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

A. Eltner et al.

anette.eltner@tu-dresden.de

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-First of all, we would like to thank Matt Westoby for his comprehensive review. It is essential to improve the manuscript, especially regarding the focus of the work. Thank you for your time and important comments. -In the supplement we include the revised manuscript and marked changes that were made in regard to the original manuscript. Thus, in the answers to the reviewers we refer to the manuscript in the supplement.

General comments: Eltner et al. summarise methods, applications and potential future developments of image-based surface reconstruction in the geosciences. The vast majority of the paper is concerned with the most recent incarnation of image-based

surface reconstruction, namely 'Structure-from-Motion'. I enjoyed reading the paper – it is generally well-written and is comprehensive, but perhaps a bit on the long side.

However, I have a major concern about the structure and focus of the manuscript. I am left slightly puzzled as to what the paper is trying to be, since it contains large blocks of descriptive text close to the beginning which reads as a manual for SfM/photogrammetry use, which is followed by, essentially, a list of key papers by field, which is in turn followed by an overview of sources of model error, and concludes with a discussion of potential future avenues for future research. I think the structure needs some work, as I struggle to see how it all fits together in its current form.

-Thank you for your comment. We reconsider the focus of our work and in the revised manuscript we concentrate stronger on developments regarding SfM performance as well as future avenues.

Much of the text that describes, in detail, how image-matching and surface reconstruction methods work could be streamlined significantly or removed entirely. Overviews of the various workflows and methods are already presented in a number of papers, and I don't see much value in repeating these (see for example Smith et al. (2015) Progress in Physical Geography – doi: 10.1177/0309133315615805). The most interesting text is that which describes the key developments and potential future avenues for research in this field, and how they relate to geomorphology/geomorphometry – I also note that there is no distinction between these two terms.

-Thank you for your thought. We shorten the method description significantly and refer to Smith et al. (2015) for more detail. Solely issues not especially discussed in Smith et al. (2015) regarding the method are kept in revised manuscript.

My recommendation is to re-focus the paper to concentrate on the key developments in this field through time, and discuss the impact that these developments have had, or may have, on geomorphological and geomorphometric science. There is plenty to write about here and much of which is already done very well in places, but it needs

some reorganisation and streamlining. This would constitute a substantial revision. Please see my specific comments below.

-Thank you for the comment. We stronger focus on your suggestions and extended some explanations. However, we believe it is very difficult to hypothetical discuss about future trends and would like to keep this to a minimum and rather concentrate on previous key developments and current accomplishments.

Specific comments:

Title: Image-based surface topographic reconstruction techniques have been in existence for decades now, with SfM approaches becoming popularised in the last 5 years or so – I think referring to them as 'promising' in the title short-changes what has already been demonstrated – I would argue that we're definitely at a stage now where their potential has been demonstrated, but perhaps not fully realised and applied. I suggest simply changing the title to end '- merits, limits and future developments.'

-We change the title according to your suggestion.

The word 'geomorphometry' is not defined. My understanding is that it refers to the science of digital terrain analysis, although the definition has been debated in the literature. Nevertheless, it is worth including somewhere a distinction upfront between 'geomorphology' and 'geomorphometry', which are different things.

-Thank you for your thought. We also think clear distinction between both terms is important. However, in the entire article we do not refer to geomorphology explicitly, we only refer to geomorphometry. Thus, we do not think it is necessary to give an extra definition regarding geomorphology but we add a short information regarding the term geomorphometry.

P1447, L6 – I'd use 'three-dimensional' instead. 'Tridimensional' isn't a commonly used term in this field.

-We change the word according to your suggestion.

P1447, L21 – already two different ways of writing SfM used... Please stick with one longhand and shorthand version throughout – would suggest 'Structure-from-Motion' or 'Structure from Motion' for longhand, and 'SfM' as the shorthand. Also define abbreviations at first usage – should write 'unmanned aerial vehicle', with (UAV) in brackets, and place (SfM) after first usage on line 14 (refer to journal guidelines).

-Thank you for noticing. We correct it.

P1448, L22 – initial estimates of what? Presume you mean camera positions, so please make this clear – this early in the paper a layperson won't know what you mean.

-Yes, indeed, we missed to clarify this. Thank you for noticing. Indeed, we mean the image network geometry.

P1448, L26 – you could be more specific here – with suitable ground control, SfM can offer centimetric levels of detail or spatial resolution, for example, and, for reasons of practicality, ground resolution generally degrades with increasing areal coverage (i.e. currently tricky to model at centimetric resolution over an area of many square kilometres...)

-Thank you for your suggestion. However, we would like to keep the statement as it is due to the following: On the one hand, SfM can offer even higher level of details (even sub-mm) solely depending at the sensor to surface distance (and closest focus distance). On the other hand, the grade of degrading resolution is rather a function of flying height/surface-sensor-distance, which of course increases with areal coverage due to practical reasons, and this point is discussed in more detail later in the manuscript. Thus, in the introduction we would like to avoid further explanations.

P1448, L27 – might be useful to explain what you mean by 4D here - three spatial dimensions plus a temporal dimension.

-Thank you for noticing. We clarify this in the manuscript by mentioning the temporal dimension.

