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Full Length Research Paper

Multi-focus image fusion in high precision close-range phaotogrammetry

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The close-range photogrammetry is a discipline of precise metric measurement of features with applications ranging from the deformation of architectural structures to the medical diagnosis. One of the limitations on the precision of the obtained images is the large differences in depth. On the other hand, obtaining pictures that focus on every direction with lenses used in close range photogrammetry is mechanically impossible. Multiple images focused to different distances are necessary in order to solve such a depth problem. The clear parts of the images are brought together, so that a clear image focused to every direction is obtained. This joint image becomes more suitable for the feature extraction as well as for dividing and classifying processes. In this study, image joining has been conducted with the spatial frequency method. The unclear parts in the images have to be determined so as to be able to bring these images together. The average filtering method has been employed to accurately determine the prescribed clarity level and the gray value levels of the image. For this procedure, software has been developed in C++ programming language that conducts average filtering. The conducted experiments show that the spatial frequency method proves to be a very efficient method to construct a multi-focus image. Due to the precision limitations of the close-range photogrammetry arising from the large differences in the depth, many applications of ultra-high precision measurements such as industrial measurements still heavily rely on the classical surveying methods. The results show that the proposed image-fusion method dramatically reduces the error budget of close-range photogrammetry down to a half and enables much higher precision applications.

Key words: Image processing, spatial frequency method, multi-focus fusion.

INTRODUCTION

The objectives of the cameras used in the close range photogrammetry due to their characteristics, focuses only on one point of the target objects at different distances. Some parts of the images acquired from the chosen focus will be sharp while the others blurred. If desired, the image can be focused to different distances while stabilizing the position of the objective. The different images are acquired in different focuses. The sharp parts of all the acquired images can be united to form a new image. Therefore, the problem of the sharpness can be handled in this way. This operation is commonly called an image fusion. The most simple image fusion method is to take the average of gray levels of the image pixels. This implementation induces a decrease in the image sharpness (Aslantaş et al., 2008; Bulatov, 2006). Many methods have been improved that can produce an image fusion. Some of them to name are: Laplacian Pyramid (Burt et al., 1983), Wavelet Transform (Yocky et al., 1995; Zhang et al., 1999), Morphology Pyramid (Matsopoulos et al., 1994) Gradient Pyramid (Burt et al., 1993), and Spatial Frequency (Li et al., 2001). Some methods related with Artificial Neural Networks have also

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Figure 1. Original image.

been suggested (Li et al., 2002).

The image fusion is used in the stereo camera compilation, the road tracing, the target recognition, the night vision guidance, the robot movements used in production, the automatic product count, MR and the tomography. In this study, the images that have objects of different distances from photographic camera will be dealt with. Generally, it is not possible to acquire a completely sharp image using only one photo at a time. Thus, the purpose in this study is to investigate a the possibility of employing multi-focus images in the close-range photogrammetry by using photos acquired with cameras of varying focal lengths (Seales and Dutta, 1996; Aslantaş et al., 2006; Aslantaş et al., 2008; Bulatov 2006).

The close-range photogrammetry is a specific field of surveying. In this field, metric observations are of priority importance, which directly corresponds to the accuracy. The elevation or depth differences of topography of the scenery have a direct effect on the measured values. In this respect, the main objective of the close-range photogrammetry is the measured metric values of the objects rather than the images themselves. In this study, applicability of the method given in Li (2001) in the field of close-range photogrammetry is investigated.

SPATIAL FREQUENCY

The spatial frequency employs the differences of pixel values in the image. The measurements of the level of the effectiveness in the image correspond to the determination of the gray level differences of two neighboring pixels. This difference is directly proportional to the sharpness measurement of the image. If we define the spatial frequency value of M x N dimension F image as SF:

$$SF = \sqrt{RF^2 + CF^2} \tag{1}$$

RF as row frequency;

$$RF = \sqrt{\frac{1}{MN}\sum_{m=1}^{M}\sum_{n=2}^{N}(F(m,n) - F(m,n-1))^2} \tag{2}$$

CF as column frequency;

$$CF = \sqrt{\frac{1}{MN}\sum_{n=1}^{N}\sum_{m=2}^{M}(F(m,n) - F(m-1,n))^2} \tag{3}$$

The expression F(m, n) in the equations (2) - (3) represent the gray level value of the pixel position at the row m and column n. Let's show the direct proportion between the gray level of the pixels and the image sharpness in Figure 1 with the dimension of 256 x 256 pixels. Figure 2 shows the image in Figure 1, which are subject to the blurring through 3 x 3, 5 x 5, and 7 x 7 averaging filters.

