Heuristic Assessment of Parameters of the Local Ground Approximation from Terrestrial LIDAR Data

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Abstract. The recently proposed quality measure is used to find the local ground approximation (LGA) from the data measured with the terrestrial laser scanning (TLS). The measure is the number of points in a thin layer located directly above the approximating surface. It can be optimized with the hill climbing algorithm. The method is robust against the data which can be treated as outliers from the ground model, so the TLS data have neither to be filtered nor segmented into those pertaining to the ground and to other objects (trees or lower vegetation). The results are compared with those obtained with the Hough transform-based method and assessed visually, with a positive result. If the ground does not depart too far from the assumed planar shape, the errors are small in relation to those obtained with other measurement modalities.

Keywords: Local ground approximation · LGA · Terrestrial laser scanning · TLS · Quality measure · Optimization · Digital terrain model · DTM

1 Introduction

Terrestrial laser scanning (TLS) is used in the research on automatic inventory control of forests. The data form a 3D cloud of points measured as reflections from objects, that is, the trees, other vegetation like bushes, the ground and any other objects which are present in the field of view of the scanner. The main target of the forest inventory is to calculate the volume of timber in the measured area. Classically, the inventory was made with the use of tree heights and the tree trunk diameters at the height of 1.3 m from the ground level, which is traditionally called the *breast height diameter*. Other measurements, like for example tree diameter at other heights, were also used. Needless to say, any trial of making the corresponding measurements automatically make it necessary to know the ground level at the foot of the tree.

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The ground level has frequently been measured with conventional geodetic methods as well as with airborne laser scanning (ALS) giving rise to the digital terrain models (DTM) (for example [1,2]; a literature survey can be found in [3]). The use of TLS for building the DTM was a rare case. In [4] the least squares estimation and interpolation was used to enhance the DTM found from TLS and complemented with other data. In [5] a precise DTM was found from TLS and data measured with an unmanned aerial vehicle. One of the first reports on finding the DTM solely from TLS is [6]. In some publications on the forest measurements the terrain model is not mentioned, like in [7].

According to [8] the standard deviation of the error of the digital terrain model found from ALS measurements can be 0.6 m. In [6] where the TLS results for the ground location were compared to the ALS ones treated as the reference the root mean square deviation equal to 0.25 m was reported. Therefore, in some locations it can exceed these values. Using the measurements made locally with TLS should not only make it possible to obtain the forest inventory results from one measurement session, but could also reduce the errors.

Due to the masking of the distant objects by the nearer ones the terrestrial laser scanning can practically be used up to the distance of approximately 15 to 20 m [9]. These results were obtained for typical tree densities in the forest in Poland. Therefore, in our work, we shall use the term *local ground approximation* (LGA) rather than the DTM. This is because we shall not attempt to develop the model of the entire terrain in the measurement stand around one LIDAR scanner location, but to provide the proper reference for measuring the tree parameters from this location.

In our previous papers we have investigated the possibility of using the ground approximation by a planar surface. In [10] the plane parameters were found with a variant of the Hough transform called there the Variably Randomized Iterated Hierarchical Hough Transform (VRIHHT). In [11] a set of measures which can be used to estimate the quality of the ground models were proposed and tested. In both papers attention was paid to the robustness of the methods against the presence of outlaying values in the data, due to that from the point of view of the ground measures, all the measurements not pertaining to the ground, that is, belonging to the trees, bushes etc. can be treated as outliers. In this way, the ground approximation can be found from the raw data measured with the LIDAR, without any prior segmentation of filtering.

Methods other than the Hough transform described in [10] should be sought, due to that if the ground model is changed from the planar one to some more complex form, the HT can appear excessively time and memory consuming.

In this paper we shall test the viability of the quality measure, proposed in [11], as the sole optimization criterion in the process of finding the local ground approximation. This measure indicated as the most appropriate one for assessing the ground model was referred to in [11] as Q_3^l. This quality measure will be the only link binding the result with the domain of forest ground level calculation. The optimization method used will be the generic hill-climbing (HC) algorithm.

