REMOVAL OF BRIGHTNESS ARTIFACTS FROM THE PANORAMAS OF MARS SURFACE RECEIVED FROM PHOBOS-2 SPACECRAFT; I.M.Bockstein[1], Yu.M.Gektin[2], [1]Institute of Problems of Information Transmission, Russian Academy of Sciences, Moscow, Russia, [2]Institute of Space Device Engineering, Moscow, Russia

The method is described that was used to remove brightness artifacts -- long vertical strips due to Phobos shadowing -- from two panoramas of Mars surface obtained from Phobos-2 space station. The main idea of this method is spatial filtering of shadow regions of the panoramas with the help of a sliding parallelogrammic window. Linear correction of lines inside the shadow region is realized to make its border invisible. The results of filtering are presented.

In 1989 Soviet spacecraft Phobos-2 has realized four sessions of Mars surface surveying. Two-channel opto-mechanical scanner TERMOSCAN was used for this purpose. It gave possibility to register four surface panoramas in visual and thermal spectral channels. The procedure and the results of pre-processing these images are described in [1]. Unfortunately, two of these panoramas (from March 26, 1989) have undesirable brightness artifacts that look as long bright strips located in their middles (see Fig. 1a). These artifacts are actually the shadows of the Mars satellite Phobos. In the middle of March, Phobos and the spacecraft were several hundred meters apart, and they moved synchronously in similar orbits. The spacecraft surveyed Mars surface with a constant Sun-to-spacecraft orientation; since the spacecraft was near Phobos and the Sun-Phobos direction was almost the same as the Sun-spacecraft direction, the Phobos shadow on Mars surface can be seen in the TERMOSCAN field of view. Some factors influenced the form of this shadow -- Phobos orientation, Mars surface curvature, spacecraft instability, etc. One can see more details in [2]. Due to the presence of Phobos shadow, the lines of each panorama (see Fig. 1a as a simplified example) were disturbed as shown in Fig. 1b. This was the result of addition of some unknown, but slowly changing, brightness Fig. 1c.

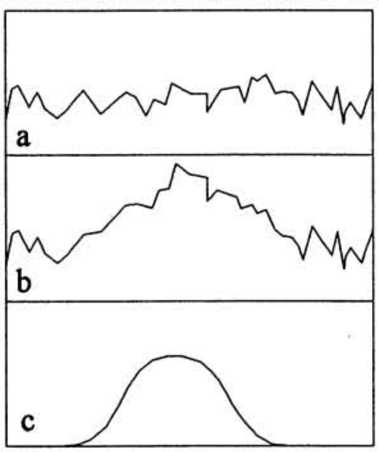

Fig. 1. Disturbance (b) of the original brightness for a panorama line (a) due to the shadow (c)

Our aim was to remove the mentioned artifacts from Mars panoramas. It was, of course, necessary to preserve the details of Mars surface (e.g., craters) both inside and outside the shadow. Since the exact form of the shadow for each line of a panorama is unknown, the only reasonable way to remove this shadow is to use high-pass filtering along its direction. It is preferable to realize this filtering in the spatial domain, i.e., to calculate the mean brightnesses for panorama lines inside a sliding window around a current line and to subtract them from the brightnesses of pixels of this current line. As a good approximation, one can consider Phobos shadow to be a straight, but slanted, artifact. So it is necessary to use parallelogrammic window that is oriented along the shadow to achieve acceptable results.

Unfortunately, high-pass filtering removes not only artifacts with slowly changing brightness, but also slow brightness changes that always exist in real images. So, it is much better to filter panoramas only in the region of the shadow. We decided to process each panorama inside a long parallelogrammic region; its short side was oriented along panorama lines, and its long side -- along the shadow. The width w of this region, its starting point i_s, and its end point i_e have been chosen to surround the shadow (see Fig. 2). A sliding parallelogrammic window with an odd length l and an odd width w was used for spatial filtering. For a current line i, the sums of pixel brightnesses were calculated along the shadow direction, starting from the line $i_- = i - l_{/2}$ and up to the line $i_+ = i + l_{/2}$, and brightness values $a_{i,j}$ for pixels j of the line i were processed in accordance with the formula

$$b_{i,j} = a_{i,j} - 1/l \sum_{k=i_-}^{i_+} a_{k,\,j+dj} + C, \text{ where } dj = (k-i)(j_s^{(i_+)} - j_s^{(i_-)})/l, \quad j \in [j_s^{(\bullet)}, j_e^{(\bullet)}] \text{ for each line } (\bullet).$$

When we tried to use the described method directly, the result was very poor. Well-visible brightness changes have arisen between border pixels located inside and outside the shadow region. As a first attempt to remove them, we tried to change values of $b_{i,j}$ linearly along panorama lines to equalize brightnesses of border pixels, a_{i,j_s-1} and b_{i,j_s} (and a_{i,j_e+1} and b_{i,j_e}). The borders have become invisible, but the result has remained poor, since the brightnesses of the border pixels located outside the region changed severely from line to line; therefore initially

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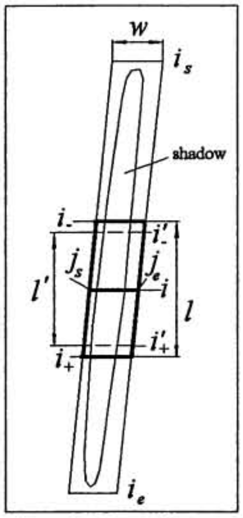

Fig. 2. Location of Phobos shadow, shadow region and filtering windows on Mars panorama (see text)

similar inner lines of the region have turnesd very different, and the region has become 'stripy'.

