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## Reply on RC1

Belizario A. Zárate Torres et al.

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Author comment on "GNSS and RPAS integration techniques for studying landslide dynamics: Application to the areas of Victoria and Colinas Lojanas, (Loja, Ecuador)" by Belizario A. Zárate Torres et al., Nat. Hazards Earth Syst. Sci. Discuss., <https://doi.org/10.5194/nhess-2021-32-AC3>, 2021

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The manuscript presents a study of landslide movement from a series of campaigns obtained with GNSS and UAS surveys at two test sites. The presentation of the manuscript is good in terms of details on data collection, understanding and interpretation of results. The scientific questions are also relevant to the scope of NHES. While the methodology adopted in the manuscript generally follows the common practice, it does not provide any novel concept or tool and does not directly attract readers. For example, in order to improve the manuscript the authors should think beyond the fundamental applications of GNSS and UAS processing, they could further explore errors associated with those techniques and the impact those errors can often have on landslide estimation. Alternatively, they could also explore other morphological attributes of DEM to identify cracks and scarps in a more automated fashion. These are some examples to further investigate landslide dynamics with a step away from the conventional geomatics techniques (i.e. GNSS and UAS). I would recommend some major revision of the manuscript to include some more interesting concepts that are currently missing and correct other issues that are included in the specific comments. The positive point in this study is that there are a lot of data collected which is not always feasible. The authors should take this as an opportunity to generate something catchy and interesting providing greater value to the geomorphological research community.

While the authors have nicely given good credit to related work there are few publications worth including in the manuscript that I have commented below in the specific comments. Additionally, there are some recommendations to change the structure of the text and explain the error propagation law earlier within the Methodology section. The UAS camera calibration part is also missing, and SfM self-calibrating bundle adjustment should be mentioned in the Methodology. It would be clearer if there are some figures showing the unstable/stable regions and which targets have been used for GCPs and which for CPs. Some more figures of detailed maps over particular scarps would be also good to add. The abstract is currently under-presented. The authors should show in a better way the bigger

picture in the abstract (why this study is important) and the novel part of the methodology, with some tangible comparable results to attract the general audience.

Firstly, we would like to sincerely appreciate your comments and suggestions. This an advance of the response we are preparing after the closure of the open discussion.

We are rewriting the abstract and restructuring the sections to make the paper more easily for reading and understanding. We also rewrite some parts of the methodology especially those related with the SfM and MVS pipeline for image orientation and DEM/orthophoto generation, and also to the uncertainties estimation. We attend also to specific suggestions.

Specific comments

Line 43: RPAS also known as UAS too.

**Answer: Suggested change has been made in the text.**

Line 50: Strictly Speaking, these processes (i.e. SfM and MVS image matching) constitute a pipeline that does not result only in an orthophoto. The actual output is a dense point cloud, then this is converted into an orthophoto, and a DEM via interpolation methods. The DTM is a by-product after ground classification. The DSM is also a by-product after some additional processing to create the surface model without noisy points. As a generic term I would recommend to use DEM throughout the manuscript.

**Answer: Your suggestion is appropriate and will be taken into account for the revision of the whole article**

Figure 2. Caption: What do you mean by photograph February 2016? Is this a UAV-based orthophoto of the entire study site or a single image taken by a UAV? Please make sure to specify this in the caption.

Line 82: Figure 2 shows an orthophoto reconstructed with UAV imagery, and detailed views over particular scarps and cracks taken with a compact camera? Please specify accordingly, see also the previous comment.

Figure 3: Same correction as for the caption of Figure 2. This is not a photograph, it seems like a UAV-based orthophoto.

**Answer. The images were captured by UAV procedures. The supporting field photographs of cracks and other surface phenomena were recorded with a conventional camera.**

Figure 4: What do you mean by ventral camera? Is this a typo? Could you please state here the GoPro camera that was carried by the quadrotor?

**Answer: The ventral camera is the one used to capture aerial images and was located at the bottom of the UAV. The term ventral refers to what is underneath the UAV.**

Line 109-110: A reference base station is used from SIRGAS which means that the accuracies mentioned earlier are relative to this station. How far is this station from the study areas (i.e. how long the baselines are)? Please make it clear that relative accuracies have been calculated with Trimble and also mention the length of the baselines.

**Answer: It is indeed a reference station in the SIRGAS network. The length of the baseline will be inserted in the document.**

Table 2: Could you please elaborate more in the text on what is the number of flyovers? Also, it is more interesting to include in the table the number of tie points reconstructed.

Line 136: It should be mentioned that the 2.77 mm focal length is the nominal one and not the calibrated one, since no calibration was performed. It is quite important to be specific with those terms to help the readers.

**Answer: The camera has a focal length of 2.77 mm and corresponds to the nominal focal length. The clarification will be made in the document.**

Line 140-141: This sentence is a bit vague. What do you mean that textured digital 3D models where appropriate? I assume you created a texture of the reconstructed 3D model for the entire study site. Also, I believe that DEM is more correct rather than using DSM as a terminology here see previous comment.

