive process of standard surveying with static laser scanning and the speed of capture of IMMS' it was considered worth investigating whether these systems provided data that was fit for purpose for BIM geometry creation for the significant time saving that they achieve. This paper

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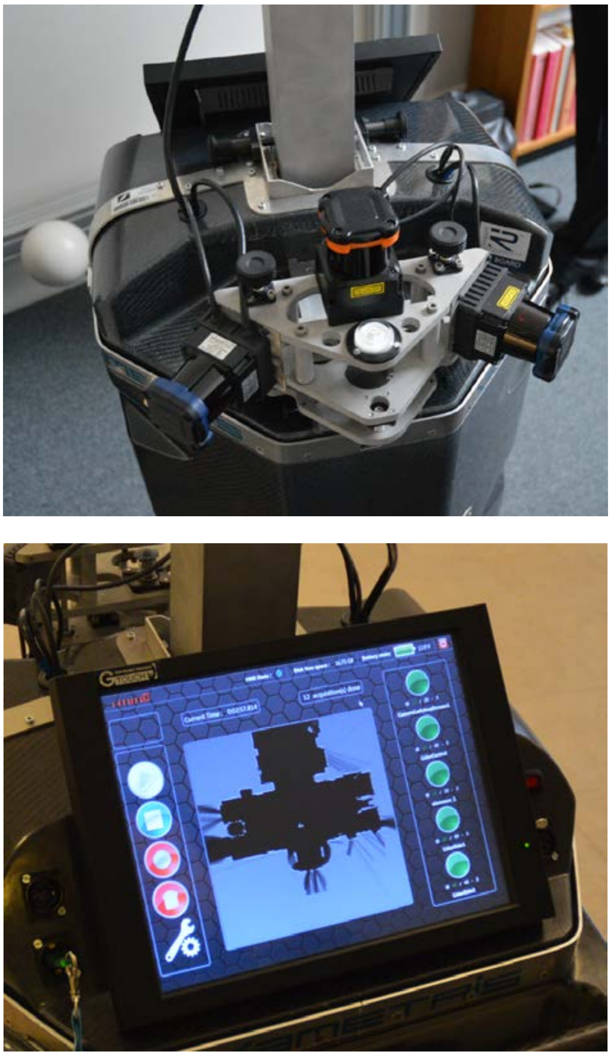

Figure 1: i-MMS scanner array (top) and control screen showing SLAM result (bottom).

investigates two systems of very different form factors: the i-MMS from Viametris and ZEB1 from 3D Laser Mapping/CSIRO and assesses them against a traditional survey workflow with the Faro Focus laser scanner both in terms of the point cloud quality as well as the ability to create accurate parametric geometry for BIM.

2. SYSTEMS UNDER INVESTIGATION

Following the success of vehicle-based mobile mapping systems to rapidly acquire linear external assets by combining sensors, there has been a recent trend towards developing solutions for the internal case to reduce time of capture associated with normal static setups. Two form factors have prevailed so far: trolley based and hand held. Trolley based systems provide a stable platform and avoid placing the burden of carrying the weight of sensors on to the operator. Hand held systems offer more flexibility as theoretically anywhere the operator can walk can be accessed. This means areas that are impossible to scan with trolley systems or difficult with static methods, such as stairwells, can be captured relatively easily. In this study one of each system type is represented.

2.1 Viametris i-MMS

The trolley based system is the i-MMS from Viametris (Figure 1) which incorporates three laser line Hokuyo scanners and Ladybug spherical camera from Point Grey (Viametris, 2013).
The three scan heads are positioned as in Figure 1 on a sliding mount to allow for compact storage for transportation to and from the work site. The two Hokuyo with blue heads actually provide the point cloud while the upright orange headed scanner provides the data for the SLAM. The configuration of the blue Hokuyos at the time of this test were set on the array as in Figure 1, with the sensor on the left pointing down and the one on the right pointing up with respect to the figure. This setup was a change by Viametris from an earlier implementation where both scan heads pointed down which had led to poor ceiling detail due to the limited 270° scan swath of the Hokuyos used.

Instead of relying on GNSS and IMU's, the i-MMS makes use of Simultaneous Location and Mapping (SLAM) a robotics technology to perform the positioning (Smith and Cheeseman, 1986). Currently this is only implemented in 2D restricting the system to measurement in areas with no significant height change and is based on that outlined in (Garcia-Favrot and Parent, 2009).

