Response to referee #2

We thank the reviewer for the time taken to review our manuscript and for the useful comments. We respond to each of the individual review comments below:

Referee text is black.

Response text is blue.

Changes are red.

General comments:

The presented technology is interesting, and the manuscript shows the potential of this technology for analyzing the movement of individual grains within a granular flow. However, the manuscript focuses solely on the interpretation of the recordings and one of the main findings is that the technology requires further improvements. For example, the manuscript indicates that the system is not really stable (one sensor out of five did not work appropriately, and another produced false results).

The Smartstone probe is a prototype and not ready for serial production. Nevertheless, it already has practical applications (e.g. helicopter rotor blades, building stability surveillance). Of course, for other applications like landslide assessments, some issues have to be addressed by further improvements. During the experimental campaign, a total number of 10 experiments was performed. In each run, 5 Smartstone probes were used in the same way as described in the manuscript, meaning a total number of 50 data sets. From these, a total number of 36 data sets were successfully recorded and could be analysed. This means a rate of more than 70 %, which we belief is quite good for a prototype. The critical task is not to build the devices in a better way. Nevertheless, a deeper understanding of the data is necessary. This is discussed in detail in the text.

Moreover, the statements at L483 and following indicate that the data analyses need to be further improved and that the current analyses are, to some extent, premature.

We agree, as mentioned in the discussion. But from our point of view, also single (complete) steps in the knowledge gaining process should be published (see next comment). To our knowledge, this is the first article that tries to go beyond only plotting the acceleration time series (which has been done quite often before) and describing trivial statistical properties of the time series. We describe how to interpret the time series from a motion's point of view.

The presented material is interesting, but I do not see substantial and original scientific results which warrant publication of the manuscript as a research article.

We disagree with this statement. Scientific research progresses step by step. We belief it is good scientific practice to publish single step progress in detail. In addition, we belief that the presented method, corresponding results and analysis are scientifically relevant due to the following reasons: (i) We identified an important methodological gap in studying landslide motion processes. Only a sensor-based autonomous instrumentation allows for an observation of the interior of a moving landslide mass, as outlined already in the introduction. (ii) We documented a significant methodological improvement. The recent probe version was technically enhanced compared to the former version, which was presented by Gronz et al. (2016). Furthermore, advanced data post-processing and analysis algorithms were used. These sensor fusion techniques are well established in other disciplines like robotics but must be adapted to geoscientific research objectives, which is - to our knowledge - done for the first time in landslide science within the presented study (although rudimentarily in the first instance). Of course, there are limitations of the current probe and data analysis that must be communicated clearly, which is - again- good scientific practise from our perspective. Beyond that we outlined future improvements, which are already in preparation (e. g. casing modifications allowing larger batteries). (iii) Moreover, the Smartstone sensor-based probes were successfully used in diverse experimental settings such as single clast transport experiments (Gronz et al., 2016), breakwater experiments (Santos et al., 2019), and rockfill dam overtopping experiments (Ravindra et al., under review).

Resubmission as brief communication.

The presented material fits to the journal objectives that are listed on the journal's web page. One main scope thereby is the presentation of "design, development, experimentation, and validation of new techniques […]". This is exactly what we did in the submitted article. The submitted paper presents substantial scientific results within this scope. From our perspective, it is not possible to identify the research gap, propose an approach to contribute to filling this gap, present an appropriate methodological description, explain the new kind of data for geoscientists, and discuss the technical and scientific results within the format of a short communication. We are aware that not each of these aspects intrigues every reader. But we also belief that it is good scientific practice to draw the whole picture and to document all aspects of a study with an appropriate level of detail, rather to publish individual short reports.

The presented study and consequently the content of the submitted article exceeds the frame of a short communication significantly and must therefore be presented in a research article.

Specific comments:

P1, L2: I am not convinced that every reader understands what is meant by external and internal information.

It would be a solution to describe corresponding meanings at the beginning of the abstract. This will result in a lengthy abstract. From our point of view, the explanation should be given in the introduction, which already contains it.

P1, L4: The first "internal" can be deleted.

