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Earth Surface Dynamics Discussions

Interactive comment on “A low-cost technique to measure bank erosion proces ses along middle-size river reaches” *by* Gonzalo Duró et al.

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P. Carbonneau (Referee #1):

General Comments

RC: This work attempts to deploy established SfM techniques over a 1.2 km river bank characterised by bays and pseudo-headlands and with numerous vertical faces along the banks. The work does present some points of interest but the authors display an understanding of SfM-photogrammetry which is average/good and as a result seem to have missed many important points. The general pitch and justification of novelty for this paper is weak. This is expressed in the second sentence of the abstract stating ’Yet, no technique provides low-cost and high-resolution to survey small-scale bank

processes along a river reach’. This is quite simply not true and is ultimately self-defeating as a statement. The authors have deployed a widely used commercial drone and processed the data with an equally widely used commercial SfM package using the standard workflow. There is no new technique in this work. The authors have cited other work that has delivered similar resolutions at slightly smaller scales or that have worked at lower resolutions at larger scales. Therefore the work occupies a very small niche of cm scale resolution work over a 1.2km scale length. The workflow and techniques used by the authors are not at all new, they have merely benefited from better drone flight durations thus allowing them to cover a 1.2km river reach with repeated operations. In itself, this is not a sufficient justification for publication. However, the work does address an important and interesting problem. Using drone-based SfM for repeated coverage of a 1km river corridor, especially a very linear one as shown here, presents some very specific challenges. Moreover, when this reach presents some vertical surfaces prone to failure, additional photogrammetric challenges must be addressed. Unfortunately, the authors did not seem to realise that this was the key point and challenge of their work and, in addition to the misplaced pitch mentioned above, the data acquisition and processing approach is very sub-optimal for this specific problem. Overall, I do think the data presented here has potential for publication without additional fieldwork, but some very significant revisions will be required which include both new analysis and re-writes of many sections. However, even if publishable without additional fieldwork, the workflow presented here is definitely not the optimal approach to survey long and highly linear river corridors and this will need to be clearly outlined in a new discussion.

AC: We thank the referee for his critical and constructive comments on the UAV-SfM technique, which has helped improving the manuscript and the analysis of the specific challenges this case study proposes for the UAV-SfM application. The manuscript addresses two aspects which have been clarified and considered in the revised analysis. First, the application of an available technique to a new setting with particular characteristics and processes. The topography of the bank area has an unusual threedimensional complexity, it is tortuous and presents exposed undermined profiles, which overall lays on a quasi-linear domain, i.e., a straight river reach. We were aware of the latter but certainly did not address it as a novelty nor analysed the rotational tendency of the model. Second, the work provides evidence of a sufficiently accurate data acquisition approach to measure bank erosion processes, without the intention of achieving an optimal solution. Yet, we do realize that this should be thoroughly discussed in the manuscript in light of the referee's comments. In addition, the fact that now it is clear for us that the SfM camera calibration phase cannot re-adjust the linear transformation, provided the opportunity to improve the manuscript towards recommending a more robust UAV-SfM approach, as well as analysing and highlighting the particular challenges this setting offered for the UAV-SfM application. We also realize that the pitch was not accurate and should be phrased again. The spirit of the motivation lays on the application of a readily available technique to measure bank erosion at the process scale, which has unique characteristics compared to previously used methods for that aim, such as a combination of low-cost, fast deployment in the field, and high 3D resolution. Section 2.2 described past experiences with other techniques. Moreover, we compared the results with other two methods and discussed them in the broader context of other available techniques to put into perspective the convenience and disadvantages of UAV-SfM to measure bank erosion processes. We have, nevertheless, also focused the manuscript on the specific challenges this case study proposes for the UAV-SfM technique, addressing the rotational tendency of such linear domain, and assessing the performance of the adopted GCP distribution with parallel UAV paths.

Specific Comments

RC: The key challenge in this work is the deployment of drone-based SfM over a very linear river reach characterised with near-vertical faces. This challenge can be understood if we consider the type of errors present in SfM point clouds. This is the main area where the authors understanding of SfM needs to improve. The error of georeferenced point clouds produced from SfM chan be partitionned in linear, non-linear and

