Earth Surf. Dynam. Discuss., 3, C596–C606, 2016
www.earth-surf-dynam-discuss.net/3/C596/2016/

ESURFD_Log

Interactive comment on "Image-based surface reconstruction in geomorphometry – merits, limits and developments of a promising tool for geoscientists" *by* A. Eltner et al.

Anonymous Referee #1

Received and published: 8 January 2016

The manuscript by Eltner and co-authors reports a complete review of the Structure from motion applications in geoscience. The manuscript is generally well written and organized. The authors give a general overview of the method describing the main algorithms implemented in the photogrammetric approach. 61 published papers are examined according to their application, divided into seven main topics. Where is provided by the authors, an overview of the obtained accuracies in the examined works is evaluated according to the main source error of the technique and to the error introduced for the accuracy estimation. Further frontiers for the SfM approach are discussed in this paper, highlighting the need of additional investigations on the technique and on the methods to estimate the accuracy, and the need to share a growing amount

of data produced by this low cost technique. The Sections describing the accuracy estimation and the source errors could be improved by defining in the text the terms used for the accuracy analysis making it easier to understand and specifying the case studies that are examined for each analysis in order to help the reader for further investigations. The corresponding references could be also included in the description of the SfM applications for each investigated topic.

Specific comments

1. I suggest to report in the Section 3 all investigated papers (i.e. authors) for each topic. This could be done adding in the Table A1 a first column with a progressive ID number for each work. Then, for each topic, specify the corresponding ID. For example p.1455, line 21: "... in 7 publications", here, the ID of the relevant papers can be reported, or specify on the Table 2. This is a suggestion. Several published papers provide both a description of the SfM application and an accuracy analysis of the reconstructed object and therefore, it is appropriate to split the considerations about the applications and the accuracies, as done in this review manuscript. However, the Sections 3 (3.1, ..., 3.7) should focus mainly on the description of the applications of the method including the authors (see comment before), the object of survey, and the platform used for each corresponding topic. Some applications are missing in the text, and should be provided in order to give a complete view of the main objects surveyed with this technique. To name a few, Woodget et al. (2015) quantified the fluvial topography using hyperspatial resolution UAV imagery and structure from motion photogrammetry; Piermattei et al. (2015) used the SfM for monitoring the mass balance of a debris covered glacier. These applications should be reported in the text.

2. The results of the statistical investigation on the achieved accuracies are reported in the main table (Table A1). Please define the parameter used to evaluate the accuracy also in the text and not only in the caption of the figures. The accuracy parameter named in the paper "measured error" is the standard deviation /RMSE measured in comparison to a reference data (e.g. LiDAR, GPS measurements or with Total station).

Please clarify better in the text. Please define how the “superior reference ration” is calculated in the text. As reported in Figure 9 ‘superior reference ratio’ is calculated as ratio between measured error and accuracy of the reference. Please define how the accuracy of the reference data was evaluated. Looking at the Figures about the error analysis (5, 6, 7, 8, 9, 10), a different number of data were plotted, but in the text is reported that 39 case studies provided a value of accuracy estimation. Please specify for each analysis how many case studies were considered and, if possible, report the corresponding references (see comment 1).

Technical corrections

p.1448, line 2: ‘Early works. . ...mapping (Laussedat, 1899)’ Please remove this sentence or move to Section 2.

p. 1448, line 17: ’to data processing and data acquisition makes it...’ It is also the easy data acquisition that increased the number of non-experts users.

p. 1448, line 21: I prefer report the automatism rather than "algorithmic advance". ’..that utilizes the high automatism of the SfM algorithm are considered’.

p. 1448, line 23: ‘fully automatic’ is not true for all applications and software used as for example the GCPs identification in the images or in the point cloud is still a manual operation in many case. Therefore, I suggest ’semi-automatic’ and maybe specifying why: ‘The data processing is highly automated and in many software the user-control is limited to some pre-processing step like the manual masking of moving object, the camera calibration parameters setting that can be applied to optimize both accuracy and precision, and the GCPs identification.