We disagree. *Internal* behaviour can – to a certain extend – be inferred from *external* observation. Or we can measure *internal* behaviour by *internal* measurements. Both of which are different approaches and to distinguish between them, both "internal" are needed.

P1, L6: "artificial laboratory-scale landslide" - artificial may be deleted

The word "artificial" was deleted.

P1, L7-10: Is this detailed information really adequate for the abstract?

Yes, it is! If a researcher scans literature searching for an appropriate sensor for his or her own experiment, he or she wants to efficiently exclude the sensors not applicable due to their size right at the beginning in the abstract.

P1, L11: I partly disagree with this statement - the movement of individual pebbles was observed with the Smartstone probe, but not the motion of 520 kg of the pebble material...

This aspect was clarified within the text.

Using the Smartstone probe, the motion of single clasts (gravel size, d_{50} of 42 mm) within approx. 520 kg of a uniformly graded pebble material was observed in a laboratory experiment.

P1, L12: Which mass is meant - the mass of the pebble-material?

The pebble material is meant.

Single pebbles were equipped with probes and placed embedded and superficially in/on the material.

P1, L13-21: This is mainly a description of what has been done - what is lacking is a more generalized description of the results - i.e. the novelty aspect of the study should be better highlighted.

The ending of the abstract has been changed:

Compared to other observation methods Smartstone probes allow for the quantification of internal movement characteristics and, consequently, a motion sampling in landslide experiments.

P2, L28: In my opinion the paper would benefit from additional considerations (including a review) on granular flow mechanics and how these can be described using the sensor data.

The article does not deal with the physics of granular flows. The material has been chosen due to different reasons: to prove the concept of the Smartstone and to allow for multiple repetitions under similar conditions, like described in Sect. 2.4.

P2, L32: What is meant by "some depositional features"? A more general description of the landslide processes would be helpful.

Meant is the extraordinary spreading of very large granular avalanches. This has been clarified in the text:

For instance, Davis & McSaveney (1999) reproduced dry granular avalanches and concluded that the extraordinary spreading of very large granular avalanches may be caused by phenomena like rock fragmentation.

P2, L36: What is meant by precess? Is "process" meant? I am also not sure that I understand what is meant here.

Process is meant. It has been corrected. No change in relative position means that blocks that started in the frontal part of the body stopped at the frontal part of the deposit as well (and vice versa).

P2, L37: Include year for reference Okura et al.

Has been included.

P2, L38: My understanding of the word "collusion" seems to be different from the understanding of the authors. Maybe "collisions" is meant by the authors?

Yes, collision was meant. Has been corrected.

P2, L40: The authors use specific terminology which has not been defined before. As indicated above, a more general description of landslide mechanics and granular flow would be helpful (also for the better understanding of the subsequent passages).

The submitted article is not intended as a review of granular flow experiments or landslide mechanics.

P2, L48: Please specify what kind of 2D section of the body is meant.

Has been clarified.

By means of (high-speed) video analysis such as particle image velocimetry (PIV) or the so-called fringe projection method (Manzella, 2008), only the surface or transversal sections of the body can be analysed.

P2, L51: This is true - but is the information also relevant for the description of the movement of the granular material?

This is correct, but we try to summarize the different types of instrumentation of landslides experiments, and this one should also be mentioned.

P2, L57: Replace "got" by "became"

Has been changed.

P2, L58: What is the technical aspect of so called 'smart tracers' for natural transport? These tracers can be helpful to collect data for the description of natural transport processes but have no effect on natural transport... (please try to be specific language wise throughout the manuscript).

Has been clarified.

Several studies focused on technical aspects (i. e. hardware and software development) of so called 'smart tracers' used to investigate natural transport processes (e. g. Spazzapan et al., 2004; Cameron, 2012).

P3, L59: What is the significance of this sentence?

It should demonstrate the wide range of applications for this method. It has also been clarified within the text.

Others applied these techniques to geoscientific or geotechnical questions, such as the impact of waves on armour units of breakwaters (e. g. Hofland et al., 2018).

P3, L65 and following: This could be more concise.

Has been clarified.

Additionally, the SSP needs wires for energy supply and data transmission and these wires confine a free movement of the device within the soil.

