

Referee Report

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Title: MAHLI on Mars: Lessons learned operating a geoscience camera on a landed payload robotic arm

Authors: R. A. Yingst et al.

The article presents the MAHLI camera aboard the Mars Science Laboratory (Curiosity) lander on Mars. The main instrument features, the good imaging capability and the adopted operation (i.e., imaging) planning are sufficiently presented. Data and comments on relative acquisition plan refers to 1150 sols on the Martian surface determining a good set for science interpretation of sand properties and processes and for operation planning discussion.

The reported results and the discussed criticisms in operation planning are very interesting and justify, in my opinion, the publication in GI but I have one major suggestion to the authors: being section 6 the "core" of the manuscript it should concentrate on real problems that should be discussed in a more clear and better-ordered way without losing time in tedious discussion that risks to shade the goal of the manuscript (i.e., staffing consideration is a problem common to any scientific team and so I think it is not an interesting element to highlight; on the contrary, its discussion seems to be an expression of malcontent and I think this is not the right place where to express it)

On the whole the manuscript is interesting but there are some typos and minor modifications to the English. In the following, I have outlined those ones I noticed. However, although not crucial, the paper could be passed to the language editor.

I would like to see the revised version of the manuscript, although it is not strictly necessary if the authors will take into account my recommendations.

In the following I list all the comments, questions, suggestions and typos:

Abstract:

- 1) "The Mars Hand Lens Imager (MAHLI) is a 2-megapixel, color..." -->
to remove comma after megapixel
- 2) "...dust-free targets yields the best results, with complimentary information..." -->
"...dust-free targets yields the best results, with complementary information..."

Chapter 1: Introduction

- 3) "Operating > 1150 sols..." -->
"Operating more than 1150 sols..."
- 4) "... the Mars Hand Lens Imager (MAHLI)..." -->
to remove acronym definition as it is already resented above
- 5) "... Mars Science Laboratory (MSL)..." -->
to remove acronym definition as it is already resented above
- 6) "... modifying the geologic record at the rover's Gale crater field site..." -->
"... modifying the geologic record in the Gale crater..."

Chapter 2: Instrument

- 7) "MAHLI is a 2-megapixel, color..." -->
to remove comma after megapixel
- 8) "...allowing MAHLI to attain a wide..." -->
"...allowing MAHLI to achieve a wide..."
- 9) "...data salient to understanding the..." -->
"...data salient to understand the..."
- 10) "...includes four white light and two..." -->
"...includes four white lights and two..."

Chapter 3: Summary of MAHLI activities

- 11) "...on a rock target was was designed..." -->
to remove 1 "was"

12) "...to provide context images for higher-resolution images (100 $\mu\text{m}/\text{pxl}$), images at scales comparable to the Mars Exploration Rovers Microscopic Imagers (31 $\mu\text{m}/\text{pxl}$) to allow 16 for direct comparison, and highest resolution images..." -->

too many times the word images; try to rephrase as follows

"...to provide the context for higher-resolution images (100 $\mu\text{m}/\text{pxl}$), data comparable (in scale) to the Mars Exploration Rovers Microscopic Imagers (31 $\mu\text{m}/\text{pxl}$), and highest resolution acquisitions..."

13) "...to provide a good estimate..." -->

"...to provide a good estimation..."

14) "...contributed to interpretations regarding rock type..." -->

"...contributed to the interpretations of rock type..."

15) "...the rover's APXS, drill and scoop..." -->

acronym of APXS?

16) "...the Rover Environmental Monitoring System (REMS) ultraviolet (UV) sensor..." -->

"...the Rover Environmental Monitoring System (REMS), the ultraviolet (UV) sensor..."

Chapter 4: Image scale and range finding

17) "...for targets at working distances of 2.1 to 210 cm..." -->

"...for targets at working distances between 2.1 to 210 cm..."

18) "...by MAHLI at working distances from 2.1 to 210 cm." -->

"...by MAHLI at working distances between 2.1 to 210 cm."

Chapter 5: Data distribution

19) "...typically < 1 hour after..." -->

"...typically within 1 hour after..."

Chapter 6: Lessons learned during operation

General comment: it is not clear what is learned (probably due to the not clear and well-ordered description)

Section 6.1.1: Use limitation

General comment: the topic is discussed too slowly losing time with no so interesting info (i.g., personal stuffing)

20) "...all science observations during the traverse to Mt. Sharp, but..." -->
"...all science observations during the traverse to Mt. Sharp, and..."

21) "...and thus MAHLI, deployment..." -->
"...and thus MAHLI deployment..."

