INVESTIGATION OF THE SUITABILITY OF A PERSONAL LASER SCANNING DEVICE FOR THE MONITORING OF SMALL WATER BODIES

R. Blaskow [1]*, A. Eltner

[1] Institute of Photogrammetry and Remote Sensing, Technische Universität Dresden, Germany
robert.blaskow@tu-dresden.de

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ABSTRACT:

This study investigates the applicability of a personal laser scanner (PLS) in surveying small creeks in urban areas. The surveying of the creek geometry can be done only with the PLS system or as a combination of terrestrial PLS measurement and airborne image sequence acquisition by an uncrewed aerial vehicle (UAV). For both methods, georeferencing is performed using RTK-GNSS. Based on the combination of the datasets and from additional terrestrial laser scanning (TLS) comparison, conclusions can be drawn about the accuracy of the PLS measurements. Point-to-mesh based distance calculations between the PLS and UAV measurement showed a variation of +/- 0.10 m (96% of points) at selected naturally vegetated sites. The comparison of the PLS and TLS data set revealed differences with a standard deviation of 0.02 m at solid natural (tree trunk) structures and ground areas. The calculated differences grow with increasing distance to the PLS trajectory.

1. INTRODUCTION

1.1 General Instructions

In order to develop small streams and creeks for the achievement of a good ecological water status according to the European Water Framework Directive a suitable data basis must be available enabling appropriate measure planning decision making. Since data collection is very time-consuming and cost-intensive, especially considering the many small second- and third-order water bodies, one goal of the research project creek 4D was the development of a measurement procedure, which enables an efficient mapping of small water bodies. The environment of the creeks, which were surveyed, varied considerably from natural, overgrown surroundings (Figure 1 left) to paved and canal-like forms (Figure 1 right). These characteristics represented a large spectrum of urban creeks.

Figure 1. Different Creek environments. Naturally overgrown (left) and artificially canalized (right)

The surveying of shoreline areas depends on many factors such as extent, water depth or accessibility. If, for example, strict regulations prevent a direct access of shore areas but there is sufficient water depth, shore areas of lakes or rivers can be surveyed with mobile mapping systems carried by normal sized boats. Schneider and Blaskow (2021) illustrate survey capabilities of inaccessible shoreline areas of an open pit lake by using a RIEGL VMZ mobile laser scanner system (MLS). For surveying shorter river sections or at shallower water depths, the use of a boat-mounted MLS system may be uneconomical or not possible at all. In these cases, an uncrewed water vehicle (UWV) as measurement platform can be a suitable alternative. Sardemann et. al. (2018) developed and deployed a multi sensor UVW to survey the shoreline of medium-sized rivers. Thereby, cameras and lidar sensors were used.

The work presented here is intended to measure streams or creeks of small extent and shallow depth, thus hindering accessibility by water vehicles, making the hand-held personal laser scanner (PLS) system a more suitable measurement platform. The usage of PLS as sensor-systems to capture geometric data increases as they can be used as a substitute for traditional surveying methods such as terrestrial laser scanning (Hess and Ferreyra, 2021). Another area of application for a PLS system is the generation of geometric data for building information models (BIM) or in cultural heritage research (Oniga et al. 2021). In addition to mapping buildings or other structures, PLS systems can be used to survey natural structures, e.g., for forest planning (Sophia et al., 2021). Gollob et al. (2020) show how a PLS system can be used for the generation of forest inventory sample plots.

Regarding the accuracy of the PLS acquired point cloud, the measurement environment plays a special role. SLAM (simultaneous localisation and mapping) based systems – such as PLS – require a fixed, i.e., not changing, surrounding areas. In terrestrial laser scanning, a dynamic measurement environment causes errors only in the resulting point cloud. But for PLS a non-rigid measurement environment during a survey also affects the trajectory determination, which underlies the 3D point cloud reconstruction. In general, it must be considered that when using SLAM, that due to drift phenomena of the inertial measurement unit (IMU) sensors used, as well as potentially insufficient information content in the 3D point clouds for reliable 3D point cloud registration, lower accuracies are possible (Cadena et al., 2016).