P3, L75: As already mentioned - the physics of the movement of granular material should be better highlighted. I fully agree with the next statement that the manuscript focuses on sensor application (i.e. on the method), and this is exactly why I see limits regarding the significance and novelty of the scientific findings. Therefore I finally recommended to resubmit the manuscript as a brief communication instead of a research paper.

The paper does not try to draw new conclusion on the physics of granular flows. In fact, this type of landslide was chosen as an example to test the usage of the Smartstone probe for experimental landslide science and what additional information can be collected (see also response to Referee #1).

P3, L79: Please improve the description of the objectives.

The description of our objectives has been modified:

1 There has been a significant technical improvement since Gronz et al. (2016) introduced the first version of the Smartstone prototype. Therefore, one objective is is the description of the recent Smartstone probe. In addition, we document major changes to the former version and the corresponding technical specifications.

2. Beyond that, we explain additional information that is supplied by smart sensors and illustrate the specific properties of motion data. Based on a quantitative interpretation, we give an introduction how to read motion data in terms of flume-scale landslide movements.
3. Subsequently, we demonstrate how physical movement characteristics can be derived from the measured raw data and in what way they are different.
4. Further, we highlight the potentials of two- (2D-) and three- (3D-) dimensional visualisation of the paths a clast took during the movement and how these visualisations allow for an easy recognition of complex motion patterns.
5. Finally, we investigate the limitations of the Smartstone prototype and discuss what developments will be necessary to improve the probe and data handling further.

P4, L93: Why "mainly"?

Because high-speed video observation was used as well but the focus of data analysis laid on probe data.

P4, L100: Why "available"?

The word was deleted.

P4, L122: Different dimensions have been mentioned before (L96) which is confusing - I find it also confusing that the dimensions are given only "approximately" - what are the exact dimensions?

As described in the text, the length of the casing can be adapted depending on the size of the plastic plugs that close the tube (see lines 96 to 101). Numbers are given as “approx.”, because they may vary slightly as the probe is a prototype and not a standardised device: each tube is manually shortened using a saw.

P4, L124: What is meant by "lager objects"? Is "larger objects" meant? Please check the language throughout the manuscript (I stop here giving comments on the language).

Has been corrected. We will engage English copy-editing services of Copernicus.

P5, L125: Sentence starting at L124 - what is the significance of this sentence for the study?

This information may not intrigue everyone but is intended for researchers who would like to use this technique. We belief it is helpful to be informed about the options of adaption during planning of other experimental campaigns.

P5, L127: This information could be given in the Acknowledgements or incorporated in the above text. The sentence that further improvements are planned already indicates that the presented findings are premature (similar statements are given at the end of the manuscript).

From our perspective it is good scientific practice to indicate that a measuring instrument was developed in cooperation with a private enterprise company and that the device is a prototype, which will be developed further in future. The company is mentioned within the text, because demonstrating the improvement and development process is a key feature of the article.

P5, L137: The reference systems could be introduced better... I find the presentation of Figure 1c rather confusing (as the reference system ’f’ is only introduced at L150).

The description has been entirely rewritten:

To compare relative movement characteristics like distance or velocity of different probes, the inner data / coordinate system *p* must be transformed into an outer reference system *rel* (Fig. 1, c). The simplest way to do this is the construction of a reference system using the probe's starting position as coordinate origin. The system is defined by the sensor's inner coordinate system of the first timestep rotated so that z-axis follows gravity. The axes of this relative outer coordinate system are donated with x^{rel}, y^{rel} and z^{rel}. After the motion has started, the probe's inner orientation will change while the outer reference system keeps its axes configuration. Consequently, within this reference system, it is possible to calculate the probe's orientation and the covered distance in each timestep. In Fig. 1 (c) for instance, the probe has changed its orientation significantly compared to its starting position while moving along the assumed trajectory.

However, the different probe-specific outer coordinate systems must be transformed into the same local reference system to compare different probes' trajectories. For the present study, this local reference system is oriented towards the experimental flume (see section 2.4). Following the former conventions, the axes were donated as x^f, y^f and z^f. Note that the axes orientations of the outer (rel) and the local reference system (f) may not be identical, except of z^{rel} and z^f, as they follow gravity.