We shall keep in mind that the HC algorithm can stop in a local extremum. Therefore, the results obtained will be tested in two ways. First, the results will be visualized and will be assessed by human investigation. Second, the results will be compared to those obtained with another method described in [10], both in the visual way and by comparing the values of the quality measure achieved.

The remainder of this paper will be organized as follows. In Sect. 2 we shall first recall the ground approximation method and the measure of its quality, and then the optimization method with which this quality measure will be maximized. In Sect. 3 we shall present the method with which the viability of the method was tested, and the results of these tests. Finally, in Sect. 4 we shall sum up the conclusions which can be made as a result of the presented study.

2 Method

2.1 Local Ground Approximation and Quality Measure

According to [11], the ground will be approximated with a plane Π in the coordinate system $Oxyz$ expressed by

$$A\,x + B\,y + C\,z + D \,=\, 0\,. \tag{1}$$

Denote an i-th measurement point by $P_i = P_i(x_i, y_i, z_i)$, $i = 1, \ldots, M$. Denote by $d(P_i, \Pi)$ the signed distance between this point and the plane Π:

$$d(P_i, \Pi) = \frac{A\,x_i + B\,y_i + C\,z_i + D}{\sqrt{A^2 + B^2 + C^2}}\,. \tag{2}$$

As the quality measure of the ground approximation (1) we shall use the measure Q_3^l proposed in [11] as

$$Q_3^l(\Pi) = \sum_{i=1}^{M} N_3^l(P_i, \Pi)\ ,\ \text{where} \tag{3}$$

$$N_3^l(P_i, \Pi) = \begin{cases} 1 & \text{if}\quad 0 \le d(P_i, \Pi) < l\ , \\ 0 & \text{otherwise}\,. \end{cases} \tag{4}$$

Therefore, Q_3^l is the number of measurement points inside a layer of height l above the plane. Its maximization should yield a plane located just under the layer containing the largest number of points.

It can be noted that if Π according to (1) is replaced with another approximating surface and (2) is redefined accordingly, the measure Q_3^l can still be used in an unchanged form.

2.2 Optimization with the Hill Climbing Method

As it has been stated above, the measure Q_3^l will be maximized to find the parameters of the LGA. The primary idea was to use the genetic algorithm (GA) as the optimization method. Genetic algorithms are a universal tool for global optimization, which always lead to good solutions irrespective of which assumptions, if any, can be made on the optimization criteria. Before using the GA, which is a very general method but can be time hungry, we have made a trial with the hill climbing (HC) method which is a simpler and also quicker tool. HC is one of the simplest heuristics working on complete solutions [12]. It can be schematically written down as Algorithm 1.

Algorithm 1. Hill climbing optimization

```
choose starting solution and set it as current solution
do
    assess current solution
    assess solutions for neighboring values of parameters
    if ( exists better neighboring solution )
        set best neighboring solution as current
while ( current solution is improved )
```

To assess the solution the measure Q_3^l according to (3) with the parameter $l = 0.05\,\text{m}$ was used. As the starting solution the horizontal plane was chosen, displaced by 1.3 m below the zero point of the LIDAR scanner coordinate system center. It is a common practice to set the LIDAR so that its center is at the *breast height* above the ground. As the neighboring values for the parameters A, B, C and D the values differing by the step s were used. The calculations were made for four constant values of s equal to $0.1, 0.01, 0.001$ and 0.0001 and for variable s changed according to two strategies specified further. The initial value of s was 0.1 . If a better neighbor can be found, the calculations are continued with the same step. Otherwise, the step is halved. Calculations stop if there is no better neighbor and $s \leq 0.0001$. Otherwise, the better neighbor is set as current. Then the first strategy *sg-return* was to return to the largest step 0.1 and the second one *sg-continue* was to continue with the current step.

3 Testing the Method

3.1 Data

We have used all the data sets scanned in 2011 at 15 stands near Głuchów in the Grójec Forest District, Mazovian Voivodship (Central Poland), with the terrestrial LIDAR scanner FARO LS HE880. The sets will be referred to as G01-G15. A data set for each stand was collected from a single position of the scanner. The sets contained between 12 and 22 millions of measurement points belonging to the trees, bushes and grass, and the ground. The set G10 was excluded from this study due to that it contained data of a stand which departed very far from the planar model considered here (see [11] for details).