The instrument is controlled via a touch screen that interfaces with the on-board computer and displays the online 2D SLAM result while scanning (Figure 1) as well as status lights for the data streams from the sensors and SLAM solution itself. This allows for feedback to the user of any experience level when any component of the system is malfunctioning through the use of traffic light colours.

2.2 3D Laser Mapping/CSIRO ZEB1

The second IMMS under test is the ZEB1 from 3D Laser Mapping developed by the Australian research group CSIRO (Figure 3). ZEB1 takes the form of a hand held post and spring with line scanner and IMU attached. The ZEB1 uses the same Hokuyo scanner as the i-MMS but adds a small IMU under the LIDAR sensor to aid the location solution (3D Laser Mapping,

Figure 2: The ZEB1 handheld unit (left) and the control laptop.

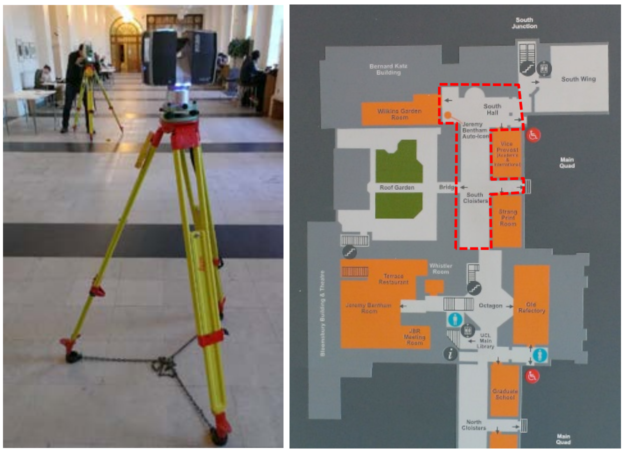

Figure 3: Control survey (left) and map (right) of the study area.

2013). The handheld device is tethered to an Ubuntu netbook that performs the data storage and real-time processing as well as a battery pack for power.

To operate, the ZEB1 must be gently oscillated by the operator towards and away from them with an online 6 degrees of freedom SLAM algorithm fused with the IMU to provide an open loop solution (Bosse et al., 2012).

3. TEST DESIGN

This paper does not attempt to perform a laboratory based accuracy analysis of the scanning systems. Rather we want to compare the systems in-the-field, i.e. assess their performance in a real-world application. This however still requires a careful test design. We need to establish a solid reference to which we can compare the results obtained from the system. Thus we have prepared a test scenario and established a control survey, which are described in the following paragraphs.

3.1 Study Area

The area under study of this project is the ground floor of the South Cloisters in UCL. It is depicted in Figure 3. It is important to mention some specific characteristics of the area that affect the scanning and modelling process and they will become apparent at a later stage. The testing environment can be roughly described as a corridor with dimensions of approximately 39×7×5 metres as shown in Figure 3, starting from the South Junction and ending before the Octagon Building of the Main Library. Adjacent to the right wall surface in the figure are offices with no access, therefore the overall wall thickness cannot be identified by laser scanning measurements. On the other side, adjoining to the left wall surface there is an open area roof garden free of clutter and the wall thickness can be measured

3.2 Reference Scan

The static laser scanning measurements were made using the Faro Focus3D laser scanner (Figure 2), which uses the phase shift principle to measure distance. The Faro Focus 3D is a state-of-the-art scanner commonly used for building surveys. Its light weight and compactness have made it a popular choice for indoor work. The characteristics of the scanner have been investigated by (García-San-Miguel and Lerma, 2013).

Before the commencement of the measurements, the area was examined in order to determine the best setup locations and time, so as to minimize data voids as well as artefacts from obstructions and pedestrians respectively. Bearing in mind the capabilities of the Faro Focus3D and the required accuracy, the distance between each of the setups and the scanned objects was approximately 6 m, while the resolution was selected to 1/8. Therefore, each scan lasted about 3:44 minutes and 10 million points were acquired from each position. In general, the whole area was covered in 12 scans in about 5 hours, from 5 pm to 10 pm, including the surveying of the target and scan locations. From the total 12 scans, 2 scan positions required for the east outer wall of the building were captured in order to determine accurately the wall thickness. Finally, 32 tie points were used across the area in order to register successfully the scans.

3.3 Network Analysis - Adjustment

The measurements in the field with the Leica Viva TS15 total station were followed by the processing of the data in LGO software, so as to estimate the accuracy of the established network. Particularly, the determination of the coordinates for the targets allowed the registration and georeferencing of the Faro scanner measurements, as well as the coordinates of elements surveyed and as a result the geometry of the area.