In this paper, the accuracy of a PLS generated point cloud was addressed in the context of surveying small water bodies. The focus was on the investigation of the influence of the measured complexity of the recorded environment. The paper is organized

* Corresponding author

as follows. First, the study areas and the data acquisition procedure are explained, which is then followed by details on the processing of the data. Afterwards, the results are presented and discussed in the context of micro water body surveying, eventually followed by a conclusion.

2. STUDY AREA AND DATA AQUISITION

2.1 Field campaigns to capture the data

The water depth of the observed small urban creeks had a maximum of 0.75 m, hence the creek axis was accessible by foot in most cases. Two study areas were investigated. Study area 1 is a 350 m long section of the stream Koitzschgraben, which is located in the Southeast of Dresden (Figure 2). It was selected because it is well suited for UAV flights. Data were collected in March, prior to leaf emergence and main vegetation growth.

Figure 2. Study area 1. Part of the Koitzschgraben located in the South-East of Dresden.

The second study area, which is also located in the Eastern part of Dresden, consists of the two test sites 2A und 2B (Figure 3). Test site 2A was surveyed in July with vegetation in full coverage (leaf-on). The area covered a section of the Koitzschgraben, which was about 70 m long. It is advisable to measure creeks and their surroundings in the leaf-off season due to the otherwise usually dense vegetation. However, the campaign was carried out with full vegetation cover to find out whether measurements were also possible during leaf-on season. Due to the higher instability (e.g., moving leaves) and complexity of the environment, the walking length was significantly shortened to enable sooner loop closures. Test area 2B covers an approx. 700m long section of the Koitzschgraben. The survey was carried out in March 2022 under leaf-off conditions. Due to the length of the section, two overlapping partial measurements were carried out (Figure 3, solid and dashed red lines).

Figure 3. Study area 2. (A) Short part and (B) long part of the Koitzschgraben located in the East of Dresden.

The focus of the geometric mapping was on the near shore environment (creek axis + 15m) and hence the walking paths with the PLS device were selected as close to the creek axis as possible. Reference points to be measured were either included in the direct path or, if they were off the trajectory to be walked, were integrated into the measurement sequence by performing smaller sub-loops (Figure 5). Most creek sections are longer than the possible maximum duration of a single PLS measurement walk. Therefore, for data collection, the creeks to be measured were divided into smaller sections that were walked in closed loops with a certain amount of overlap. In this case, a closed loop means that the start and end points of a measurement are identical (Figure 4). Although it would theoretically be possible to map the individual creek sections with open loops, it was decided to measure them with closed loops. On the one hand, this should increase the stability of the SLAM processing and, on the other hand, it should enhance the data coverage, especially in areas where the river bank rises higher than the PLS system's carrying height. Thereby, we recommend to walk the outward path along the creek axis and the return path on the raised bank. To increase the stability of the SLAM calculation in these non-static environments, the single loop lengths were kept shorter than theoretically possible.

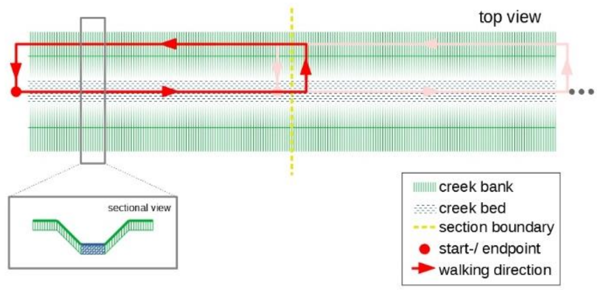

Figure 4. PLS data acquisition procedure to measure a creek

The georeferencing of the measurements can be done in several ways. In this study, two RTK-GNSS based variants were tested. In the first case, a conventional control point field was established and surveyed using RTK-GNSS. Subsequently, the PLS and UAV measurements were carried out. Finally, a second RTK-GNSS survey was performed as a check. In the second case, the measurement of the control points was carried out in parallel with the PLS measurement. For this purpose, a second person walked together with the PLS operator and measured a temporary control point with RTK-GNSS. Directly afterwards, the control point was measured with the PLS system. This process was repeated several times throughout the PLS measurement. The coordination between the two operators must work very well so that the person responsible for the RPs, e.g., does not walk within the measuring field of view of the PLS.