3.2 Results of the Tests

The drawback of the HC algorithm is that it can stop in a local extremum. By comparing the result with those found with HT it could be found whether this was the case. Tests made indicated that the HC method yielded larger values of the quality measure than those for the results of the HT, already assessed as acceptable in [10]. Further, to see whether the results achieved conform to the expectations, the results were visualized. For this, 0.01 m wide vertical slices were cut from the data along the horizontal axes Ox and Oy and shown with the measuring points contained inside and cuts through the planes approximating the ground. In this way, for each data set two images were obtained.

In Table 1 the results for 14 data sets, for the Hough transform (in the version with all data points) and for all the versions of the hill climbing optimization are shown: for variable step with two strategies and for constant step with four values.

Table 1. Results of optimization – achieved values of the measure Q_3^l for the Hough transform (HT) with all the data taken into account (HT) and six variants of HC with Q_3^l as the optimization criterion. Average number of iterations until stabilization for all data sets given in the second row. Best result for each data set, in the sense of maximum Q_3^l, typeset **bold**.

Set	HT	HC with Q_3^l					
		sg-return	*sg-continue*	$s = 10^{-1}$	$s = 10^{-2}$	$s = 10^{-3}$	$s = 10^{-4}$
No. iter		78,90	22,43	2,30	15,77	149,30	1092,33
G01	4302794	**4639980**	**4639980**	3842784	4578294	4639078	1396536
G02	3041891	**3359955**	**3359955**	2795328	3324298	3359025	1463245
G03	4871221	**6433712**	**6433848**	3222021	6389405	6432473	2801175
G04	4955470	**6454744**	**6454744**	4306104	6434044	6452912	6454680
G05	2622571	**3053982**	3053975	2270557	3047939	3053191	3052169
G06	4474230	5296824	5296824	3133640	5161469	**5297056**	3383733
G07	6759960	**9006977**	**9006977**	4677454	8981072	9005881	9006708
G08	7113005	10132162	10132162	8615957	9405729	10127568	**10132580**
G09	5243061	**6532281**	**6532281**	5667501	6433235	6529922	6531014
G11	6229232	**8998283**	**8998283**	2747618	8735206	8996286	1583847
G12	7717864	**10635960**	**10635960**	1647341	10582841	10635238	**10636016**
G13	5705181	**10112587**	**10112587**	7129943	9662389	10110759	10112500
G14	5146301	8417649	8417649	5998452	8161496	8413424	**8417688**
G15	6247893	**7987105**	**7987105**	4028943	7850807	7983638	1099045

In most cases, the best results are obtained with the variable step strategy with returning to the large step (*sg-return*), as well as with the continuation with the small step (*sg-continue*). However, from these two strategies the continuation with the small step needs less iterations. In some cases the optimization with constant small steps yield better results, but the difference in the quality measure is relatively small. Therefore, the HC with the varying step, with the strategy *sg-continue*, can be finally chosen as the best one. The results obtained with the HT have significantly worse results in the terms of the achieved Q_3^l.