p. 1449, line 1-3: Please clarify this sentence. What do you mean with ‘a novel point of view’? I suggest to simplify the sentence writing that the SfM characteristics (low-cost and high portability of the instrumentation) allow to increase the temporal analysis of the events but also the spatial analysis thank to the high versatility of the images

acquisition. These characteristics and the possibility to acquire images also from aerial platform using UAV increase the applications of the survey method in remote area with limited accessibility and the detection of fast changing environment.

p. 1449, line 23: I suggest to specify the corresponding Section for each point as following: ’1. The method... are clarified (Sect. 2); 2. Different field... (Sect.3); 3. ... (Section 5); 4. ... (Section6)’. I suggest to move the Section 4 “non commercial software” in the Section 2, especially because at the end of Section 2, p.1453, line 10-22, an introduction about the SfM software is provided. Maybe dividing the Section 2 in two paragraph, ‘2.1 . . .: state of art’ and ‘2.2 . . .: tool and data post processing. A brief description also about commercial tool should be described. See comment p. 1457-1458.

p. 1450, line 14. ’...usually at least nine homologous points per image’ this statement requires a reference.

p. 1450, line 22: the acronym SfM is already described.

p. 1451, line 6: I would mentioned also the need to scale the model, as reported also by Snavely at el., 2008, because the SfM estimated the relative position of each camera. To have metric information of the reconstructed surface, in local or global-coordinate system, the ground control points or a scale definition by using a known distance are required to scale and georeference the SfM 3-D model.

p.1451, line 25: ’These extrinsic parameters ...’ the authors refer to camera position or also intrinsic parameter. Please clarify the sentence.

p. 1452, line 27. Please change ’DSM’ with ’DEM’.

p. 1453, line 10: I suggest mentioning also the commercial software because they are used in the investigated papers.

p. 1453, line 23: I suggest to move the section 4 here, in connection with the paragraph above about the SfM software.

p. 1454, line 25: Please define the acronym ‘LiDAR’.

p. 1455, line 21: The authors may also want to refer to Ryan et al. (2014).

p. 1456, line 19: Ružic et al. (2014) is not mentioned in the bibliography.

p. 1456, line 20: ‘... have been retreating up to 5 m since the 1960s. . .’ it is not relevant here.

p. 1456, line 23: An emerging application of SfM is related to snow depth estimation, snow map and rock glacier monitoring. This topic should be reported here, or in the Section 3.3 extended the topic. For example, Fugazza et al. (2015), Dall’Asta et al. (2015).

p. 1457, line 12: ‘Also . . .intervals.’ please move this sentence in Section 6.6.

p. 1457, line 19: Please reorganize Table B1 regarding the software of photogrammetry and cloud processing (if you want to include the latter in this table). Additionally please report both in the text and in the table the free-web service SfM tool, like Photosynth and 123D Catch, especially because they are used in the investigated paper as reported in Table A1 and in Figure 3. In table B 1, I suggest to include also the commercial software adopted in the published papers.

p. 1459, line 10: I have my doubts about this statement ‘. . .the systematic error . . . can be displayed by the mean error values’, please support by a reference. As reported by Smith and Quincey (2015), the Mean error values should be treated with caution to estimate the accuracy of SfM reconstruction that often include both positive and negative errors which approximately compensate for each other. Also Dietrich (2015), James and Robson (2014) demonstrated that the systematic error is visible as a pattern of positive and negative differences compared to a reference ground truth data. The effect of this error is principally caused by the parallel geometry of the photographs along the flight lines in case of UAV acquisition and by the radial distortion propagation (Dietrich, 2015) as it is reported in Sect. 5. However this error is not apparent in

the mean values, but can be explained by an error distribution map. Perhaps worth a comment in the text.

p. 1459, line 4: I suggest to include this Section in the previous one.

p. 1459, line 18: "measured error" please define better what represent this value (See specific comments). I suggest change line 17 to ’In this study, we reported with the term "measured error" the standard deviation or RMS calculated comparing the SfM reconstruction (point cloud, DEM or mesh) with a reference data (i.e. Lidar , total station or GPS measurements)’. Additionally, as reported in the lines 19-25, the GCPs residual error defines an approximate accuracy estimation, especially if the GCPs are including in the BBA. I suppose there is not a big differences by selecting the control point in the model (of course depend on the model resolution) or in the images as is highlighted in your plot (Fig.5). Instead, would be interesting the "measured error" depending on whether the GCPs have been performed in the BBA (one-stage) or after dense matching computation (two-stage).