In different applications, where a global positioning is required, reference points of the outer coordinate systems must be known in the global system to determine the absolute probe position in the global system.

P5, L140: Why is 'relative' in italics? I don't think that "donated" is adequate terminology... (throughout the paper)

Italics are typically used to emphasize a word. Which is what we wanted to do. Donated should mean denoted. Has been changed (throughout the paper).

P5, L143: Why 'probably'?

Because it is almost certain but not sure.

P5, L151: I don't understand - please improve the description and be more precise (e. g., it is only mentioned below that z follows the direction of gravity).

The description has been rewritten completely, please check response to RC P5, L137.

P5, L153: What is meant by higher-order global system (i.e., why higher-order)?

The description has been rewritten completely, please check response to RC P5, L137.

P5, L154: Why was this not done?

The natural magnetic field is disturbed within the experimental facility due to ferro-concrete surrounding. Additionally, the description has been rewritten completely, please check response to RC P5, L137.

P6, L162: I am not sure that I understand what is meant by (i) as well as (ii and iii).

All these errors result from the sensor technology. We simplified the description to:

The recorded acceleration values of each axis (a_x^p, a_y^p, a_z^p) are generally erroneous due to two reasons: (i) A (quasi-) constant misreading. The mass inside the sensor, which moves to measure acceleration, is not precisely equal in all sensors (manufacturing tolerance), resulting in a bias as well as a linear scaling of true values. (ii) The imprecise orthogonal alignment of the sensor axes and crosstalk. This means that a fraction of each axis acceleration will result in readings at the two other axes.

P6, L163: ’describes’ must be ’describe’.

Has been corrected.

P6, L165: All this remains a black box and could be explained in some more detail. I also find that the ’damaged probe’ is mentioned too often...

The black box is described in the given reference Frosio et al. (2009). We removed the sentence regarding the damaged probe in this paragraph, as it is not necessary here.

P6, L170: Some more details would be desirable (or at least references where relevant information can be found). I find this important section rather short.

We merged this paragraph with the next one, where the explanation as well as the reference are given.

P6, L178: What is meant by ’various studies’?

Future studies are meant.

The design of the experimental setup focussed on an exact and rapid triggering mechanism of the artificial landslide and flexibility for future studies.

P6, L180: A more precise length is given in the figure, which I find confusing (why approx. when the exact length is known?).

We changed the number to 4.24 m.

P6, L181: I find this difficult to read - please improve language.

Has been improved.

Some clasts also reached the lower part of the flume, which is inclined by 10 °.

P7, L206: Please check language. What was the accuracy of these measurements?

Has been changed:

This was done using a laser distance meter (accuracy +/- 1 mm).

P7, L210: This statement defines the scope of the study - the demonstration of the applicability of the sensor to monitor the motion of individual pebbles within a landslide - this calls again for publication as a brief communication instead of a research article.

As argued above, presenting the scientific progress (technical, analytical) of this technique since 2016 is not possible in the form of a brief communication.

P7, L211: The information on the date should be presented in Section 2.4 (is this information important)?

Has been deleted.

P7, L216: As mentioned above, the calibration of the sensor remains partly foggy, and I am not sure that the terminology "calibrated raw data" is adequate - it seems to me that raw data are presented which were obtained by a calibrated sensor?

The calibration description has been modified as written at comment concerning P6, L162. Details are described in the given reference. The word "raw" has been removed. This correction has been done in the complete article.

P7, L217: Could this be measured without activated IMU? If not, the statement in brackets could be deleted.

Has been deleted.

P7, L217/218: I had first difficulties to understand this sentence when looking at the figure - this could be formulated more clearly.

Has been clarified.

Note that the three curves of x^p, y^p and z^p (Fig. 3, a) show the acceleration along the particular axis (see below). The gyroscope data curves (Fig. 3, c) show rotation around these axes. At the top of each plot, white bars indicate stationary (no motion) and black bars non-stationary (motion) periods.