random components. Linear errors affect the point cloud as a rigid block and can be expressed in terms of translation errors, rotation errors and scaling errors. Non-linear errors are often caused by camera calibration problems and are manifest by warps and curvature effects that distort the geometry of the point cloud. One notable error in the authors understanding is that the seem to think that camera calibration errors can cause overall rotation of the block as 1 rigid body. This is not the case. Camera calibration errors cause errors such as the now famous dish effect. However rigid block rotation errors are caused by errors in the 7-parameter Helmert transform used to scale, rotate and translate a relative point cloud to georeferenced coordinates. The parameters of the Helmert transform are calculated by least squares regression of the control data, if the control data is highly co-linear, the lest squares regression could converge on a false solution that is rotated around the axis formed by the line of control points. This is not the same as the non-linear camera calibration errors. It is also different from random errors are localised errors (often expressed as elevation errors) that are generally not spatially correlated and represent the classic concept of precision. In this work, the authors have been rigorous about possible effects of camera calibration and small scale noise, but they have completely missed possible rotation errors caused by the geometry of their case study. From a photogrammetric perspective, there are 2 challenges posed by this case study. First, it is a highly linear reach with a very high length:width ration. Second, the presences of vertical faces will require highly oblique views. It is the first challenge that the authors have missed. There are 2 main problems in the data acquisition plan. First, the location of the GCPs is almost co-linear. As stated above,this means that numerical solutions to the georeferencing of the model (via the Helmert transform) will have a degree of equifinality around a family of solutions that rotate around this co-linear axis of GCP points. The addition of 2-3 points perhaps 50 meters inland would have reduced the co-linearity of the model. The authors need to consider the cross-stream footprint of their GCP points relative to the errors in the RTK GPS and in the human error associated to locating the GCP in an image (see below) and make a case that the model is stable. In the future, the authors must seek to distribute their GCPs in a very non-colinear pattern that, as much as possible, occupies the full X, Y and Z extent of the area covered by imagery. Second, the choice of flight patterns that are lines parallel to the shore does not help this situation. A possible option would have been to fly the drone in a much wider pattern that goes further inland and off-shore. However, in this case, the relatively high error of the drone GPS would have required a fairly wide (in the cross-stream direction) flight pattern in order for the drone GPS data to make a beneficial contribution to the rotational stability of the model. Ultimately, the entire data acquisition setup proposed here is prone to delivering models that will have a tendency to present rotation errors where the entire point model is tilted with respect to an axis that is parallel to the shore line. This is a very significant weakness of this workflow. With this consideration in mind, it is very worrying that the authors have chosen to cut the data and have selected a portion of the point cloud that is near the GCP axis. In figure 7, the authors need to show the readers all the available data. Additionally, if they do choose to cut some peripheral data, some objective criteria must be chosen. And the moment, the choice of area seems subjective and does not give the reader confidence that the authors have not cherry-picked the part of their point cloud with the least error. I note that in figure 9, cross sections 1,2 and 4 do seem to have a rotational effect. The authors will need to demonstrate their current GCP setup does prevent rotation or return to the field with a better, wider GCP arrangement.

AC: As previously indicated, we assumed it was possible to re-adjust the linear transformation during the camera calibration step, and missed an analysis of possible rotation errors. We have added a new section 4.3 to analyze the linear rotation of the model, evaluating linear trends of elevation errors across the axis of potential rotation. We also included discussions on linear errors in section 5.1 and on the adopted workflow on a new section 5.3, including considerations on GCP distribution, target visualization and UAV paths. Regarding Figure 7, the cropping of the floodplain boundary was done to avoid the bush lines across the floodplain (visible in the background aerial photo) to prevent comparisons over vegetated areas. Also, the domain had been cropped at the terrace end, before a narrow sloped strip because it was considered beyond the target area (the bank). Now, all available data has been plotted in the revised Figure 7 (whose extent was already visible in Figure 3). In addition, Figure 7 now has another panel showing the signed elevation differences between SfM and ALS for further analyses. The new Section 4.3 shows that there is a slight model rotation, resulting in an absolute elevation difference between the least and most retreated bank scarps of 4 cm. This has been discussed in Section 5.1 in the context of the other error sources. Also, the new Section 5.3 discusses the adopted workflow and recommends improvements for future works. The magnitude of the model rotation cannot be appreciated in the metre scale of Figures 9 and 10. These Figures show that the DSM was sufficiently accurate to measure bank erosion processes. This implies both sufficient accuracy and resolution at the bank area to quantify the three phases of the erosion cycle and the respective processes. We have added a quantitative reference to assess the performance of the method in this regard.

Technical corrections:

RC: Abstract. Whilst Westoby et al 2012 did use hyphens when writing Structure-from-motion, this is an error . In the computer vision domain, where SfM was invented, hyphens are not used and so it is corectly written as Structure from Motion.

AC: The hyphens have been removed in all sections.

RC: Section 2.2 This section does not cover the needed material to adress this case study. Need more on GCP distribution and on how a point cloud is georefenrenced. See Fonstad et al 213 or Carbonneau and Dietrich 2017 (both aldready cited) for details

AC: An explanation of the particular challenges of this case study for SfM has been added in Section 2.2. Also, a description of error sources and model georeferentiation has been added to Section 3.3.