p. 1460, line 27: ‘...an increase of distance the measured error decreases’, looking at the Figure 5 probably you mean ‘. . .the measured error increase’. Figure 5 shows more than 39 values (number of case studies that performed the accuracy analysis) probably because it is included all available data from multi-temporal analysis. Please provide the total number of plotted values (See specific comments).

p. 1461, line 5: ‘. . . and at large distance’. Perhaps this sentence requires a reference or an example.

p. 1464, line 3: ’Stumpf et al. (2014) show that higher overlap resolves in better results, even though ground sampling distance decreases due to a smaller focal length.’ it is not clear in this sentence the connection with overlap and GSD. Please clarify this sentence.

p. 1464, line 7: I consider Table 3 not necessary, I suggest to write in the text the

number of published applications that use UAV or terrestrial acquisition. I suggest to rewrite this sentence.

p. 1464, line 25-28. Please clarify the concept. The authors may also want to refer to Wenzel et al. (2013) that explain the relation between the intersection angle and the baseline, the depth accuracy and the image similarity.

p. 1465, line 11: '... 3-D reconstruction...' is defined in Table 1 as the three-dimensional shape of an object reconstructed from overlapping images, but I suppose here the authors mean the camera geometry reconstruction.

p. 1465, line 12: I suggest to remove the sentence '...because MVS...point cloud'. The MVS algorithm is not the only algorithm used for the dense matching in the investigated papers, and furthermore the image matching computation to generate dense point cloud is mentioned in the next line (line 15...).

p. 1465, line 24: To estimate the accuracy of the sparse point cloud (tie points) before the dense image-matching computation, a possible solution is to compare the sparse points with an area-based truth data, if this is available. Many software allowed to export the computed tie-points that are used to estimate or refine the camera orientation, and therefore a preliminary accuracy estimation of the SfM reconstruction is performed. This could be explained in the text.

p. 1466, line 9: What do the authors mean with'.., if possible, ...'. I suggest to remove it. Moreover, please provide the number of investigated case studies for the error assessment.

p. 1466, line 20. I suggest to include the statement of Bemis et al. (2014) about the influence of the duration of the photogrammetric survey on the SfM 3D model quality. He reported that "model quality degrades significantly for durations >30 min".

p. 1467, line 2: Here, may also provide the statement that by including the control measurements (i.e. GCPs) in the bundle adjustment the error is reduced. Javerinick

et al. (2014) provided a reduction of z-error to the decimetre level by including control points in the bundle adjustment.

p. 1467, line 16: The authors may also want to refer to Piermattei et al. (2015) in this sentence: '... be possible (e.g. glacier surface reconstruction, Piermattei et al., 2015)...'.

p. 1467, line 25: Please include in the text these statements: Bemis et al., (2015) and Smith and Quincey (2015) reported that the control points should be distributed widely across the target area and at the margins, covering a good range of values in each spatial dimension. This is especially true in case of the GCPs are including in the bundle adjustment and the presence of parallel axis camera configuration. Additionally, linear configuration of GCPs should be avoid as reported by Smith and Quincey (2015).

p. 1468, line 1-3: 'Figure 5 illustrates...'. I suggest to report that there is not difference in the measured error of the investigated studies if the GCPs were selected in the point cloud or in the images. Contrary, white points (i.e. GCPs measured in the images) show higher "measured error" than gray points. However, a limited number of case studies selected the control data in the point cloud. Perhaps report the number.

p. 1468, line 19: Please define what the authors mean with 'superior accuracy assessment' and the number of case studies that were considered for this accuracy evaluation (see specific comments).

p. 1468, line 22: Please change 'scale dependent' with 'to depend from the camera-object distance.'

p. 1469, line 7: Please change '3-D reconstructed DEM' with '3D-reconstructed surface' as you explain after, the comparison can be done using the point cloud of the reconstructed surface and not only after the interpolation (DEM). I suggest to report here the necessity of a spatial error distribution for a proper evaluation of systematic error (see comment p. 1459, line 10).