In order to avoid the visibility of region border without inserting severe changes between neighboring lines, we decided to use linear brightness correction that equalizes the brightnesses b_{i,j_S} and b_{i,j_e} with *averaged* brightnesses of the pixels $a_{k,j_S}{}^{(k)}{}_{-1}$ and $a_{k,j_e}{}^{(k)}{}_{+1}$. The averaging was realized along the border of the shadow region; averaging interval had the length l' and was centered on the current line i; its starting line was $i_-' = i - l'/_2$, and its end line -- $i_+' = i + l'/_2$ (see Fig. 2). For this purpose, the formula for $b_{i,j}$ was modified; the expression $S_s^{(i)} + (S_e^{(i)} - S_s^{(i)})(j - j_s^{(i)}) / (j_e^{(i)} - j_s^{(i)})$, where

$S_s^{(i)} = 1/l \sum_{k=i_-'}^{i_+'} a_{i,j_s^{(i)}-1}$, $S_e^{(i)} = 1/l \sum_{k=i_-'}^{i_+'} a_{i,j_e^{(i)}+1}$, was used instead of the constant C.

The proposed filtering method was realized interactively with the help of the IMS-VGA image processing system [3]. System operator pointed to the beginning and to the end of the shadow; the filtering was then performed automatically. Even extension was used at the borders of panoramas. We tried various window sizes, w, l, and l'. The values of 41 for w and 129 for both l and l' appear to be the best. The results of filtering are shown in Fig. 3 for a fragment of one Mars panorama. One can see no trace of the shadow and no border of the shadow region on the filtered image.

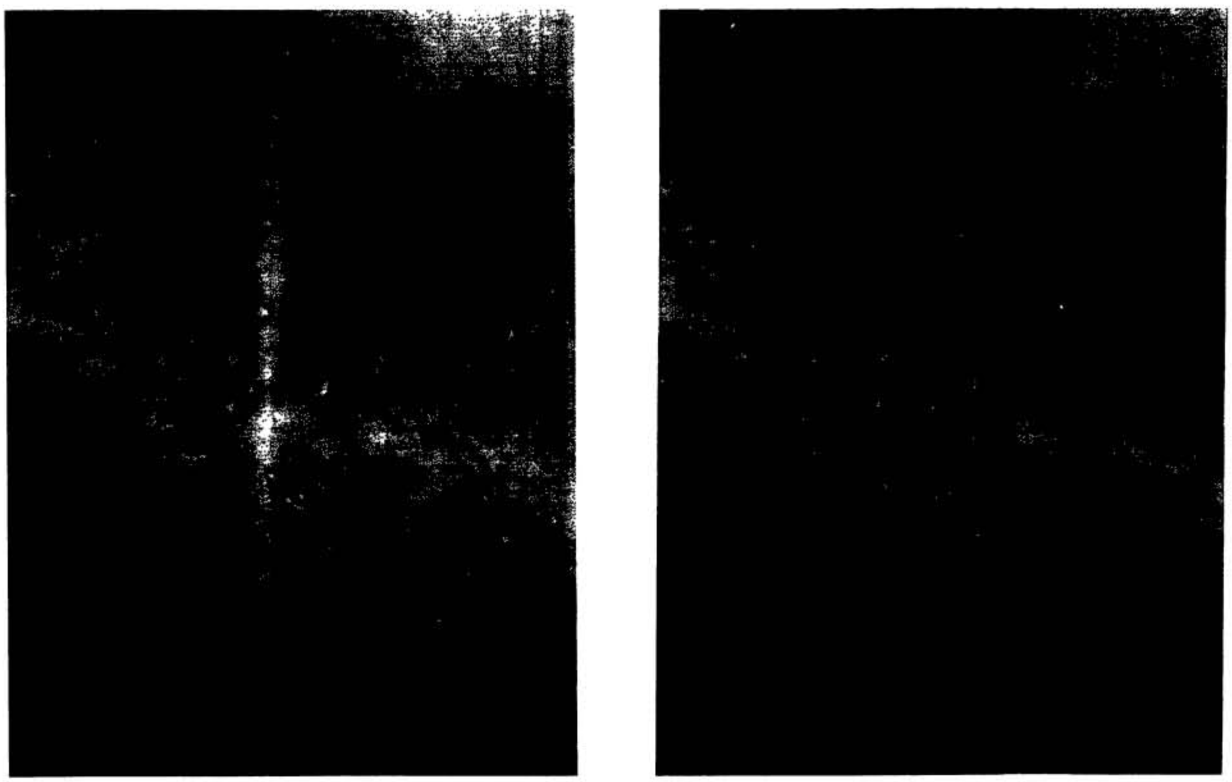

Fig. 3. A fragment of a panorama (left) and the result of its filtering (right)

[1] Bockstein I.M. et al. (1993) *LPSC XXI.*
[2] Selivanov A.S. and Gektin U.M. (1993) *The planetary report, v. XIII, No. 1, pp. 20-21.*
[3] Bockstein I.M. and Kronrod M.A. (1993) *Pattern Recognition and Image Analysis, v. 3, No. 4.*