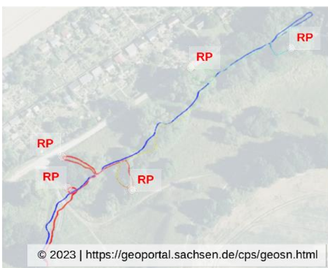

Figure 5. PLS trajectory at an exemplary creek with reference point positions

2.2 Personal laserscanner device

The PLS system used in this project was the ZEB Horizon from GeoSlam with an additional ZEB Cam used during the measurement campaigns (Figure 6). Especially the compact design (scan head + datalogger) was essential for the partly very rough terrain. With additional exchangeable battery packs, a long operating time could be achieved. The PLS system has a point capture rate of 300'000 points/s with a range measurement noise of +/- 30 mm. The maximum measurement distance of the system is specified by the manufacturer at 100 m, under optimal measurement conditions and 60-80 m under typical conditions (ZEB Horizon User Guide).

Figure 6. PLS System used, consisting of GeoSlam ZEB Horizon with optional ZEB Cam and GeoSlam Data logger.

The length of the walked loops is particularly decisive for a good quality of the resulting 3D data. In this project, the loop lengths walked with the ZEB Horizon varied from short durations of approximately 5 min long loops to maximum data capture intervals of 28 min long loops. The geo-referencing of the point clouds was carried out by centering the PLS system on control points measured by RTK-GNSS.

2.3 Data processing

The data post processing of the raw data was realized by using the GeoSlam HUB Software to enable the usage of the captured image data of the ZEB Cam. The result was a geo-referenced point cloud and the corresponding trajectory for each walked section. Further data processing and analysis was carried out with the open-source software CloudCompare.

3. METHOD

Additional sections with further comparative or reference measurements were surveyed besides the creek areas surveyed only by PLS and georeferenced with the RTK-GNSS. Thus, one case study consisted of a combination of terrestrial PLS measurements and an additional UAV flight of the creek area. The study 2A was a validation campaign in which the measurement area was first surveyed with the PLS system, followed by a large-area scan using terrestrial laser scanning. Extended loop measurements were carried out on a long creek section in Study 2B. The results of these measurement campaigns were used to derive information about the suitability of a PLS mapping system for small water bodies. The 3D point clouds of the UAV and TLS campaigns serve as comparison values. First, the data was pre-processed using the cloth simulation filter (CSF), developed by Zhang et. al. (2016) to separate the ground points from the higher vegetation points and from ascending structures. The point clouds were then interactively processed in a second step by manually editing areas that were too sparse or did not overlap. The analysis was based on cloud-to-cloud or cloud-to-mesh comparisons of interactively selected areas of the point clouds utilizing standard tools implemented Cloud Compare.

3.1 Combined PLS and UAV measurement

The aim of the combined campaign was to gain knowledge about the added value of extending a PLS measurement (Figure 7 centre) by an additional UAV flight (Figure 7 right) in case of a creek measurement. Both methods supplement each other theoretically very well in this application due to their complementary properties. An advantage of ground-based terrestrial PLS is the short distance to the area of interest, which results in a good coverage of the shore area. Furthermore, the laser scanning based method provides a better vegetation penetration during leaf-off season. However, ground-based PLS data acquisition in areas with steep slopes, offers limited terrain coverage due to the low height of the platform above ground. The UAV based mapping provides a higher coverage of the area of interest regardless of the slope of the terrain. However, during image-based UAV aerial surveys, trees, which are common for creek areas, lead to occlusion effects of the underlying surface.

The aerial survey was performed with a DJI Phantom 4 RTK consumer UAV. Circular targets with a diameter of 0.3 m were used as reference points in this campaign. They were measured by RTK-GNSS in two epochs, with a mean difference of 0.02 m, and could be used directly for the PLS system. In addition, they served in identical configuration as reference points for the structure from motion (SfM) based 3D point cloud reconstruction from the UAV imagery, which was carried out with Agisoft Metashape. The geo-referencing of the UAV image data resulted in an overall check point deviation of 0.01 m.