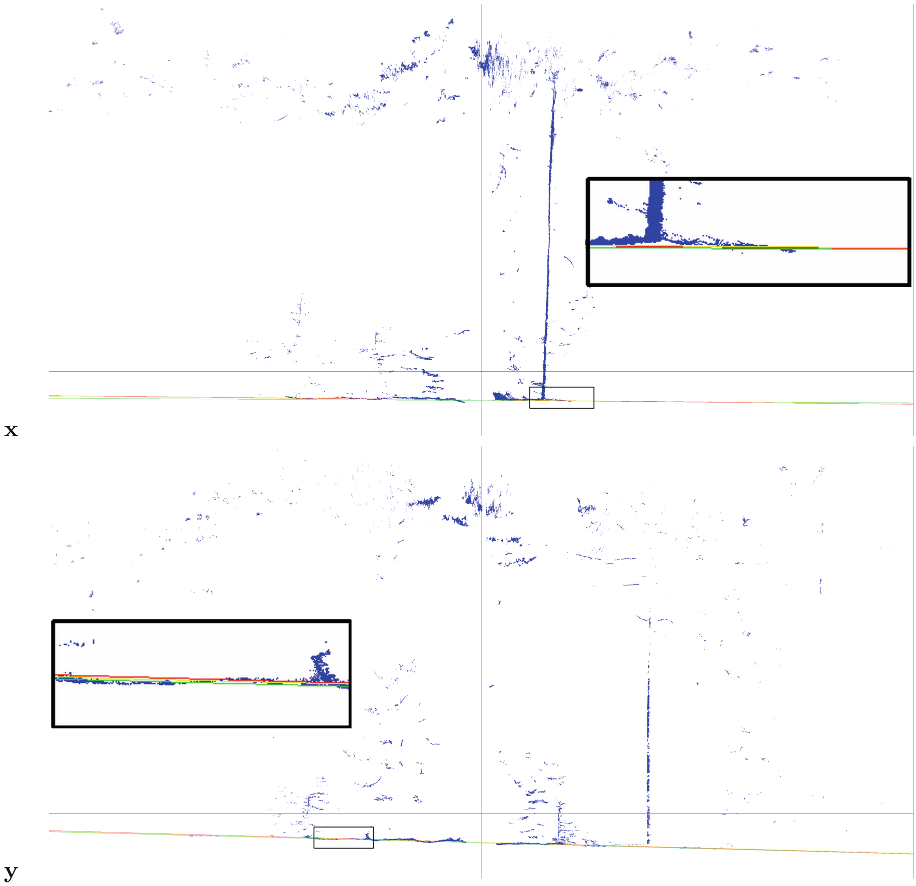

Fig. 1. Full views of results for data set G06: sections along (**x**) Ox; (**y**) Oy. Fragments in rectangles 5× enlarged, so a pixel corresponds to 0.1×0.1 m. See text for explanation of colors (Color figure online).

The results obtained with the best version of the HC, as chosen above, and two version of the HT will be shown in Figs. 1, 2 and 3. In Fig. 1 the overall layout of the data and results is shown and the details are enlarged to make it easier to see what is the range of the errors of the approximation and to show which parts of the images are important. In Figs. 2 and 3 only these significant parts are shown.

In Fig. 1 the actual dimensions of the imaged area are: width 40 m and height 20 m (17 m over the horizontal axis and 3 m below). In the remaining figures the width is the same, but a 3.14 m thick layers are cut from the most interesting parts of the images. The data points are marked with blue. The results of the HC method are marked with green. Two results of two versions of the HT differing by the fraction of data used in calculations are marked, accordingly: yellow for