P8, L222: Why does the time series begin at a 'negative time'? When exactly was the landslide triggered? This should be mentioned/explained more clearly. Also, the statements relate to accelerations along the considered axes, this should be better highlighted in the text (xp and yp show low values - but strictly speaking, these are coordinate axes; the same applies to the statements given in the next sentences).

Negative time has been clarified:

The start of motion of pebble 4 was defined as 0.0 s.

All statements related to "axis shows values" have been changed to "values along this axis".

P8, L223: Why 'seems'? The data show this higher level.

Has been changed.

Before the actual motion begins (stationary conditions, left white bars in Fig. 3), low values were recorded along x^p and y^p, though x^p-readings are on a slightly higher level (approx. 0.0 g).

P8, L230: Please improve - this is difficult to read and understand (suggestion: alpha, beta and gamma define the angle between xp, yp and zp and the gravity vector).

Suggestions are thankfully accepted.

[…] where α, β, and γ give the angle between x^p, y^p, and z^p and the gravity vector, respectively.

P8, L230 - L312: This qualitative presentation of the raw data is difficult to read and understand - it should, in my opinion, be coupled with the derived trajectory.

This section is intended to be an introduction on how this kind of data has to be read and interpreted. We still see the need of a detailed explanation, what motion features are displayed by the data. The paper is structured from low complexity to higher complexity (single clast raw data - single clast derived data - single clast spatiotemporal visualisation - multi clast spatiotemporal visualisation). From our perspective, explanation and understandability of the content would not benefit from the mixing of these complexity levels.

P8, L231: 'downwards direction' is, in my opinion, a rather confusing terminology.

Has been changed.

Accordingly, under static conditions the probe's orientation relative to the gravity vector (vertical direction) can be calculated from the three readings of a_x^p, a_z^p and a_z^p.

P8, L234: If the pebble is stationary, it is clear that it cannot rotate...

Constant readings (except for noise) do not necessarily indicate stationary conditions, as we always have non-zero readings due to gravity. The probe might also move. If also the gyroscope indicates that no rotations occur, the conclusion that the probe is not moving becomes more probable. It is correct that this sentence should be placed above. The new sentence in line 224 is:

This pattern represents non-motion conditions, where only gravitational acceleration is recorded. This assumption is supported by the zero readings of the GYR.

P8, L234: I guess the landslide was triggered at 0.00 s? This should be mentioned in the text. Define 'the change' in the plots more clearly.

This has been explained before (see comment P8, L222) and is also clarified within the text.

A sudden change in the axes-readings at 0.0 s is visible in all three plots.

P8. L235: The text implies that the zp-axis drops, which is not the case (and which is rather confusing). What drops is the acceleration value, and this needs to be described more clearly (also in the following passages).

Has been clarified.

Between 0.0 s and approx. 0.03 s, a clear drop of z^p-recordings to the halve of the former level is visible in the acceleration plot (Fig. 3, a).

P8, L238: This could be explained better and the motion characteristics 'free fall' and 'hampered free fall' should be defined more clearly.

Has been clarified.

Low absolute values of acceleration can only be achieved if free fall (unconfined acceleration within the earth's gravitational field into the direction of its centre of mass) is mixed with an additional. Thus, values between 0 g and 1 g imply a hampered free fall (no completely developed free fall, confined motion) and/or an additional lateral acceleration.

P9, L248: This seems to be rather speculative - a statement like 'a conclusion might be...' is very vague...

Has been changed.

We conclude that the surrounding part of the mass moves coherently downwards.

P9, L251: Note that the values range between 1 g and -1 g (and do not correspond to 1 g and -1 g as presently stated).

We mixed up the letters in the description. Correct description:

Along y^p, values around -1 g were recorded; along z^p, values around 1 g were recorded.

P9, L257: However, I can see other spikes which are defined by two data points.

Therefore, we wrote "most of the other peaks". These features indicate short periods of pronounced acceleration instead of single hits, which is worth mention. Moreover, from these observation distinct motion patterns can be interpreted as demonstrated within the text.

The strongest peak of the whole sequence (approx. 4.6 g) is measured at z^p for two subsequent readings. Thus, the change in velocity is bigger than all other changes as the strongest absolute acceleration also lasts longer than most other acceleration peaks, which only consist of one reading.