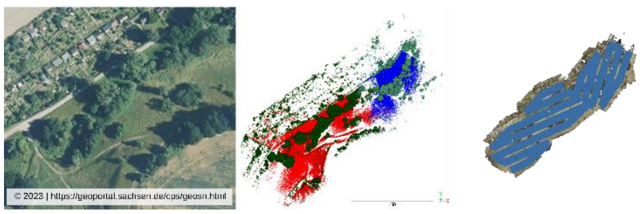

Figure 7. Surveyed creek area (left), generated PLS-data (centre) and UAV-data (right)

Since a small part of the creek was not accessible due to a private property, the PLS measurement was divided into two sections. The geo-referencing resulted in a control point RMS of 0.053 m for the longer section (Figure 7 centre, red points) and an RMS of 0.029 m for the second shorter section (Figure 7 centre, blue points). The duration of the PLS data capture of the first section was 12 min, which was almost twice as long as the measurement of the second loop.

3.2 Comparison to TLS reference data

In the measurement campaign 2A, a small creek section, already covered by PLS data, was also measured with a terrestrial laser scanner of higher accuracy (RIEGL VZ-400i). The PLS and TLS measurements were geo-referenced using RTK-GNSS and then compared by a cloud-to-cloud distance calculation.

3.3 Extended loop measurements in a natural environment

In campaign 2B, an approx. 700 m long section of an urban creek was measured to investigate the combination of a very long measurement duration in a natural environment. The area was divided into two sections, including a small overlap. In these sections the maximum duration recommended by the manufacturer was almost exhausted with loop lengths of ~28 min. Georeferencing was performed using the 2-person method (sect. 2.1). Each creek section was individually processed. Due to the high measurement duration and a relatively unfavorable distribution of the control points, the georeferencing could only be performed with a relatively low accuracy with an RMSE of 0.234 m and 0.126 m, respectively. This also resulted in decimeter-scale differences in the overlap area of the two point clouds.

4. RESULTS AND DISCUSSION

In this section the derived results are shown and discussed in the context of the usability of a PLS in creek surveying. Assertions on the accuracy are derived from the point-to-point and point-to-mesh comparisons.

4.1 PLS and UAV data fusion

The investigation of two data sets from UAV and PLS focused on a possible data fusion. Therefore, it was examined how well the data fit to each other or whether larger differences or systematic deformations exist between both data sets. Since the terrain surface is natural and partly overgrown, areas were interactively selected which have the lowest possible vegetation cover and which are distributed over the entire measurement area. The point cloud acquired from the UAV flight was meshed for the comparison. The point-to-mesh distance between PLS and UAV data amounted to a mean standard deviation of 0.04 m for selected meadow areas (Figure 8 top left). Thereby, 96% of the PLS points were within a range of +/- 0.10 m to the meshed SfM point cloud.

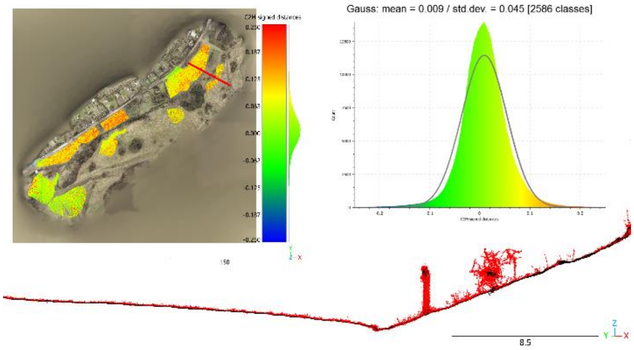

Figure 8. UAV based surface mesh overlaid with areas of the PLS measurement (top left), distribution of the cloud-to-mesh distances (top right) and cross section of PLS and UAV data (bottom)

In addition to the accuracy, area coverage plays an important role when supplementing PLS data with additional UAV data. To evaluate whether the additional effort can be converted into a concrete benefit, both data sets were meshed. Figure 9 on the left shows the meshed point cloud of the PLS system together with the two trajectories. A visual interpretation of the color gradient (blue = sparse / red = dense) shows that the density of the calculated mesh is high in the area along the walking path and decreases with increasing distance to the PLS trajectory. In contrast, the meshed UAV point cloud exhibits a homogeneous density distribution over the entire measured area. Both data sets were cleaned after meshing, i.e., border areas and redundant triangles were removed. Figure 9 shows that the terrain coverage of the UAV measurement is higher than that of the PLS.