The RF, CF, SF values are calculated through a program coded in C++ for the original image and for each filtered image along with the average filtering and the spatial frequency values. As depicted in Table 1, the spatial frequency value decreases as the image blurs which means that the spatial frequency can be used to calculate image sharpness.

FUSION METHOD

The Spatial Frequency image fusion method has four sequential steps. It will be more explanatory to show these steps in a diagram. The required steps of the algorithm can be summarized as follows:

Step 1-Original images are divided into windows of M x N dimension.
Step 2-Spatial frequency value of each window is computed.
Step 3-A_i and B_i spatial frequency values of the corresponding windows of the original images are compared. At the end of step 3, the fusion forms the resulting image's i^{th} window as the equation 4 (F_i).

$$F_i = \begin{Bmatrix} A_i, & SF_i^A > SF_i^B + TH \\ B_i, & SF_i^A < SF_i^B - TH \\ \frac{A_i+B_i}{2}, & \text{otherwise} \end{Bmatrix} \tag{4}$$

Step 4-The resulting image of step 3 is controlled by the majority filter. If there are errors, then they are eliminated or corrected. The majority filter in this step works on a window-by-window basis not pixel-by-pixel.

Multi focus spatial frequency image fusion method is shown schematically in Figure 3. In summary, the original images are divided into windows and the sharper part of the images is selected and pasted into the resulting image.

APPLICATION

For the application of the proposed method, a configuration was

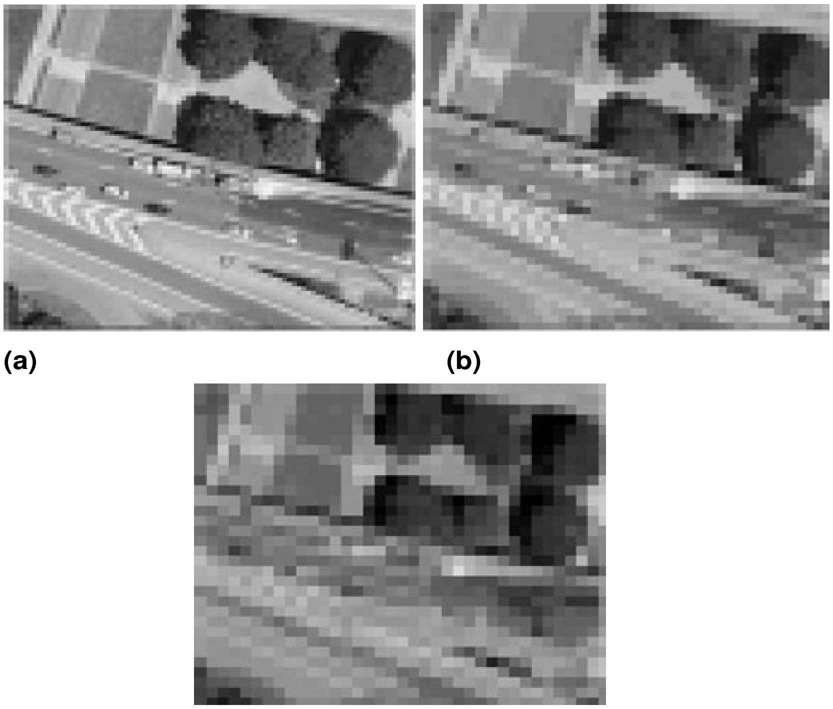

Figure 2. Blurred Images with Averaging Filter: (a) 3x3, (b) 5x5, and (c) 7x7.

Table 1. Spatial frequency values of the images in Figures 1 and 2.

	Figure 1	Figure 2a	Figure 2b	Figure 2c
RF	12.84	10.02	8.78	7.88
CF	9.30	6.63	5.78	5.12
SF	15.86	12.01	10.51	9.36

formed which consists of a digital camera and two target objects (a theodolite and a leveling rod). Although the selection of the objects is quite arbitrary, the surveying instruments, a theodolite and a leveling rod were preferred. The distances between the theodolite and the camera and between the leveling rod and the theodolite are 8 and 7 m, respectively. The camera employed in this study is Nikon 18 AF-S DX f/3.5-5.6G ED VR with a focal length of 105 mm. The set-up for this application is shown schematically in Figure 4.

Both images obtained with a focus on the theodolite and on the leveling rod are shown in Figures 5 and 6, respectively. The fused image produced with the fusion through the spatial frequency filter method outlined in the previous the chapter is shown in Figure 7 and numerical verification of the results is shown in Table 2.