P1450, L14 – do you have a reference to support this number of 9 tiepoints per image?

-Thank you for your question. However, we rephrase the entire chapter and exclude this information in the revised manuscript to avoid confusion and concentrate on main issues.

P1450, L22 – no need to define SfM again.

-Thank you for noticing. We correct it.

P1453 – Section 3 currently reads much like a list, with scope for much more reference to how the studies you highlight fit within the wider field of geomorphometry. I actually think that section 3 would work better if placed later on in the paper, after you have introduced non-commercial tools for SfM photogrammetry (section 4), and before section 5 – although see my general comments on this section above. I think it would work better to cover all the methodological developments from oldest to newest, then showcase existing applications, and then conclude the paper by discussing potential future developments or avenues for research. Another option might be to weave the various applications in with their associated methodological developments as the paper progresses – you have begun to do this in places – e.g. in section 3.5 you state how Prosdocimi et al. (2015) used smartphone imagery for SfM input – this is an important development (see also Micheletti et al. (2015) - ESPL) and is a methodological advance which has wider applications beyond just fluvial science.

-Thank you for your suggestion. We move section 3, as you propose. Regarding section 3 in more detail, we would like to keep our depiction of displayed studies because we try to show these applications that made a step forward, just as you suggest later. However, we conquer that a better presentation would be advisable. Thus, we include a timeline (table 3 in the revised manuscript) displaying the key developments and applications that enlarged the view on SfM photogrammetry and also reconsidered our corresponding listing in the revised manuscript. We further restructure section 3 and 5 in the manner that we include a chapter displaying the method on how we got to our

conclusions.

P1456, L16 – strictly speaking, the paper by James and Robson (2012) was the pioneering paper to demonstrate the application of SfM in a coastal setting, not Westoby et al. (2012). I would clarify this.

-Thank you for noticing. We rephrase the sentence to avoid confusion with the work by James & Robson (2012).

P1458, L24 – section 5 – at this point the manuscript reverts again back to a kind of 'user manual' style of writing, which is at odds with the previous section, and doesn't flow very well. This section is very descriptive, and would fit far better into the manuscript as a whole if it focused on the literature which identifies model errors and develops methods to recognise or eliminate them. It seems as though the authors have scrutinised the papers that are summarised in Table A1 and looked at what degree of data quality analysis has been carried out, but in fact it might read better if it was structured in a way that describes how researchers have come to identify and mitigate these errors as SfM usage has increased in recent year. I agree that a full appreciation of the sources of error in the SfM workflow is crucial, but I'm not sure this is the right paper in which to delve into this much detail – indeed, if you expanded this section, there's probably enough material for an entirely separate paper.

-Thank you for your comment. We would like to keep the current structure because we believe to better comprehend and recall errors it is advisable to order them after their sources. However, we move the error explanation and approach to retrieve the information into an extra methodological chapter (which also contains the application chapter approach). Also, we try to connect better to the application chapter by considering the timeline. We believe error evaluation should be considered in this review because we also want to show limits of the method and we believe a detailed description is important to minimise disadvantageous method implementations in the future.

P1471, L21 – I like section 6. To me, this is the most interesting part of the entire

paper. I would like to see these sections expanded – they are quite short at present (with the exception of section 6.1), and could be developed much further. One major development which is not covered is 'direct georeferencing', which entirely removes the requirement for ground control when constructing 3D models which can then be subsequently used for formal, metric analysis – see e.g. Nolan et al. (2015) The Cryosphere. This technique is mentioned in Figure 11, but does not make an appearance in the text, which I find strange. Direct georeferencing can significantly expand scales and locations of observation since previously inaccessible areas, where establishing a ground control network would be impractical or altogether impossible, could be surveyed. I would request that the authors include this as a new sub-section and discuss its merits and current limitations.

-Thank you for your suggestion. We expand the chapter where possible and include a sub-chapter regarding geo-referencing.

Figures:

Figure 1 – remove 'exemplary' from figure caption.

-We remove it.

Figure 5 – is the error ratio in the form '1:XXXX'? Needs labelling. Is 'distance' the distance between camera and object, or scale of the feature or landscape of interest? Not clear at present. There are a total of seven figures concerned with model error statistics. These need combining into one or two multi-panel figures if the authors decide to keep them following revisions to the text.

-Thank you for your suggestion. We correct the labels. We certainly will combine figures for better readability (fig. 5 in the revised manuscript) and delete some to keep the figures to a minimum.

Figure 11 – you mention 'direct referencing', otherwise known as direct georeferencing, in this figure, but I can't find any mention of it in the text. It needs discussing since it

is currently one of the most significant developments in the field as it removes the requirement for ground control, thereby expanding the potential scale and types of application.

-Thank you for noticing. We discuss direct georeferencing in more detail in the manuscript.

Figure 11 – 'Vehicles'... UAVs, helicopters and boats are all types of vehicle. I think you mean wheeled vehicles (e.g. cars, jeeps etc) – please clarify.

-Thank you again. We clarify the types of vehicles.

Please also note the supplement to this comment:
http://www.earth-surf-dynam-discuss.net/3/C720/2016/esurfd-3-C720-2016-supplement.pdf

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