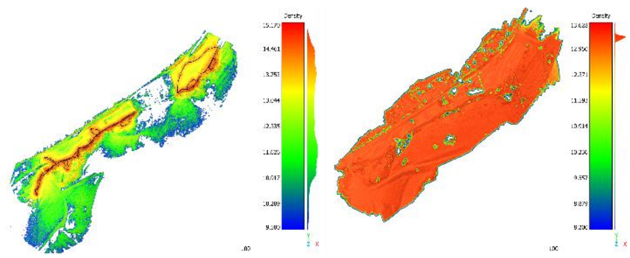

Figure 9. Terrain surface coverage of the PLS-data (left) and coverage of the UAV-data (right). Colorized according to surface point density.

Also, the summed area of the individual triangles of the meshes indicates a higher coverage of the UAV. Looking at the total area (Figure 9), the area of the UAV measurement totals to 42025 m², whereas the total area of the mobile mapping measurement adds up to 30735 m². This corresponds to an increase of about 27 %. Since this calculation also covers areas that are not part of the study area, the calculation is reduced to the relevant creek environment. Then, the area adds up to 18538.6 m² for the UAV measurement and 16230.7 m² for the PLS. This result corresponds to an area increase of around 13 %. The comparison of cross sections (Figure 8 bottom) and an analysis of the area coverage (Figure 9), showed that both data sets complement each other well and can be combined to fill gaps in the data and extend the coverage.

4.2 PLS / TLS data comparison

The comparison of raw 3D point clouds of natural environments is usually difficult. Particularly vegetation such as tall grass or wind-susceptible small to medium-high bushes can lead to high differences when comparing two datasets. In addition, deviations can occur due to the use of different measurement systems. In contrast to the PLS system, the TLS RIEGL VZ-400i, used for the collection of the reference data, is capable to measure multiple laser pulse returns. Therefore, depending on the vegetation density, the point cloud of the TLS also contains ground points underneath vegetation, whereas the PLS point cloud mostly contains the return pulses of the vegetation. Therefore, comparing PLS and TLS data in vegetation areas results in very large deviations that do not reflect the accuracy. For a more realistic assessment of accuracy, the comparison is therefore limited to areas of low vegetation cover. For this purpose, only deviations in the range of +/- 0.10 m are included in the comparison.

Table 1 summarizes the results of the cloud-to-cloud comparison. All three coordinate directions show relatively high minimum and maximum deviations (Table 1, columns 2-3). This can also be seen in Figure 10, especially in marginal areas as well as in areas with denser vegetation color-coded in red and blue.

	min	max	Pts in ±0.10 m	Standard deviation
	m	m	%	mm
X	-0.707	0.622	98.5	15
Y	-0.746	0.665	98.6	14
Z	-0.581	0.920	95.6	19

Table 1. Results of the cloud-to-cloud comparison divided into the coordinate system components.

If the calculated cloud-to-cloud differences are limited to a range of + / - 0.10 m, still 98 % (lateral) and 95 % (vertical) of the total number of points remain (Table 1, column 4). The resulting standard deviation of 0.015 m in the position deviation and 0.02 m in the height difference shows a good accuracy of the PLS measurement (Table 1, column 5).

