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Discussions

Interactive comment on "The SF3M approach to 3-D photo-reconstruction for non-expert users: application to a gully network" *by* C. Castillo et al.

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Received and published: 23 June 2015

R stands for the referee comment and A for the authors′answer.

- R1: "General comments: This valuable paper presents a well-timed contribution to the current developments in photo-reconstruction and closes a gap for users from various disciplines. As discussed in earlier publications a demand for a straightforward workflow for image based surface reconstruction existed since open source tools (such as vSFM, CloudCompare or meshlab) emerged throughout the last years. The here presented publication introduces SF3M as a new open source GUI that avoids switching between software including tedious steps of data preparation such as considering different file types for different tools or formatting .asc-files with point cloud data.

The functionality of the tool is achieved by combining the great software CMVS/PMVS (Furukawa and Ponce) respectively the according GUI approach named visualSFM (Wu), various Matlab scripts and point cloud editing tools (filters) from CloudCompare (Girardeau-Montaut). During this review the program was tested with an own (UAV) datasets. Results proved to be of high quality (dense reconstruction showed very little noise in the point cloud), calculating times were fast and the process all in all stable. In comparison to commercial equivalents the operability can be improved in certain aspects but this also goes along with other open source tools. Final assumptions on the performance of SF3M are not yet to be made as it needs to withstand a trial phase of inexperienced users and different data sets. Nevertheless, first test runs are very promising. The overall quality of the manuscript is high and with only one exception (description of the "SFM precision") very comprehensible.

The structure and figures are appropriate. A minor improvement could be achieved by a clear separation of both methods applied: On the one hand the authors present a new approach for data acquisition with a pole and two GoPros and a long walking itinerary while on the other introducing a novel software tool. A clearer distinction between both parts could be given in the introduction. Still, the here described campaign of gully measurement is a good choice to demonstrate the capabilities of the method due to the inherent morphologic complexity of gully systems. As mentioned above, the presented work has the potential to play an important role for DEM generation for non-expert users in various geoscientific contexts.

A1: We will reorganize the introduction to provide a more consistent distinction between the software development (SF3M) and the survey methodology according to the reviewer′s suggestion:

"3D photo-reconstruction (PR) based on structure-from-motion (SfM) algorithms has been applied to date to a large number of geoscience applications (James and Robson, 2012; Westoby et al., 2012; Fonstad et al., 2013). Although there has been a great advance in the last years regarding imagery collection (for instance, derived from the

development of UAV platforms) and image processing (commercial as well as free software), the complete photo-reconstruction (PR) and analysis workflow frequently remains lengthy and not straightforward (Kaiser et al., 2014).

If using freely available software, it requires working on a number of different applications to cover basic image pre-processing, photo-reconstruction, georeferencing and post-processing operations. Commercial PR software generally has the ability to perform full PR workflows, but can lack detailed processing information and can restrict user interaction with intermediate and final results. New recent computer developments offer new opportunities to improve data processing. Powerful and freely available software applications have been developed - e.g. VisualSFM for photo-reconstruction (Wu, 2013) or CloudCompare for cloud processing (Girardeau-Monteaut, 2015) among others - and are being constantly improved through the valuable effort of their developers and users' feedback.

While recent UAV technologies have the capacity of surveying large areas of the landscape (Mathews and Jensen, 2013; Mancini et al., 2013), not all stakeholders (e.g. researchers, technicians and land owners) have the technical and financial resources to use such sophisticated techniques. In addition, government regulations in several countries are becoming increasingly stringent for UAV operations, which hamper the widespread application of this tool. Terrestrial PR approaches represent an alternative which might still be advantageous for several applications, especially when there are regulations or budget constraints as it is frequent in both developing and developed countries. Fonstad et al. (2013) suggested that terrestrial PR techniques could improve their cost-benefit performance by using multiple operators, poles, video capture or a combination of terrestrial and aerial images.

3D PR has been used for gully erosion assessment at the gully reach or headcut scale (Castillo et al., 2012a; Kaiser et al., 2014; Gómez Gutiérrez et al., 2014) and ephemeral gullies (Castillo et al., 2014), usually not more than over a few meters extent. However, the fully characterization of gully erosion requires the assessment of entire gully net-

works to understand their geometry and dynamics and this brings several challenges for terrestrial PR: 1) morphological complexity: gullies comprise long networks of varying size along their length; 2) valley location: gullies are deep trenches that do not facilitate easy all round image collection, hampering multiple convergent perspectives; 3) linearity: gullies present very high length/width ratios making the photo-reconstruction models more vulnerable to systematic errors.