Just for clarity: SfM pipeline constitutes the first step for image alignment which leads to tie points (or sparse point cloud reconstruction based on Agisoft terminology), the densification of point cloud results in a dense point cloud and is performed with the aid of dense image matching multi view stereo algorithms, texturing helps the orthophoto creation. I would suggest to rephrase those sentences and make the description clearer. A good reference to use when it comes to terminology in photogrammetry is: <https://doi.org/10.1111/phor.12146>. Please correct some terminology throughout the manuscript using this reference: for example "point cloud is reconstructed"

**Answer: The paragraph has been rewritten according to the suggestions and the terminology recommended. Besides, the term DEM has been used in a coherent way through the whole text.**

Figure 5 and 6 a and b do not offer anything interesting as they are similar to Figure 2 and 3. It would be more interesting to differentiate which points were GCPs and which were check points in all maps. Also it would be interesting to show the scarps and cracks over the generated DEMs. I think it is better to show the DEMs only rather than orthophotos. If you really want to have all generated orthophotos you can have them as a separate figure in Appendix (or supplementary material).

**Answer: We have preferred to keep all the figures. Thus, in Figures 2 and 3 we**

**present the morphological features and the GNSS network over the orthoimage. We think that cracks and scarps are better visible on orthophotos at the figure resolution. Then, in figures 4 and 5, we present both the orthoimages and the DSMs, with the GCPs and checkpoints.**

In terms of dense matching: it would be interesting to mention in the manuscript what method was set up in Agisoft in terms of depth mode reconstruction (e.g aggressive, mild, or moderate?) Each method has different results. Also, have you used high (or ultra) accuracy for point cloud generation? What did you do to check any errors in the point cloud (biases e.g. high uncertainties in the tie points)? Have you performed any clean-up process before generating the DEM and orthophoto? Perhaps some points were erroneously located (e.g. flying points etc.).

**Answer: In terms of depth mode reconstruction we used aggressive mode and high accuracy. The DEMs were subjected to a process of manual removal of vegetation such as grasses and small shrubs. High vegetation areas were not eliminated. The control points were located on the ground with the utmost care in order to avoid location errors.**

Line 176: Why did you use 3 m as a threshold how did this come from, could you please elaborate more on this?

**Landslide evidence in the study area are related to subtle changes in the terrain elevation, usually lower than 3 m and even 1m. Thus to detect visually these changes, we saturate the palette in values higher 3 m that is enough to observe the landslides evidence. The text has been to express better this idea.**

Table 4 and 5 do not really add anything in the narrative, can be just included as complementary materials. Instead, the displacement uncertainty per point is more valuable to be added in a table. For some reason it is not really clear that you have calculated the uncertainties based on the error propagation law from the beginning of the methodology description. I had to reach the Discussion to actually realise that you have adopted the error propagation law but this is placed wrongly too late in the manuscript. I would suggest to move the accuracies and errors section back in section 3 as a main part of the methodology before presenting the results.

**The suggested change has been made, and the uncertainties will be included in the methodology section.**

Line 234: Before calculating the displacements at monitoring points from the subsequent DEMs, have you checked how well the DEMs are co-registered with each other? The fact that they have been georeferenced with very few GCPs (5 and 6 are not really many points) does not mean that there might be unresolved co-registration errors. This is a step that should be included in the methodology.

**Answer: Responding to Table 4 and 5 and line 234, the suggested changes have**

**been made**

Table 6 and 7: SDs and RMSEs in Tables 6 and 7 are relatively high (e.g. 0.08 in xy). Have you considered to remove features above ground first, before calculating DODs? It would be perhaps better to remove/mask/filter out areas with buildings and trees and perform a point cloud cleaning process and then a ground classification to remove unwanted flying points over the grass that might be picked when extracting their location in DEM. Other questions that arise here is how easily you could identify those concrete targets on the DJI images in Agisoft (there are no black and white markers in the middle for a better recognition aren't they) and what are the settings you used for the image alignment?

**Answer: For the generation of the DoD, manual filtering of the arboreal areas and pastures was carried out using the Agisoft software tools. For the orientation of the models, the control points and checkpoints were used, and they are found on the ground in the form of crosses of rocks painted white, in the maps they are not possible to visualize them due to the assembly of the used symbols. Considering the suggestion, this topic will be supplemented in the article to clarify the adjustment work.**

Lines 326-327: Displacements of points over stable areas should be null. Table 6 and 7 show high SD and RMSEs with a cm-level mean displacement. So small mean value but high errors, how do you explain this? Do you think that if you had applied point cloud cleaning and ground classification before calculating the displacements would have reduced those errors? Also, what about co-registration errors (see previous comment).

**Answer: The main photogrammetric products obtained using the UAV technique are orthophotos and MDS. If an automatic or manual filtering of vegetation or other elements on the surface is carried out, a DTM could be generated, however, this could be obtained with the use of LIDAR techniques that allow generating a more real terrain.**

**This difference causes errors to be generated in the measurements that can be generated mainly by manual filtering.**

Lines 332-333: I would suggest to clean the point clouds and check any unresolved co-registration errors (Cloud Compare is a good free tool for that) and re calculate the uncertainty threshold, because I think some noise can be reduced at earlier stages of the methodology.

**Answer: The dense point clouds generated in the Agisoft software were entered into the Cloudcompare software. Vegetation filtering was performed, generating DEMs and DoDs were generated. The results generated the same results. The variation of the errors generated is + - 0.012 m, which when compared with precision thresholds do not affect the initial results. It should be noted that the area of the slope movement lacks mostly vegetation greater than one meter, so in this work, the most significant errors occur in the margins where there is vegetation greater than 1 m.**

Line 446: Even though it is well acknowledged here in the Conclusions that the methodology need to be improved with vegetation filtering, I still believe that point cloud noise filtering and error checking should be undertaken at this stage and not in the future to further enhance the quality of the results.

**Answer: The comment is valid, this section will be analyzed and written**

Technical corrections

**All technical corrections have been made according to the suggestions given.**