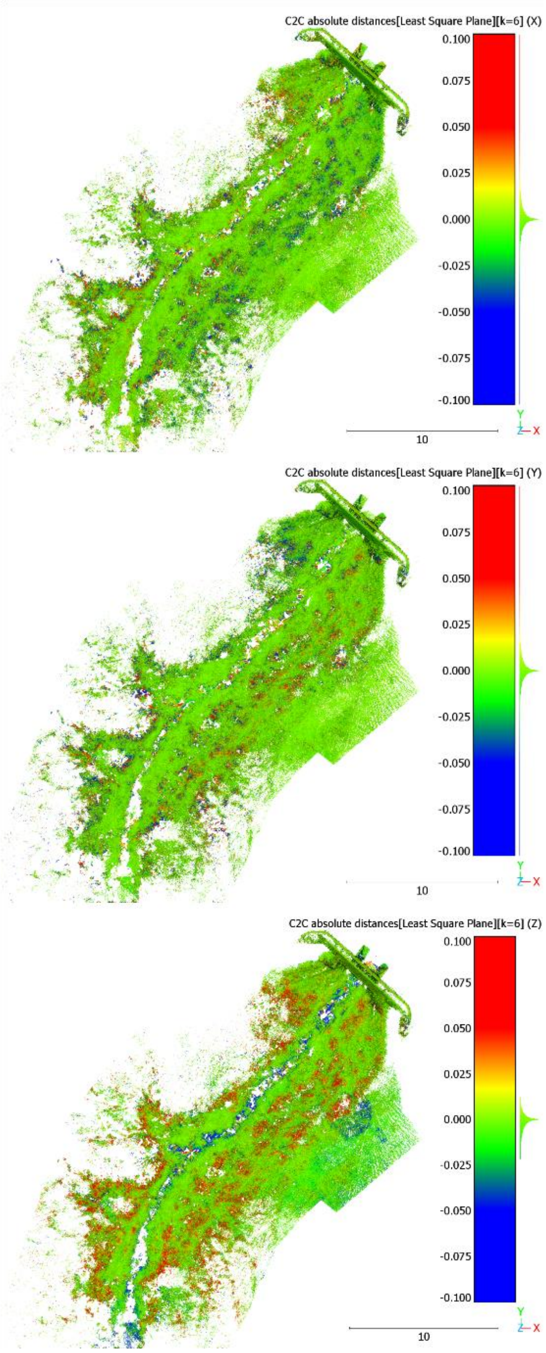

Figure 10. PLS point cloud coloured by point-to-point distances into coordinate axis direction in X, Y and Z (from top to bottom)

The directional difference values between TLS and PLS point clouds show a higher proportion of deviations in the range above 0.05 m (higher vegetation) and below -0.05 m (erroneous measurement caused by the water surface), especially in the Z direction (Figure 10). Furthermore, a uniform distribution of differences in the lower centimetre range can be seen in all three coordinate directions.

Besides comparing the entire point cloud, which contains many areas with vegetation, only areas with fixed structures were compared. These were solid natural surfaces such as tree trunks and branches as well as surfaces of constructed objects such as houses and bridge walls.

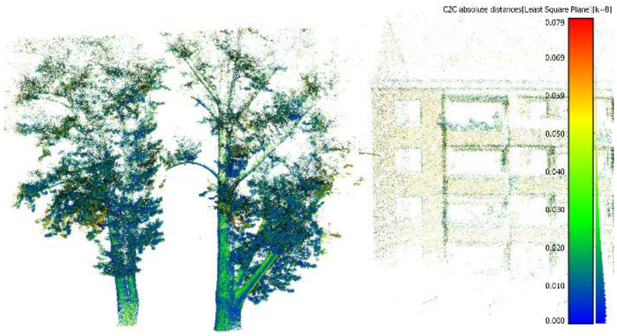

Figure 11. Point-to-point distances between PLS and TLS data of rigid vegetation structures and a house wall

Looking at the values for the extracted points of the rigid structures (Figure 11), differences with a standard deviation of about 0.02 m were measured. Thereby, 93% of the differences are below 0.06 m. However, these areas are close to the trajectory of the PLS measurement. Differences at more distant house walls showed slightly higher values. Differences at the bridge wall (Figure 10, upper end of the point clouds) showed a similar characteristic. A slight shift of the distribution in X and Y direction pointing away from the trajectory was recognizable. This is due to the fact that the wall surface was measured multiple times at close range with a lower noise and from a greater distance with higher measurement noise.

5. CONCLUSION

In this study, the performance of a PLS system was assessed in regard of its performance for the monitoring of small creeks. The results revealed that small river sections can be geometrically measured. The loop length should be adjusted to the complexity of the terrain and the degree of vegetation. The maximum possible measurement duration of 30 min should not be fully utilized in a non-static measurement environment. In addition, a sufficient number of control points should be measured along the creek, which are ideally distributed on both sides of the stream. Including the control points directly in the SLAM processing provided an additional increase in accuracy. The comparison of the PLS with the TLS data showed that good accuracies can be achieved with shorter loop lengths also in natural environments. Furthermore, it was shown that a combination of PLS and UAV data is suitable to increase the survey area. Future studies should focus on the analysis of the accuracies of longer loop lengths and an adapted control point distribution to increase the efficiency of mapping small creeks.

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