22) "...MAHLI images are often acquired of targets that are available, rather than targets that are scientifically optimal. After Curiosity arrives at an end-of-drive position and the stability of the rover for arm deployment is confirmed, constraints on positioning the 5 degree of freedom, 2.25 m long robotic arm and the 50 kg, 60 cm diameter instrument turret on its end yield a restricted usable workspace ~2m wide and 1m deep in front of the rover. Only individual targets of interest within this workspace that are characterized as safely reachable by the arm and turret are available for imaging by MAHLI" -->

to synthesize as follows

"...MAHLI images are often acquired of targets that are available (i.e., within camera workspace after arm deployment) rather than targets that are scientifically optimal."

23) "Expending extra sols to perfect rover positioning for arm placement of MAHLI at a given target has thus far been viewed too resource intensive. Finally, MAHLI use is curtailed by staffing considerations. Sufficient rover engineering staff is available only one planning day per week to plan both a drive and contact science activities within the same plan. Otherwise, the science team must choose between planning a drive or contact science in a given plan. Thus, use of MAHLI is limited to available contact science planning days or requires the sacrifice of a planned rover traverse." -->

to remove since it is not interesting and a bit polemical

- 24) "MAHLI use has also been limited over long weekends or holidays to avoid a situation that occurred early in a campaign in the Pahrump Hills region (that campaign is explained in more detail in Section 6.1.2), in which the arm faulted with the MAHLI dust cover open. This situation required emergency commanding sessions to close the MAHLI cover when staff was normally not available. Because such emergency tactical procedures were a significant stress on personnel and other resources, it was decided that MAHLI use would be precluded in any command situation in which a fault could result in the dust cover remaining open over multiple sols. This further limits the observations that MAHLI can acquire." -->

to synthesize as follows

"MAHLI use has also been limited during the Pahrump Hills campaign (see Section 6.1.2), in which the arm faulted with the MAHLI dust cover open."

- 25) "Future missions will likely continue to rely on arm-mounted imagers for micron-scale grain analysis, and all such imagers will have a similar limitation. One candidate solution for mitigating this limitation would be for the mission to include an additional camera (mast-mounted) that acquires similar high-quality, high resolution images without the need for arm motion; such images would be used to prioritize candidate contact science targets, including those for higher-resolution, arm mounted camera viewing (e.g, MAHLI) (Yingst et al., 2014b)." -->

to synthesize in the conclusions even if... with an additional camera MAHLI design shall be reduced in capabilities

Section 6.1.2: Optimizing target selection and imaging

General comment: imaging optimization (which is treated at the end of the section) could be moved, if necessary, to another section or, as suggested, in section 6.2

- 26) "...region by Curiosity (Grotzinger et al., 2014;..." -->
"")" is missing

- 27) "...imaged between Sols 753 and 948..." -->
sols is not with the capital letter

- 28) "Put another 14 way, the Pahrump Hills MAHLI science image set represents 41% of all MAHLI science driven images up to Sol 1100." -->
to remove since already clear in the previous sentence; if necessary you can put the percentage value in "()".

29) "But even during this period at 21 Pahrump Hills, when grain-scale science was driving high MAHLI use, ideal science targets occasionally had to be passed up for less science-rich but more reachable targets." -->

to remove since it not interesting

30) "Another scenario where MAHLI use can be optimized is at drill sampling locations; the processes of identifying and assessing a potential drill target, drilling the target and then delivering the sample to the geochemical suite (SAM and CheMin) requires multiple sols (martian days); these sols provide opportunities to identify targets of high-scientific interest (other than the drill target) and design observations (i.e., number and type of images, best time of day for illumination) for MAHLI to execute." -->

to move in Section 6.2 since it represents a consideration for best imaging practice

31) "We recommend that for those locations studied in-depth (i.e., campaigns such as those for the areas informally known as Yellowknife Bay, and Kimberley; Grotzinger et al., 2013; Grotzinger et al, 2015), the walkabout-first strategy be utilized where possible to maximize MAHLI science return. For those locations where the walkabout-first strategy is not desirable" -->

to synthesize in the conclusions

Section 6.1.3: Terminal descent plume

32) "...survived Curiosity's descent to the martian surface..." -->

"...survived to the Curiosity's descent on the martian surface..."

Section 6.1.4: Stowed camera position

General comment: in my opinion it is not a "operation lesson learned". In any case it could be synthesized.

33) "...an "End of Drive Stowed Image" or EDSI)." -->

"(" is missing

Section 6.2.1: Dust free surfaces

34) "...surface dust provided better..." -->

"...surface dust providing better..."