As an effort to facilitate the use of freely available PR software for demanding gully erosion applications, here we develop a combination of SF3M (a workflow software tool for efficient processing of accurate 3D models of gully networks at a reduced cost) and a rapid terrestrial survey method. For this purpose, 1) we present SF3M, a new graphical user interface to guide PR workflow carried out with existing freely available software; 2) we describe a field methodology for the rapid assessment of gully networks; and 3) we evaluate their performance and the 3D model accuracy with a study case of gully erosion in the Campiña landscape."

- R2: After minor revisions, mainly a few typing errors and suggestions, I fully recommend and support the publication of the manuscript. Please also note the supplement to this comment: http://www.soil-discuss.net/2/C161/2015/soild-2-C161-2015-supplement.pdf" A2: We will answer the reviewer's comments following this supplement.

- R3 supplement: Page 371, title I somehow miss the fact that you present a whole new software tool A3: After the reviewer comment, we have changed the title to: "SF3M software: 3-D photo-reconstruction for non-expert users and its application to a gully network".

- R4 supplement: Page 372, line 3 Alternative: "surface models" as elevation might be misleading to classic DEMs while also pointclouds and meshes are produced

A4: Thank you for the suggestion. We will change to 'surface models' in this context.

- R5 supplement: Page 372, line 4 The purpose of this sentence is not clear. Does it refer to challenging scenarios during data acquisition or later data handling?

A5: We will modify the sentence to be more specific: 'However, innovative approaches are required to overcome some limitations that this technique may present for field image acquisition in challenging scene geometries'.

- R6 supplement: Page 373, line 22 Montaut A6: Our apologies. This will be corrected in the final version of the manuscript.

- R7 supplement: Page 375, line 17 How was this guaranteed? There might occur an offset during long campaigns due to different exposure times of the GoPro dependent on the lighting. Could this cause issues?

A7: Our apologies. We will change 'simultaneous' for 'near-simultaneous'. It is not necessary for reconstruction purposes in static field scenes to guarantee the exactly synchronised triggering of both cameras. Only a suitable overlap to provide connectivity (image matches) across the image set is required.

- R8 supplement: Page 375, line 17 On

A8: Our apologies. We will correct this in the final version of the manuscript.

- R9 supplement: Page 376, line 7 Could the properties and type of the lens be given?

A9: Our apologies. We will include their specifications in the final version of the manuscript. The first GoPro was modified by installing a 4.14 mm focal length f/3.0 aperture non-fisheye lens and the second one installing a 5.4 mm focal length f/2.8 aperture non-fisheye lens. Both lenses were provided by Peau Productions company (http://peauproductions.com/store/).

- R10 supplement: Page 376, line 14 Information on a potential overlap would be of high interest, especially with regard to the non-fisheye lens.

A10: The camera arrangement (adjacent cameras, that with nadir perspective in a

slightly higher position) was designed to provide a very high overlap between images. The nadir camera provides a closer look to the gully while the tilted one captures a larger scene (both in length along the gully and in width across the gully margin). The text will be modified to include a reference to the overlap: "Both cameras were fixed to the pole end adjacent to each other and held in a horizontal position with the help of plastic wedges and cable ties. One camera looked down in a roughly nadir perspective (closest to the pole end for a higher elevation to compensate for the less deep perspective) and the other was inclined to around 10°. This camera arrangement was intended to: a) obtain a high overlap between images taken with both cameras; 2) ensure the connectivity of the whole image set obtained from different sides of the gully: the two nadir image sets (up- and downwards itineraries) will serve as connectors and the two tilted sets will provide image convergence. Both aspects would be helpful to obtain one single 3-D model with geometric consistency. The typical overlap derived from this camera setting, the walking speed and the time-lapse interval was around 90% for successive images taken from the same camera. As for the overlap between different camera images, the tilted images encompassed totally the scene captured by the nadir camera due to its higher position and inclined orientation".

- R11 supplement: Page 376, line 21 Please explain the purpose

A11: Using two different colours of GCPs corresponding to odd and even numbers (for instance, for geo-referencing and checking errors respectively) is not really necessary for georeferencing purposes, but it can be useful for deploying the GCPs in the field in an orderly manner. This strategy is advantageous when deploying a GCP on one side of a gully to make easier for the operator to visualize that GCPs are set in alternate positions by looking to the colour of the targets deployed on the other side. Thus, the operator can avoid locating georef or check GCPs on the same area. Ideally, one would prefer to distribute both georeferencing and check points homogenously across the gully. We will modify the text in the following manner: "Forty five targets, hereafter called ground control points (GCPs), of 20x20 cm dimensions in two colours (pink

for even numbers and yellow for odd numbers). This colour symbology was meant to differentiate georeferencing GCPs (even numbers) and error-checking GCPs (odd numbers) to facilitate the operator the deployment of targets in the field."

