

Interactive comment on “MAHLI on Mars: lessons learned operating a geoscience camera on a landed payload robotic arm” by R. A. Yingst et al.

R. A. Yingst et al.

yingst@psi.edu

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Referee comments RC2 were responded to during the initial review process; we repost those responses here.

Abstract: . 1) "The Mars Hand Lens Imager (MAHLI) is a 2-megapixel, color..." → "The Mars Hand Lens Imager (MAHLI) is a 2-megapixel, color..."

â€ We have made the suggested change.

. 2) "...dust-free targets yields the best results, with complimentary information..." → "...dust-free targets yields the best results, with complementary information..."

â€ We have made the suggested change.

Chapter 1: Introduction . 3) "Operating > 1150 sols..." → "Operating more than 1150
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sols..."

â€ We have made the suggested change.

4) "... the Mars Hand Lens Imager (MAHLI)..." → "the Mars Hand Lens Imager (MAHLI)..."

â€ This is a question for the editor, as some journals don't "count" acronym definition within the abstract. We have left it as is and are happy to abide by the decision of the editor.

. 5) "... Mars Science Laboratory (MSL)..." → "Mars Science Laboratory (MSL)..."

â€ See response above.

. 6) "... modifying the geologic record at the rover's Gale crater field site..." → "... modifying the geologic record in the Gale crater..."

â€ We agree the sentence is not clear as written; it now reads, "...modifying the geologic record at the rover's field site in Gale crater..."

Chapter 2: Instrument . 7) "MAHLI is a 2-megapixel, color..." → "MAHLI is a 2-megapixel, color..."

â€ We have made the suggested change.

. 8) "...allowing MAHLI to attain a wide..." → "...allowing MAHLI to achieve a wide..."

â€ We have altered the sentence to read, "allowing MAHLI to image from a wide variety of perspectives. ..."

. 9) "...data salient to understanding the..." → "...data salient to understand the..."

â€ The sentence structure is correct as-is.

. 10) "...includes four white light and two..." → "...includes four white lights and two..."

â€” In this case the word “light” is a modifier (it modifies the noun “LEDs”), so the phrase would be “white light LEDs”.

Chapter 3: Summary of MAHLI activities 11) “...on a rock target was was designed...”
→ to remove 1 “was”

â€” We have made the suggested change.

. 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...” → “...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...”

â€” We have removed a few “images” and reworded as follows: “The first science-driven imaging sequence on a rock target was designed to provide context for higher-resolution images (100 $\mu\text{m}/\text{pxl}$), data at scales comparable to the Mars Exploration Rovers Microscopic Imagers (31 $\mu\text{m}/\text{pxl}$), and highest resolution images (16-22 $\mu\text{m}/\text{pxl}$).”

. 13) “...to provide a good estimate...” → “...to provide a good estimation...”

â€” We have altered this to, “. . .it was close enough to resolve microtexture. . .”

. 14) “...contributed to interpretations regarding rock type...” → “...contributed to the interpretations of rock type...”

â€” We have made the suggested change.

. 15) “...the rover’s APXS, drill and scoop...” → “...the acronym of APXS?”

â€” We have defined APXS.

. 16) “...the Rover Environmental Monitoring System (REMS) ultraviolet (UV) sensor...”

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→ “...the Rover Environmental Monitoring System (REMS), the ultraviolet (UV) sensor...”

â€” REMS has an ultraviolet sensor, so the current wording is correct, e.g. REMS 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...”

â€” Since the range is inclusive, we have changed the wording to, “. . .at working distances of 2.1-210 cm. . .”

. 18) “...by MAHLI at working distances from 2.1 to 210 cm.” → “...by MAHLI at working distances between 2.1 to 210 cm.”

â€” See previous comment.

Chapter 5: Data distribution 19) “...typically < 1 hour after...” → “...typically within 1 hour after...”

â€” We have changed this to “. . .typically less than 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)

â€” While we appreciate the reviewer’s comment, we respectfully disagree with the suggestion to reorganize. Each section contains the background for each lesson learned, the lesson itself, and an associated recommendation. This organization was graded “excellent” by another reviewer, so we suggest this may be a subjective question of preference.

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...”

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â€¢ We have made the suggested change.

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

â€¢ We have changed the sentence to read, "...resources allow arm (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" -> â€¢to synthesize as follows â€¢"...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."

â€¢ The proposed synthesis unfortunately over-simplifies the complex decision process leading up to the choice to use the MAHLI.