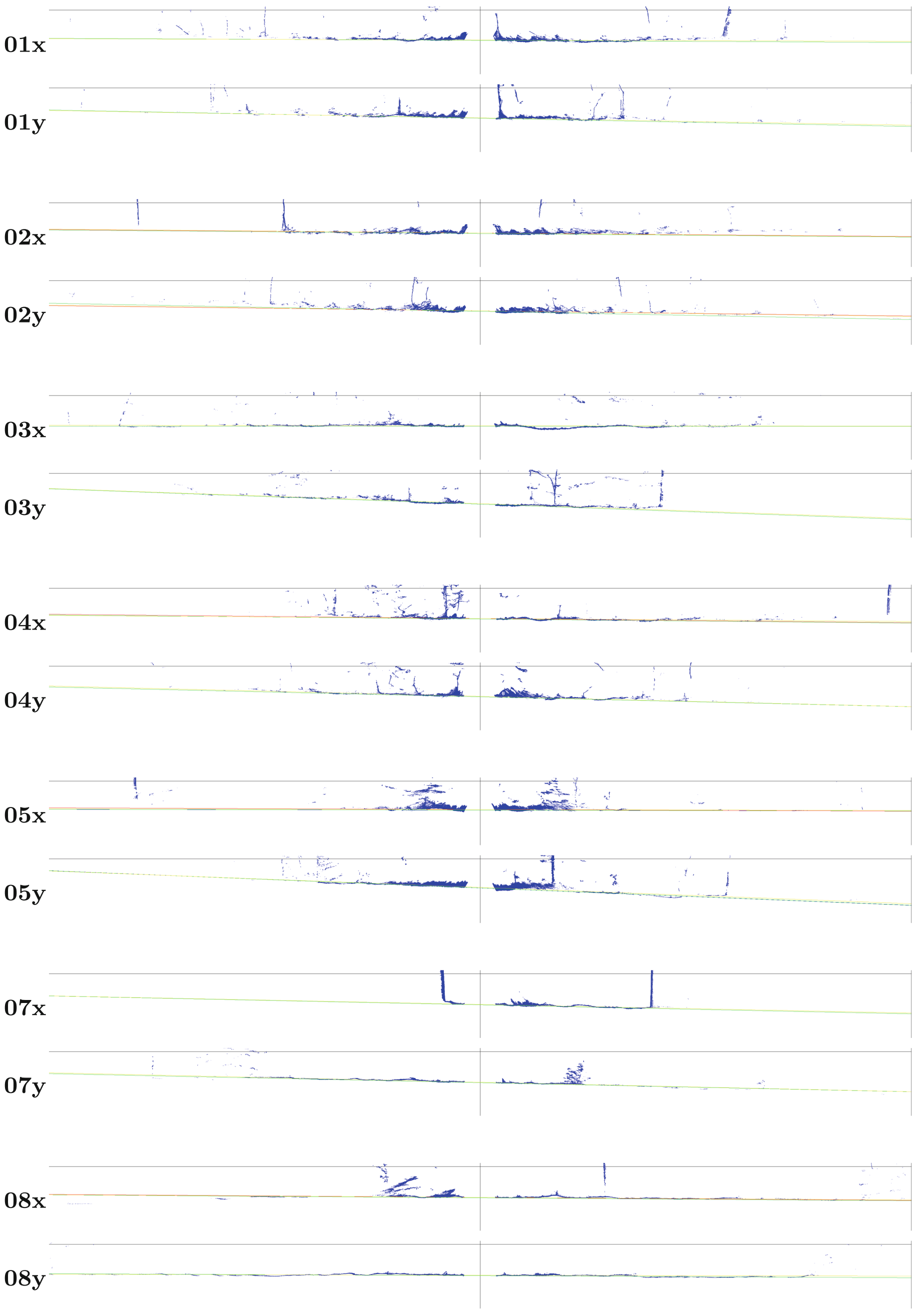

Fig. 2. Lower fragments of views of results for data sets G01-G05 and G07-G08. See text for explanation of colors (Color figure online).