Leica Geo Office (LGO) 8.1 was used to process the data captured with the Leica Viva TS15 and the goal of the analysis was three-fold, depending on the three different tasks performed:

1. To estimate the accuracy of the established network in the area under study.
2. To determine the coordinates of the Faro Focus3D scanner locations and the target positions used for the registration and georeferencing of the 12 scans.
3. To determine the coordinates of specific elements captured during the measured building survey and as a result the geometry of the area.

4. SYSTEM COMPARISON

Using the laser scans from the control survey two comparisons could then be performed. The first was a cloud to cloud comparison, of the point clouds obtained with the mobile systems compared to the static laser scans. The second was a comparison closer to the intended application. We compared the BIM geometry derived from the point clouds of each mobile system to that derived from the control survey. The following two subsections present the results of these two experiments.

4.1 Point Cloud Comparison

4.1.1 Focus3D and i-MMS

The artefacts in the scans caused by people and glass were deleted in the Autodesk software Recap Studio and the registration of the two scans was performed using CloudCompare (Girardeau-Montaut, 2011). The ICP algorithm was used for the registration of the two point clouds. The benchmark model is the Faro data and the compared one is the Viametris. After the registration the cloud to cloud differences of the two scans were compared using both techniques presented by CloudCompare: Height Function and Least Squares Planes. The results and Figures are presented below.

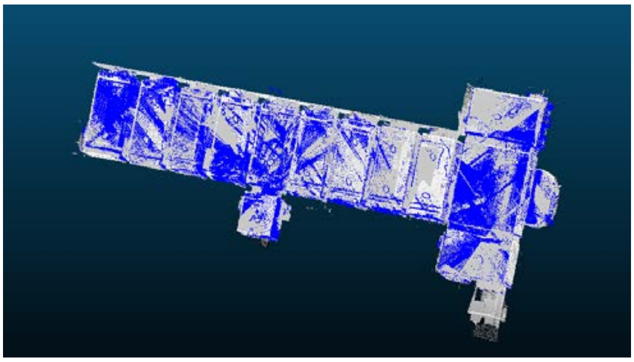

Figure 4: Registration of the Focus3D and i-MMS point clouds

		Deviation Method	
	ICP algorithm	**Height function**	**Least Squares planes**
RMS (m)	0.0253	-	-
Mean (m)	-	0.0278	0.0264
Std Dev. (m)	-	0.0545	0.0421

Table 1: Results of the ICP registration and the residual deviations of the point cloud comparison for the i-MMS system.

4.1.2 Focus 3D and ZEB1

Again the same process, whereby the data was registered together with the ICP algorithm in CloudCompare and the cloud to cloud differences were assessed.

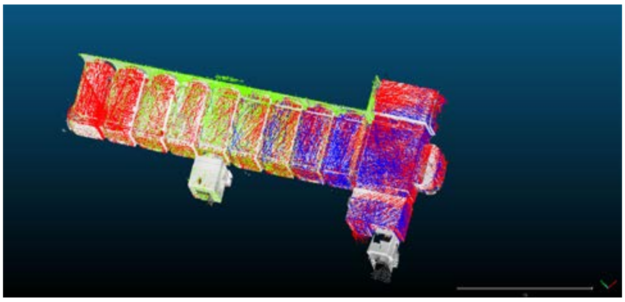

Figure 6: Registration of the Focus3D and ZEB1 point clouds

		Deviation Method	
	ICP algorithm	**Height function**	**Least Squares planes**
RMS (m)	0.0259	-	-
Mean (m)	-	0.0364	0.0320
Std Dev. (m)	-	0.1880	0.1091

Table 2: Results of the ICP registration and the residual deviations of the point cloud comparison for the ZEB1 system.

For both systems the residuals after point cloud registration is within very few centimetres. Overall the results of the i-MMS agree slightly better with the Focus3D data.

4.1.3 Model comparison

With the point cloud data from the various instruments transformed to the same coordinate system through the ICP method, the parametric modelling could be performed from these data sets to gain the geometry for a BIM. This process was carried out in Autodesk Revit 2014 which required the point clouds to be converted into the proprietary RCS format before import to Revit.

In Figure 5 distances extracted from the created models derived from Focus3D, i-MMS, ZEB1 and TS15 data are shown. We can see that the distances deviate by a few centimetres. Figure 7 shows some detail in the point clouds. We can clearly identify some level of noise. However the models derived from the point cloud agree well.