p. 1470, line 11. If the authors want to report these results, please be more quantitative.

p. 1470, line 12: Please provide the reference of this equation, Fraser (1996), and describe better the component. For example, the standard error is for the x, y, z object coordinates; q is a design factor expressing the strength of the camera network, basically dependent on the angles between intersecting homologous rays; k corresponds to the average number of images at each station; 'D mean distance object-target' probably the authors mean 'camera-object distance'; '. . . (0.29,. . .)' please provide the reference.

p. 1472, line 1-6: Perhaps this statement needs more clarification.

p. 1474, line 23: The authors may also want to refer to Mulsow et al. (2013) about the time lapse application for monitoring the margin lake, and Whitehead et al. (2014) to use the time-lapse cameras to measuring the daily surface elevation change across an arctic glacier.

p. 1492, Table 2: I suggest to put the references for each topic. It could be done adding a consecutive ID in the table A1 and reporting here the relative ID in order to help further investigation (see specific comments). This is especially suggested because in each section about the SfM application for each topic not all corresponding papers are described. I think it could be useful write the work/authors for each topic, in the table 2 or at the beginning of each paragraph. Some observations about the Table. The last column represents the total number of reviewed papers, please provide a title to this column; the last row is the sum of each column. But if it is like so, probably there is an error in the number: 11(7) rather than 10(7).

p. 1493, Table 3: Wrong number of investigated studies '62'. In the text is reported 61 publications. Additionally I consider this table not significant.

p. 1495, Table A1: Different symbols (comma or dash) are used to separate the values. Please try to be more consistent or specify the differences.

p. 1499 Figure 2 is not reported in the text.

p. 1500, Figure 3: Wrong number of investigated studies '62'. In the text is reported 61 publications.

p. 1505, Figure 8: Please specify what represent the different scales in the legend and in the caption. I am assuming that 'scale' refers to the 'camera-object distance'.

p. 1508 Figure 11 is not reported in the text.

References

Dall'Asta, E., Delaloye, R., Diotri, F., Forlani, G., Fornari, Morro di Cella, U. M., Pogliotti, P., Roncella, R., Santise, M.: Use of UAS in a High Mountain Landscape: the Case of Gran Sommetta Rock Glacier (AO). ISPRS-International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XL-3/W3, 391-397, 2015.

Fraser, C.S.: Network Design, in Close Range Photogrammetry and Machine Vision, Whittles Publishing: Caithness, UK, pp. 256–281, 1996.

Fugazza, D., Senese, A., Azzoni, R. S., Smiraglia, C. Cernuschi, M. Severi, D. D., Guglielmina A. High-resolution mapping of glacier surface features. The UAV survey of the Forni glacier (Stelvio National Park, Italy), Geogr. Fis. Dinam. Quat. 38, pp. 25-33, doi:10.4461/GFDQ.2015.38.03, 2015.

Mulsow, C., Koschitzki, R., Maas, H. G.: Photogrammetric monitoring of glacier margin lakes, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 27 – 28 February 2013, Padua, Italy, Volume XL-5/W3, 1-14, doi:10.5194/isprsarchives-XL-5-W3-1-2013, 2013.

Ryan, J. C., Hubbard, A. L., Todd, J., Carr, J. R., Box, J. E., Christoffersen, P., Holt, T. O., Snooke, N.: Repeat UAV photogrammetry to assess calving front dynamics at a large outlet glacier draining the Greenland Ice Sheet. The Cryosphere Discussions, 8(2), 2243-2275, doi:10.5194/tcd-8-2243-2014, 2014.

Wenzel, K., Rothermel, M., Fritsch, D. Haala, N., 2013: Image acquisition and model selection for multi-view stereo. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci, pp. 251–258.

Whitehead, K., Moorman, B., & Wainstein, P.: Measuring daily surface elevation and velocity variations across a polythermal arctic glacier using ground-based photogrammetry, Journal of Glaciology, 60(224), 1208-1220, 2014.

Interactive comment on Earth Surf. Dynam. Discuss., 3, 1445, 2015.