RC: P7 line 7. By default, Cloud Compare computes differences along the Z axis. Did you use the M3C2 module which computes differences along the surface normals? Please clarify.

AC: The two computations P7 line 7 refers to were done with the cloud/cloud distance tool of CloudCompare. The distances between the 129 GPS points and the ALS grid were computed with a local 2.5D Delaunay triangulation of the latter. Then, the vertical component was obtained whose statistical results were presented in Table 3. The, ALS – SfM comparison was done between the nearest points of the respective clouds. This has been clarified in Section 3 of the manuscript.

RC: P8 line 13. Please add a photo of your target. If you have a 12cm diameter circle in the centre, then how do you accurately place the GCP in Photoscan? Are you using some machine assisted algorithm? At 25m, the P4 camera will give you 1.3 cm pixels at nadir. This means that you target centre could be almots 10 pixels wide. How do you find the exact centre and so benefit fully from the accuracy of the RTK GPS? Note that errors at this stage, combined with your co-linear steup of GCPS could contribute greatly to rotational errors of the whole point cloud.

AC: The centre of the targets was manually identified, without any machine assistance. The identification of the target centre relied on three concentric geometries, which were respectively used depending on the camera-GCP distance and the specific light conditions of each case. The smallest target was the CD inner circle with approximately 3.5 cm of diameter. This was used whenever visible. For the furthest targets and in those cases where the whole CD or tile were reflecting too much light to the camera, the CD or tile centres were estimated based on the shape of their boundaries. Later, fast flipping through photo focusing on single GCP at a time (with the PageUp / PageDown keys in PhotoScan) helped to adjust the estimation of the target centre. This procedure turned consistent the location of the GCP among all camera views. Yet, this does not prevent introducing errors when identifying GCP target locations. A photo of the target has been added to Figure 3, together with two more panels showing how a target is seen from the UAV paths 1 and 2. A new Section 5.3.3 clarifies the GCP identification

procedure and the effects it has on accuracy.

RC: P10 Figure 3. This is not a good view since scales are hard to determine. Better use a side view and a top view, both in orthometric perspectives so that a scale bar can be added.

AC: Two scales were added in the perspective view of the DSM as references (for the corridor width and bank scarp height). Figure 3 has been expanded with two more panels showing an orthometric top view from Photoscan and an schematic side view with the UAV positions (since the sideview in Photoscan turned confusing with too many photographs).

RC: Also, the choice of linear flight paths (here called tracks) parallel to the shore is again highly sub-optimal. This will only contribute to possible rotation errors. A grid pattern with multiple views would have been much more stable.

AC: We have included a discussion on UAV paths in Section 5.3.2.

RC: Figure 4. Please overlay the image footprints.

AC: It has been done.

RC: P11 From here you only use vertical error estimations to characterize method success. But as stated above, you could have other linear errors affecting the model. I note that the error distributions are bimodal with a dip for the number of errors in the 0 bin. This is consistent with a block rotation where few points (along the line of GCPs) are exactly corect. Many are either too high or too low. But this is not a vertical error in the photgrammetry process, it is the effect of rotation.

AC: Thanks for this interesting observation. We have plotted the elevation errors at the rotational plane to analyse the signs and distances to the rotation axis. Indeed, this tendency is confirmed showing that errors at the floodplain and the terrace not only have respective positive and negative biases (as already presented in Table 2, column for Test 3), but also present a consistent trend across the rotational axis. This is then most likely caused by a small model rotation. We also acknowledge the role of vegetation cover (grass over the floodplain) as a source of overestimating ground elevations, and we do not discard non-linear effects on the terrace (beyond GCP limits), as possible errors present in the DSM that result in the achieved overall model accuracy. Overall, we agree with the analysis on the basis of the results, and do not discard the influence of other error sources that may contribute to enhance the linear trend. The analysis of linear rotation of the model is in a new section 4.3, and the results are discussed in section 5.1.

RC: P13, Figure 7 Before you decide to crop data, you must show all the data. If you do crop, please select an objective criteria. e.g. 100 m buffer around each GCP. At the moment, the data looks manually cropped to variable distances away from the GCPs. A more rigorous approach is needed.

AC: The crop criterion along the floodplain had the intention to avoid the lines of brushes that lay across it (visible from the aerial photograph in the background). This shape was the result of cropping the LIDAR data prior to the comparison with the SfM point cloud. For a more robust approach, the ALS data has been cut along the boundaries of the SfM dense point cloud (visible in Figure 3), which are bounded by the area photographed from the nadiral UAV view (track 2). This criterion results in a overlapping domain between ALS and SfM data with an approximate constant width of 42m. Figure 7 now shows all available data.

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