- R12 supplement: Page 377, line 1 Maybe a, b, c... would clear things up a bit for the reader as there are two lists with figures entangled.

A12: Our apologies. We'll follow the reviewer's suggestion and use letters to order the first list: "a) pre-processing to prepare the image set (automated); b) project definition, to check the image connectivity and the number of subprojects to process (semi-automated); c) photo-reconstruction (automated); d) georeferencing (semi-automated); e) post-processing (semi-automated)."

- R13 supplement: Page 377, line 7 Space.

A13: Our apologies. We'll insert the missing blank space.

- R14 supplement: Page 378, line 3 Than.

A14: Our apologies. We'll change for 'than'.

- R15 supplement: Page 378, line 21 As a general remark it would be advantageous for users to have the numbering fitted to the actual steps in SF3M (e.g. 4. Photo reconstruction). Maybe the first bullet point can stand alone

A15: Although we agree with the reviewer that it would be advisable to be as consistent as possible in the numbering across the manuscript (text and figures), the classification in 2.3. section (Processing methodology in SF3M) focuses on the key features rather than on the specific commands included in the main window of the interface. We believe that trying to follow the same numeration in this case would result in excessive detail and missing the significant contributions of the SF3M design in this section.

- R16 supplement: Page 380, line 6 Please explain how SF3M tackles double z-values in case of undercuttings in gullies during DEM export A16: The DEM export tool in

SF3M follows the classical 2.5 D raster approach of assigning each cell a unique height value (z). Thus, all the height values of the 3D points (x,y,z) falling inside a particular cell are averaged to give this height mean estimate. Although this is a geometrical simplification (higher for coarser raster cell sizes), for many applications this approach may still be valid depending on the objectives of the study. If the user is interested in dealing with full 3D information, the better option would be processing the dense point clouds provided by the photo-reconstruction algorithm directly with a suitable point-cloud processing tool such us CloudCompare.

- R17 supplement: Page 380, line 12 Hard to understand the described procedure, please explain "image measurement". A17: We have reworded to clarify and to remove the phrase 'image measurement': "For each point, the local uncertainty is approximated by considering (a) the camera's focal length, (b) the camera-to-point distance in world coordinates, and (c) the maximum image error, where image error is defined as the image distance between an identified feature position and the projection of the associated 3D point in that image."

- R18 supplement: Page 381, line 7 Image collection, GCP deployment... A18. Our apologies. We will modify the text to clarify the sentence: "Image collection and GCP operations (deployment and measurement) had similar time requirements, ∼90 min each."

- R19 supplement: Page 382, line 25 Include "were"? A19: Our apologies. We will modify the text to clarify the sentence: "The points filtered as this last type of vegetation amounted to 4.1% of the total, although its detrimental effects on the model were significant at some gully bottom areas (Fig. 6b)."

- R20 supplement: Page 382, line 27 Bottom. A20: We'll correct this. This is included in the former correction.

- R21 supplement: Page 385, line 17 Single heavy rainfall events would be of interest. A21: Following the reviewer's suggestion, we will provide some extra information:

"Most likely, the peak of gully erosion took place during the 2009 and 2010, a wet period with annual rainfalls exceeding 1000 mm in the area (425 mm in one month during December 2009-january 2010 and 350 mm during December 2010). These wet years were preceded and followed by seasons closer to the average (650 mm per year)."

- R22 supplement: Page 386, line 7 Besides an evaluation a short outlook would be good: other possible applications, practicable improvements...

A22: Thank you for the suggestion. As an outlook, we will include: "Therefore, the survey design and processing methodology included in this study is a promising tool for gully erosion evaluation in scenarios with demanding budget and time constraints and reduced operator expertise. Moreover, SF3M provides a means for easy and fast 3-D photo-reconstruction in other geomorphological applications beyond gully erosion assessment. Future versions of SF3M will try to include new tools including improved GCPs detection and post-processing algorithms such as topographic analysis of the resulting DEM along with further improvement on the interface usability or on other aspects that might be suggested from users′ feedback ".

- R23 supplement: Page 386, line 13 Their A23: Our apologies. We will correct this in the final version of the manuscript.

- R24 supplement: Page 390, Table 2 Please insert lines above and below (compare to other work steps and required time) A24: Our apologies. We will correct this in the final version of the manuscript.

- R25 supplement: Page 394, Figure 3 The difference in their angles is hardly visible in this figure.

A25: Yes. This image was included to illustrate the camera settings on the pole (camera positions, wedges and cable ties) rather than differences in angle. We believe that this perspective provides the most practical visual information for other users interested in the image capture procedure. Moreover, a clearly visible depiction of the difference in

angle between both cameras is provided schematically in Figure 3c.