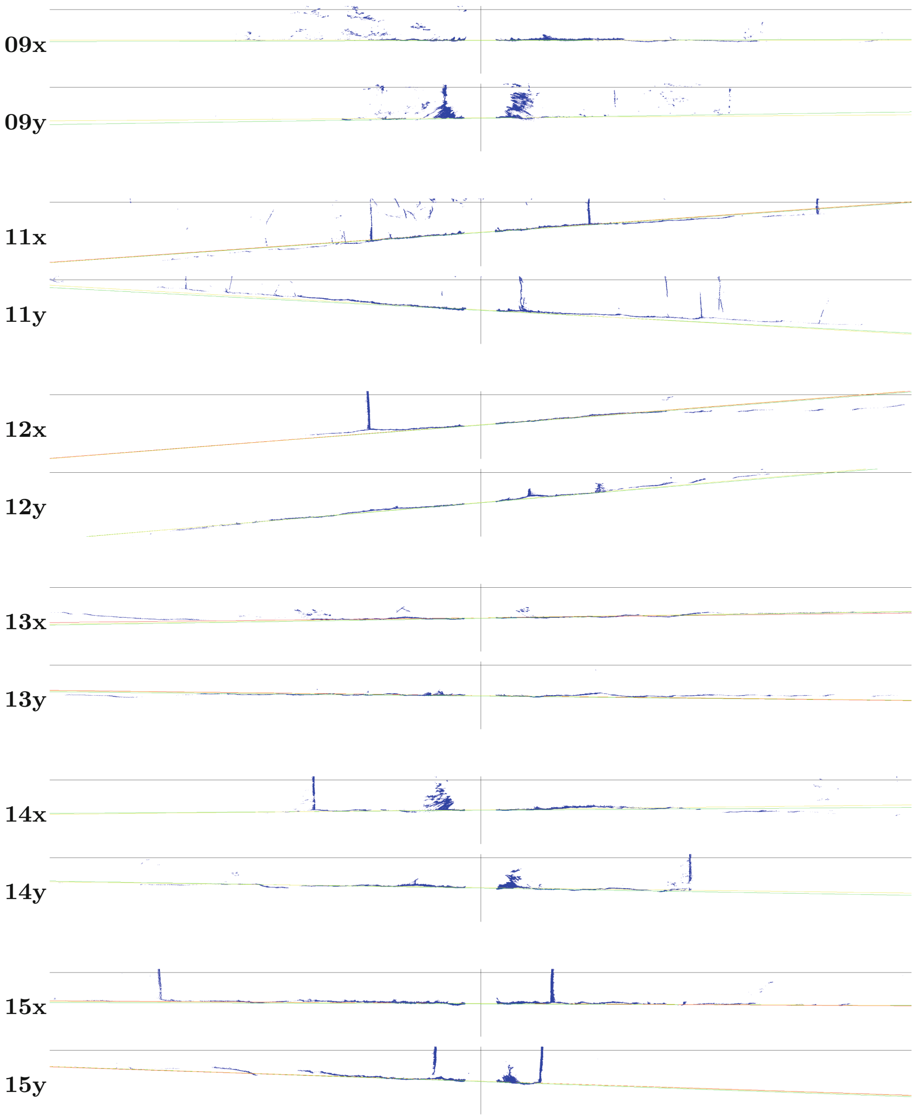

Fig. 3. Lower fragments of views of results for data sets G095 and G11-G15. Data set $G10$ was excluded due to the ground departed very much from planarity, so the approximation (1) was not appropriate. See text for explanation of colors (Color figure online).

all the data used in calculations, and red for a variable fraction equivalent to 0.01 of the data (see [10] for details; these two results can be the same or differ only slightly). Results of HC are drawn on top of those for HT.

3.3 Discussion and Results

The differences between the results obtained with the hill climbing according to the quality measure Q_3^l and the Hough transform are not large. As a rule, the plane according to Q_3^l is lower than that found with the HT. This conforms with the construction of Q_3^l which promotes the location of the ground *below* the most dense cloud of the data, while HT finds the plane which passes *through* the dense data cloud. This observation is in favor of the results found with Q_3^l and HC optimization, with respect to the results from the HT, although both results are usually close to each other. In visual inspection, both results conform to the expected location of the ground as a rule; obviously, they are slightly farther from the ground measurement points in cases where the ground departs from flatness, like for example in data sets G11-G13 and G15, but the differences are far less than 0.6 m referred in [8] and close to 0.25 m reported in [6]. Therefore, the planar approximation is acceptable for the plain terrains tested. As it could be expected, it fails for the regions where the ground level is uneven.

The results can be treated as satisfactory, within their range of applicability. The LGA – the local ground approximation – with the equation of a plane can be considered a sufficiently accurate ground model in the investigated application.

4 Conclusion

The possibility of finding the local approximation of the ground level, called here LGA, directly from the raw Terrestrial laser scanning data was investigated. The method used was the optimization method in which a quality measure recently proposed specially for the application of interest was used. The quality measure was the number of points contained in a layer of specified thickness located directly above the ground approximating surface. The thickness of the layer was 0.05 m. The measure does not limit the form of the LGA, but in this paper a planar model was used, which is admissible in plain regions. At present, the simple hill climbing algorithm was applied. In the considered application, the proposed quality measure proved to yield good results. Other more advanced optimization methods and local ground approximation functions will be investigated in future.

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