Section 6.2.2: Solar illumination and shadow

- 35) "...are best acquired when the target is illuminated by sunlight, particularly with phase angles approaching 90°." -->
to simplify as follows
"...are best acquired with phase angles approaching 90°."
- 36) "This is because targets on Mars in full shadow tend to appear to be more orange-brown than they actually are, and the shadowing de-emphasizes vital color and textural detail. That being said,..." -->
this sentence can be simplified starting with (and see below)
"In any case,..."
- 37) "...scale, because both provide information that the other does not provide alone. Fully..." -->
"... scale, since fully..."
- 38) "...subtle color differences. These differences can be seen in Fig. 14." -->
"...subtle color differences (Fig. 14)."
- 39) "Images acquired in partial sunlight have proven to be least useful, as both of these advantages are lessened. Specifically, such a mixed image provides less of the target in full illumination, and stretching the shadowed portion of the image is less effective as a fully shadowed image." -->
to remove since it is not interesting

Section 6.2.3: Artificial illumination source

- 40) "MAHLI's white light LEDs are at different positions that can operate independently (Edgett et al., 2012), which provides shadowing, lessening this problem." -->
MAHLI's white light LEDs, which are at different positions and can operate independently (Edgett et al., 2012), can provide shadowing, lessening this problem.
- 41) "When imaging at night, the placement of the LEDs is adjusted to create the best image. When imaging a drill hole, for example, one set of LEDs is pointed directly into the hole." -->
to remove since it is not interesting

- 42) "Though it did not improve image quality when used to illuminate shadowed targets during daytime or twilight, under Mars conditions, the LEDs provided effective illumination of target color and texture under nighttime conditions (Minitti et al., 2014). This is thus an important capability, as it increases the number of MAHLI imaging opportunities by permitting the acquisition of MAHLI images without delaying other activities that require daylight (e.g., driving). Thus, while the preferred illumination conditions are daytime full sunlight or shadow, the LEDs have significantly increased useful MAHLI image acquisition." -->

to simply as follows

"LEDs can also be used to illuminate shadowed targets during daytime or twilight and nighttime conditions (Minitti et al., 2014) increasing the number of MAHLI imaging opportunities."

Sections 6.2.4: Focus range and field of view

- 43) "...engineering observations including imaging..." -->

"...engineering observations (e.g., imaging..."

- 44) "...Fig. 11)." -->

"...Fig. 11) saving time and data resource (e.g., "MAHLI wheel imaging originally included a six image sequence and obtained with only two dedicated middle observation on sol 587; mosaics of the entire rover in field context (Fig. 2), using 2–3x fewer images than would a similar camera with a resolution of 7–8 $\mu\text{m}/\text{pxl}$ (and correspondingly narrower FOV)).

- 45) "A smaller FOV would have resulted in significantly more images being necessary for each of these crucial imaging activities (and thus more time and rover resources), potentially limiting the ability of the team to monitor and protect the instruments and the rover. For example, MAHLI wheel imaging originally included a six image sequence with an image manually focused on each wheel; however, the two dedicated middle 1 wheel images were dropped starting on sol 587 as extraneous, because the relatively large FOV allowed all wheels to be imaged using only four images. Additionally, it has been able to produce mosaics that show the entire rover in field context (Fig. 2), using 2–3x fewer images than would a similar camera with a resolution of 7–8 $\mu\text{m}/\text{pxl}$ (and correspondingly narrower FOV). This translates to significantly less time spent on engineering and housekeeping activities, and thus more time and resources that can be devoted to science-driven activities." -->

to remove as synthesized above (point 43 and 44)

- 46) "Future landed missions (e.g., Moon, Mars, small bodies) should consider the benefits of utilizing a high-fidelity arm-mounted camera with a large FOV and focus range to support engineering diagnostic concerns, both seen and unforeseen." -->

to synthesize in the conclusions

Chapter 7: Conclusions

General comment: missing suggestions present in Chapter 6 (and highlighted in 25, 31 and 46)

Figure 3 caption

47) "...MI..." + "...MER..."
acronyms stay for?

Figure 4 caption

48) "...images acquired..." -->
"...images were acquired..."

Figure 5 caption

49) "...holes made by drill..." -->
"... holes made during drill..."

Figure 6 caption

50) "...avoid terrain that is potentially..." -->
"...avoid terrains potentially"

Figure 8 caption

51) "...their status post-landing..." -->
"...their post-landing status..."

Figure 9 caption

52) "...wall of Gale crater." -->
"...wall of the Gale crater."

Figure 10 caption

53) "MAHLI images acquired of..." -->
"MAHLI images of..."

54) "A is a sol..." -->
"A is at sol..."

55) "...SAM..."
acronym shall be described at first occurrence

56) "As the only..." -->
"Being the only..."

Figure 12 caption

57) "Note that the time of day at which..." -->
to note for what?

Figure 14 caption

58) "...slightly different for each image." -->
"...slightly different in the images."