EVALUATION OF LUCKY IMAGING ALGORITHM FOR LUNAR OBSERVATIONS. Jinkyu Kim[1] , Chae Kyung Sim[1], Sungsoo S. Kim[1] , and Ho Jin[1], [1]Kyung Hee University, Yongin, Gyeonggi, Repubilc of Korea (jinkyukim@khu.ac.kr).

Introduction: We are performing polarimetry speckle imaging observations of the lunar surface using a 24-inch Ritchey-Chretien telescope, PolSpeck, installed at Sierra Remote Observatory (SRO) in California, USA. Spatial resolution of PolSpeck is about 0.14″/pixel. As the radius of theoretical airy disc is about 0.227″, blurring of the images due to the optical system is considerably limited. However, without adaptive optics, blurring of the images will be caused by the atmosphere. At SRO, the typical seeing is about 1.0″ to 1.2″.

Lucky imaging is one form of speckle imaging that select the highest-quality image from a large observed images of short exposures [1]. In general, when selecting a lucky exposure, measure the sharpness of the speckle pattern observed at the point-source object. However, speckle patterns cannot be identified in an image of an extended object like the Moon. In this work, we present a new method to evaluate the quality of lunar images obtained with PolSpeck.

We obtained series of speckle patterns with PolSpeck. Then we created a pseudo-observation image with the data of the moon taken from the spacecraft and the speckle. From the generated image, we measure the sharpness quality with number of ways and compared with each other. The Result provide useful information for determining the best algorithm.

Speckle Pattern Generation and evaluation: To obtain the speckle patterns, we take series of 1,000 consecutive images with 5-ms exposure. We calculated the Strehl ratio, standard deviation, and second-order moment of each of the speckle pattern [2]. Among them, the Strehl ratio seems to be the best method with high consistency and sufficient discrimination ability to determine the quality of the image [3].

Generation of pseudo-observation images: In order to use the Strehl ratio of the speckle pattern as a reference quality, a pseudo-observation image corresponding to each pattern have to be created. At first, we process the data of the lunar surface taken by the Terrain Camera (TC) onboard the Kaguya spacecraft [4] to generate reference image without atmospheric effect. Then, speckle patterns and reference image were used to create 1000 pseudo-observation images for each of the four regions of mare Serenitatis, highland region centered on Cavendish crater, Copernicus crater, and Reiner Gamma swirl with 512 × 512 resolution.

Table 1 Parameters of sharpness measurement methods

Abbr.	Description	Parameter
GRA	Total of gradient image	Kernel size 3 × 3 , 5 × 5
LAP	Energy of diagonal Laplacian filtered image	Kernel size 11 × 11 , 17 × 17
MEAN	Sum of ratio between local mean and pixel	Kernel size 11 × 11 , 17 × 17
DCT	AC component Energy of Discrete Cosine Transform	Block Size 4 × 4, 8 × 8

Evaluation of sharpness measurement algorithms: A number of image sharpness measurement algorithms have already been developed for various purposes, but since all algorithms cannot be tested, we have decided to test with algorithms that are expected to be useful under our observation conditions.

We have selected algorithms that were evaluated for superior performance among the algorithms tested in simulations for solar observations [5]. The first one is an energy of diagonal Laplacian, which gives weighted Laplacian operator [6]. Another one is a modified-mean algorithm which analyzes the difference between local average and each pixel value [7]. And the other is Energy value of block discrete cosine transform (DCT) [8]. Along with these three algorithms, we have tested a traditional algorithm, which is called Tenengrad method [9], as a comparative group. Then, we applied the four algorithms listed above to the generated pseudo-observation images and measured the sharpness of the images in each method.

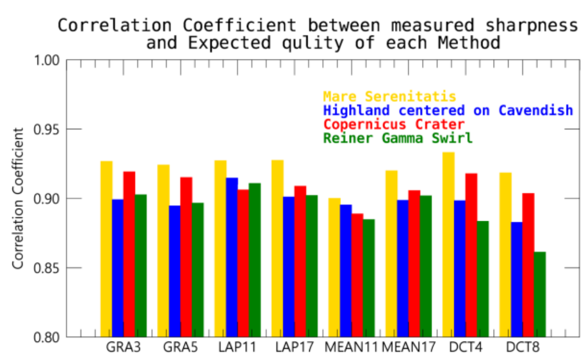

Figure 1. Correlation coefficient between expected quality and measured parameter with each algorithms from 1000 pseudo-observation images per region

Result and Conclusions: Figure 1 shows the correlation coefficients between the measurement results obtained by processing 1000 pseudo-observation images with various algorithms and the Strehl ratio obtained from the speckle pattern corresponding to each image.

Among the methods used in the experiment, the results of the DCT4 algorithm are more accurate than the other algorithms in the mare region, but less accurate in the highland and swirl regions. The accuracy of the GRA3 algorithm is better than DCT4 in the swirl region, but it is still not accurate in the highland region. For the LAP11 algorithm, the score of the mare region is lower than the previous two algorithms, but it has higher average and more uniform score in all regions.

It is especially easy to apply to various areas when observing the moon, since the worst case results are not so bad and they maintain a consistent score. This universality is an important benefit of this method. We are observing the various terrain of the moon from actual observations. Therefore, it is very important for us to have stable performance under various conditions. We also observe very complex and diverse areas, such as areas where the highlands are in contact with mare, or areas with significant rays or swirls. In conclusion, the LAP11 algorithm is the most useful method in our observation.

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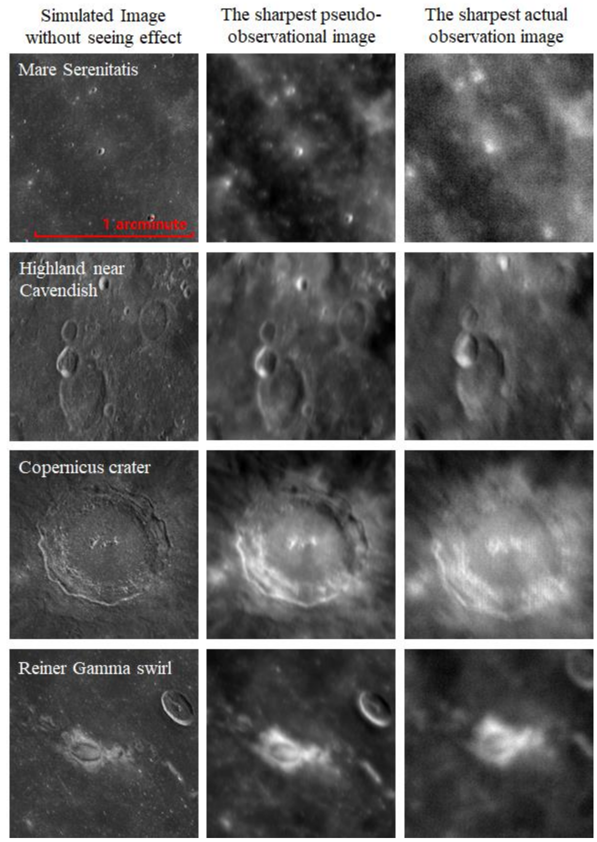

Figure 2. From the left, the simulation image without atmospheric effects, the sharpest image of each of the 1000 pseudo-observations, and the sharpest image of each of the 100 actually observed images, were evaluated using the LAP11 algorithm.