P9, L260: Indicate which axis is analyzed here.

Has been clarified.

Here, the phase begins with relatively low ω of approx. 260 ° s^{-1} at 0.898 s on y^p.

P10, L289: 'Of cause'?

Has been corrected.

P10, L290: Why?

Because we know that the flume is oscillating after the impact of the material. We clarified the text:

Concerning the whole time series, some interesting aspects shall be mentioned: The small deviations from the mean axes readings of the ACC after the motion (right white bar) can be interpreted as oscillation of the flume construction after the impact. This is supported by the pattern: uniform oscillations with gradually decreasing amplitude.

P10, L290: This is trivial - I would be surprised if the pebble would not change its orientation.

Yes, one can see and would also expect that the orientation will change during the motion. Apart from that, one can interpret this from the data. Consequently, this interpretation could be done as well if the object would not be visible (e. g. embedded into the material).

P10, L313: The above qualitative statements regarding the motion mode should be coupled with the considerations of the movement with respect to position and time.

Has been changed.

This is also supported by the alternating pattern of high *a* peaks and almost zero acceleration magnitude. This pattern results from saltation as the pebble bounces at the flume bottom before it rebounds and falls again.

P10, L315: This could be mentioned earlier.

It is mentioned there, because the statement serves as a bridge passage to the quantitative movement analysis.

P11, L316: Are these relationships really that simple?

Simple has been replaced by basic.

P11, L317: Check language ('calculated after...').

Has been changed:

[…] according to Eq. 1 […]

P11, L318: Why were the angles ’received’? How can the accelerations be ’rearranged’? Please check language throughout.

“Received” has been changed to “calculated”. “Rearranged” has been changed to “rotated”.

P11, L320: This is a description of a method which is described in detail in the literature - it could therefore be included into Section 2.

The methodological aspects are described at this part of the text, because it is one of the key features of the study that we apply these algorithms on geomorphic motion data, which was not done before. Again, this is also why we describe it in detail.

P11, L328: ’srel’ is not integrated. It is obtained from integration.

Has been changed.

After the rearrangement of the recorded accelerations and with respect to time t, the movement characteristics v^{rel} and s^{rel} can be obtained from the integration

P11, 336: I am not sure that I understand what is meant here. Please improve.

Has been changed.

During stationary periods these values are defective. This can be seen at x^{rel} (Fig. 3, a), where values of approx. -4 m s^{-2} were calculated. Obviously, this cannot be true as the pebble does not move. However, these false calculations are excluded from further integration (compare Fig. 3}, b and c) and do not influence the following interpretations.

P11, L337 and following: All this could be combined with the qualitative discussion.

The paper is structured with increasing degree of complexity. Mixing different levels would not be beneficial (see response to comment P8, L230 - L312).

P11, L338: I disagree with this statement: a_zrel does not increase but decrease from 0 to -9.4. It also does not do this continuously decrease as clearly shown by the fluctuations in the plot.

This important aspect was already discussed within the text. An acceleration reading on a particular axis represents the magnitude of acceleration along this axis. The positive or negative algebraic sign refers exclusively to the direction. It does not imply an increase or decrease. Consequently, if the values change from 0 g to -9 g, acceleration increases (the object is accelerated more) against the direction this axis is pointing to.

We agree that “continuously” is the wrong description.

As displayed in Fig. 4 (a), a_z^{rel} generally increases until at approx. 0.32 s a local maximum of approx. -9.4 m s^{-2} occurs.

P11, L339: Why? This should be explained better. I also cannot see in the Figure that the pebble ’swims’. Please improve.

This aspect was explained before for acceleration in “g”-units. The explanation only has to be adapted to the other unit. Only if earth’s gravitational acceleration is calculated as resultant acceleration magnitude, pure free fall conditions are present. If the calculated resultant acceleration magnitude is ≠ 9.81 m s^{-1}, other motion components (or the underlying material, for instance) confine a free fall.

The verb “swim” has been replaced by “moves”.

P11, L342: What is the significance of the maximum velocity v_yrel? Why is v_zrel decreasing afterwards while it further increased simultaneously? This is confusing.