. 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." -> â€¢to remove since it is not interesting and a bit polemical

â€¢ We see the reviewer's point that this may sound like a complaint; however, the point must be made for the reader to understand how and why acquiring MAHLI im-

C5

ages is time-, resource-, and human resource-intensive (and thus, why we don't simply blanket an outcrop with hand lens-scale images once we get to a target). As a balance, we have reworded the section to read, "Finally, because staffing constraints limit the science team to either a drive or contact science in any given plan, the use of MAHLI is limited to available contact science planning days or requires the sacrifice of a planned rover traverse."

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." -> â€¢to synthesize as follows â€¢"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."

â€¢ Unfortunately the suggested synthesized text could be misconstrued to suggest that only the Pahrump Hills campaign saw limited arm use. Additionally, it does not explain why the arm fault led to less use; instead the text sounds like mechanical issues kept us from using the arm after the fault. We have elected to retain the original text.

. 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

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(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

↻ The suggestion is not entirely clear to us, but we have opted not to reorganize the text.

Section 6.1.2: Optimizing target selection and imaging . . 26) "...region by Curiosity (Grotzinger et al., 2014;..." → "is missing

↻ We have made the suggested change.

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

↻ We have made the suggested change.

. 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 "()".

↻ We have elected to retain the clarification.

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

↻ Though the comment is subjective, the text is not absolutely crucial and we have removed it.

. 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

C7

↻ See our answer to the general comment for Section 6.

. 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

↻ See our answer to the general comment for Section 6.

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..."

↻ We don't understand the correction. It is not "the Curiosity".

Section 6.1.4: Stowed camera position

33) "...an "End of Drive Stowed Image" or EDSI)." → "(" is missing

↻ We have made the suggested change.

Section 6.2.1: Dust free surfaces 34) "...surface dust provided better..." → "...surface dust providing better..."

↻ The full sentence as written is correct: "Areas where wind, the rover's dust removal tool or the ChemCam Laser Induced Breakdown Spectrometer removed the surface dust provided better science return than dust-covered surfaces."

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°."

↻ The suggested simplification does not include the concept that sunlight is a variable. As noted in the text, we have taken night images as well, and state that solar illumination is better.

C8

. 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..."

â€¢ The suggested simplifications in 36-37 do not convey the original meaning. Determining the ideal set of illumination conditions required imaging dozens of targets under multiple conditions over thousands of sols. The details here are important to report in detail so that future missions will not have to repeat the learning process.

. 38) "...subtle color differences. These differences can be seen in Fig. 14." → "...subtle color differences (Fig. 14)."

â€¢ We have made the suggested change.

. 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

â€¢ See our response to #36-37 above. This is one of the more important things we have discovered, and because it is true, it costs us significant time and resources in planning, because we must model sunlight at all times of day to avoid shadow.

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.

â€¢ We have made the suggested change.

. 41) "When imaging at night, the placement of the LEDs is adjusted to create the best

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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

â€¢ This statement is an example of the fact presented above.

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."

â€¢ See our response to #36-37 above.

Sections 6.2.4: Focus range and field of view . 43) "...engineering observations including imaging..." → "...engineering observations (e.g., imaging..."

â€¢ Following this suggestion would require putting parenthetical statements inside parenthetical statements.

. 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)).

â€¢ The suggested edit no longer carries the meaning of the original statement.

. 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),

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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)

“Again, this level of detail explains why this is such a big time and resource savings, and indicates that this savings was something that was discovered during over 1000 sols of use.

. 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

“See our answer to the general comment for Section 6.

Figure 3 caption 47) "...MI..." + "...MER..." acronyms stay for?

“We have added a definition in Section 3, where these terms first show up.

Figure 4 caption 48) "...images acquired..." → "...images were acquired..."

“We have made the suggested change.

Figure 5 caption 49) "...holes made by drill..." → "... holes made during drill..."

“The holes were made by (as in because of) drill activity.

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Figure 6 caption 50) "...avoid terrain that is potentially..." → "...avoid terrains potentially"

“We have made the suggested change.

Figure 8 caption 51) "...their status post-landing..." → "...their post-landing status..."

“We have made the suggested change.

Figure 9 caption 52) "...wall of Gale crater." → "...wall of the Gale crater."

““Gale crater” is the appropriate terminology.

Figure 10 caption 53) "MAHLI images acquired of..." → "MAHLI images of..."

“We have made the suggested change.

. 54) "A is a sol..." → "A is at sol..."

““A is at sol” is the appropriate wording.

. 55) "...SAM..." “acronym shall be described at first occurrence” “We have now defined this in Section 3.

. 56) "As the only..." → "Being the only..."

“We have made the suggested change.

Figure 12 caption 57) "Note that the time of day at which..." → to note for what?

“We have removed the phrase “Note that. . .”

Figure 14 caption 58) "...slightly different for each image." → "...slightly different in the images."

“We have reworded this to read, “Resolution of each image varies.”

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