To quantitatively assess the direct contribution of the image fusion on the orthophotos obtained through close-range photogrammetry, the lengths of the objects points of the set-up were measured precisely, the lengths of thirty objects were determined. Some the selected object lengths are shown in Figure 8. These lengths are first measured through precise equipments to obtain the real value, and then measured separately photogrammetrically from the orthorectified images given in Figure 5, Figure 6 and Figure 7. The differences between the real values and the close-range photogrammetry results reveal the applicability of the proposed method in the high-precision close-range photogrammetry. The root-mean-square values of the differences were computed as;

$$\text{r.m.s.} = \sqrt{\frac{\sum_{i}^{n}\left(x_i - x_T\right)^2}{n}} \qquad (5)$$

Where n is the sample size, x_T is the true value of the lengths determined through a caliper or a micrometer. Since, the true values are determined independently from the sample, the degree of the freedom is n.

The obtained numerical values for each image in Figure 5, 6, and 7 are given in Table 3. The gauges employed to obtain the true values of the lengths are a digital vernier caliper (Mitutoyo, 500-161U model, 0.01 mm accuracy) and a digital micrometer (Mitutoyo, Digimatic Micrometer Series 293 model, 0.001 mm accuracy). Considering the precision of the equipments, the obtained precision for each image can be attributed solely to the photogrammetric precision.

RESULTS AND DISCUSSION

The metric values measured in the close-range photogrammetric applications are very sensitive to the elevation or depth differences arising from the topography or the scenery. Such metric values have a direct effect on the accuracy of the produced digital models. In this respect, the main objective of the close-range photogrammetry is to increase the accuracy of the measured metric values of the objects rather than properties of the

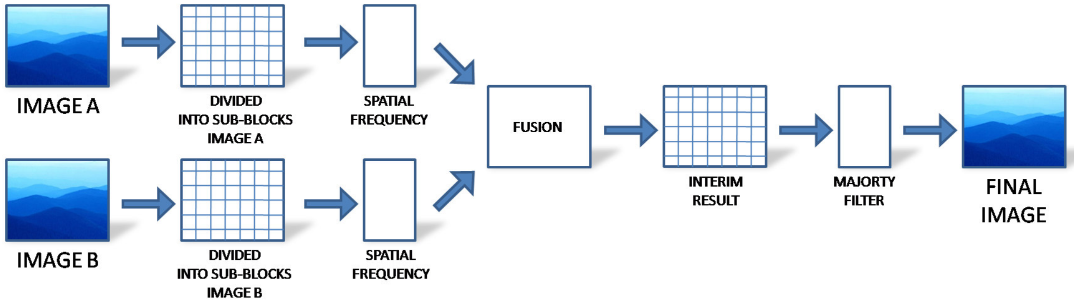

Figure 3. The schematic diagram of multi focus spatial frequency image fusion method.

Figure 4. The schematic diagram of set-up for the application.

Figure 5. The image obtained by different object distances (the object on the left side is sharp while the one on the right side is blurred).

Figure 6. The image obtained by different object distances (the object on the right side is sharp while the one on the left side is blurred)

Figure 7. Fused resulting image (both the objects are sharp).

the images themselves. In this study, applicability and performance of the method given in Li (2001) in the field of close-range photogrammetry is investigated in detail and a numerical application is given.

Moreover, the spatial frequency method was tested to fuse images acquired by different focal distances and an illustrative application was given. The results show that the spatial frequency fusion approach to multi-focus imagery is one of the most efficient methods. It is concluded that the spatial frequency can easily be used in many photogrammetric and satellite imagery applications that require feature identification at different distances. Results show that the proposed methodology enables the precise photogrammetric interpretation/stereo plotting/measurements.

Table 2. Spatial frequency values of the images in Figures 5, 6 and 7.

	Figure 5	Figure 6	Figure 7
SF	3.56	3.97	4.63

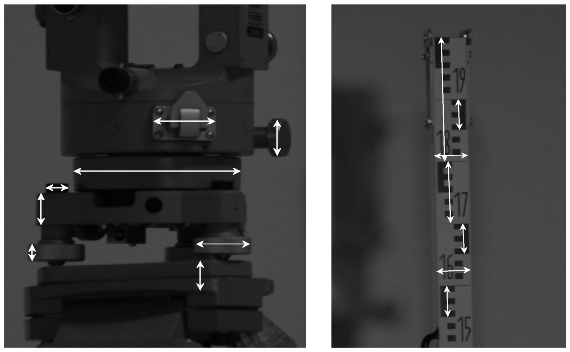

Figure 8. The lengths measured for comparison.

Table 3. The statistics of the photogrammetic measurement errors for the orthorectified images.

	Figure 5	Figure 6	Figure 7
m_0	± 3.24	± 2.78	± 1.52

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