The variables v_y^{rel} and v_z^{rel} were swapped. This has been corrected.

P11, L343: Why ’covered’?

“Covered” has been replaced by “calculated”.

P11, L345: I disagree again - the plots for the y-axis do not really exhibit a major change. I am also not sure about the relevance of the capture of the high-speed sequence.

Modified text:

At 0.389 s after the start, a discontinuity at x- and z-axes is visible in fig. 4 (a) and (b).

P11, L346: Is the ’acceleration curve’ really smooth before 0.389 s?

No, it is not. Modified sentence:

The variability of the acceleration time series increases.

P12, L349: This is difficult to understand and should be explained better.

If no hits would be present between the clasts, no acceleration peaks would occur. This means: a peakier curve indicates pronounced contacts. However, it is not necessarily friction but, more general, energy dissipation. New sentence:

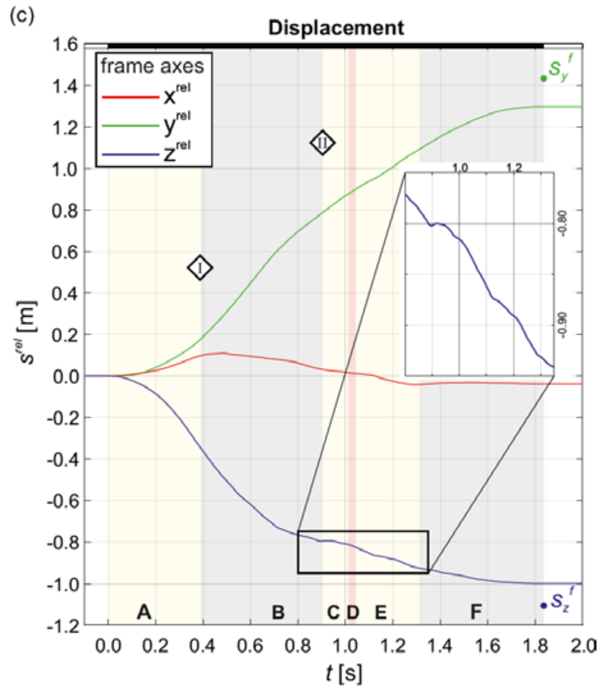
Additionally, the peaky pattern of the acceleration and velocity curves indicates pronounced clast contact and energy dissipation.

P12, L351: What is the significance of this observed maximum?

It is the maximum velocity for this probe.

P12, L353: Please explain better - this is hard to see from Figure c.

We added a detail figure in Fig. 4 (c).



P12, L355: Figure 4 d shows photographs and not displacement plots?

This was a wrong cross reference. It has been corrected to Fig. 4, c.

P12, L355: I do not see these staircases (if plot c was meant).

See detail figure two comments above.

P12, L372: This was mentioned before.

The sentence was removed.

P13, L390: I am not sure that I understand what is meant.

The sentence has been modified:

On the side view plot (Fig. 5, a), y^p and z^p are almost drawn in full length, whereas x^p is short, indicating its orientation towards the viewer's perspective.

P13, L390 and following: This could be combined with the previous analyses.

Again, the paper is structured with increasing degree of complexity. Mixing different levels would not be beneficial (see previous responses).

P14, L432: This sentence is incomplete.

Has been corrected.

It is visible that pebble 1 and 2 were embedded into the material, whereas pebble 3 and 4 were placed at the surface of the material (see Fig. 2).

P14, L437: This indicates that further work is required.

From our point of view, it is common and good scientific practice to communicate advantages as well as deficiencies that have to be dealt with if a method is presented to the scientific community. Nevertheless, further improvements are necessary. This will always be the case if scientific progress is sought. Apart from that, necessary improvements are discussed in detail within the text. This includes also comments for benefits that are expected from particular improvements.

P15, L470: This is a drawback for field applications, but not really for laboratory experiments.

This might also be problem under laboratory conditions. For instance, if the probe is built within a model slope that will fail due to artificial rain. Here, the time of failure is not known, but batteries cannot be changed. This issue is currently the objective of our work.

Additional References:

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