The distances show the larger scale agreement of the measurement. The quality of the model in detail can be assessed by looking at individual architectural features. We have chosen doors and windows as they are the most common features. Table 3 and Table 4 show the average and extrema of the deviation between the models. They also show a deviation of the models derived from the reference scan to a classic total station survey and tape measurement. This indicates a general uncertainty in modelling from point clouds, related to the density of the point cloud.

Figure 5: Distance measurements extracted from the BIM. Left to right the models derived from Focus3D, i-MMS, ZEB1 and TS15 are shown. All measurements are in millimetres.

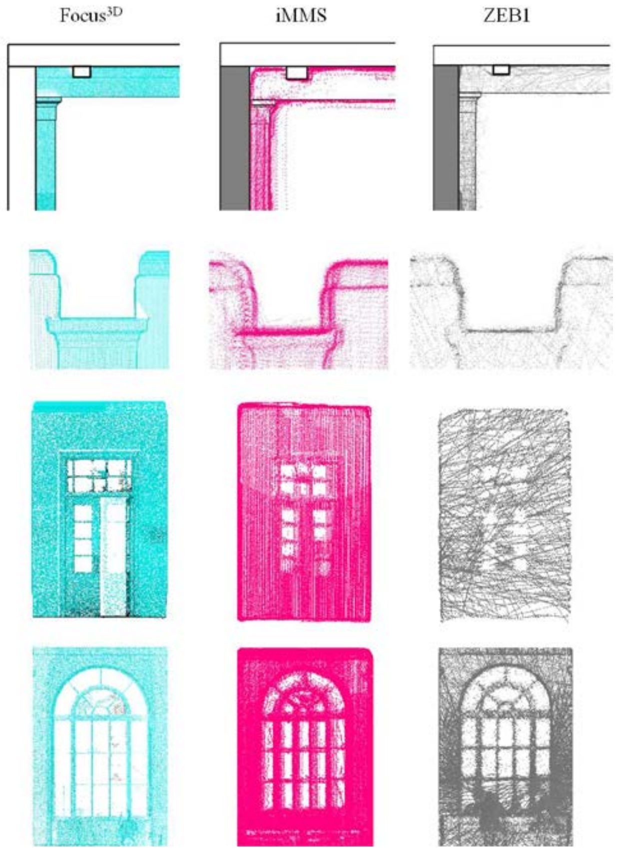

Figure 7: Detail of the point clouds and the model (top row solid lines) for the systems; in the same sequence as before.

	Differences of door elements			
Model Comparison	**Mean Δ Width**	**Mean Δ Height**	**Max Δ Width**	**Max Δ Height**
Focus 3D &				
i-MMS	5.1 cm	4.4 cm	26.0 cm	16.0 cm
ZEB1	6.4 cm	4.6 cm	42.0 cm	13.0 cm
Leica TS15	1.3 cm	2.0 cm	3.0 cm	6.0 cm
Leica TS15 &				
i-MMS	5.9 cm	5.0 cm	21.5 cm	10.7 cm
ZEB1	7.0 cm	4.9 cm	42 cm	10.1 cm

Table 3: Differences based on 10 door elements

	Differences of window elements			
Model Comparison	**Mean Δ Width**	**Mean Δ Height**	**Max Δ Width**	**Max Δ Height**
Focus3D &				
i-MMS	3.5 cm	2.7 cm	21.0 cm	15.0 cm
ZEB1	5.8 cm	4.7 cm	39.0 cm	28.0 cm
Leica TS15	1.9 cm	2.1 cm	3.4 cm	4.0 cm
Leica TS15 &				
i-MMS	5.0 cm	3.3 cm	25.0 cm	19.0 cm
ZEB1	6.9 cm	3.9 cm	30.0 cm	40.0 cm

Table 4: Differences based on 7 window elements

5. CONCLUSIONS

The systems under investigation are of a novel class of scanners. These types of systems are still at a very early stage. However, we can already identify use cases, where these systems can deliver suitable results, such as asset capture and facility management. For applications requiring the highest level of accuracy such as survey engineering and monitoring where millimetre level accuracy is required the systems can currently not perform adequately.

Overall the systems have provided results that deviate only a few centimetres from the reference survey. Considering the enormous savings in time this is remarkable. Future developments for this category of systems have the potential to significantly impact the current practice.

6. ACKNOWLEDGEMENTS

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