Multi-focus image fusion using a fuzzy criterion function

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Abstract

Everywhere-in-focus images are more desirable for human perception and computer based analysis such as vision based industrial inspection and quality control in manufacturing. In this paper, a region based fuzzy method that combines the sharper regions of images with diverse focuses is proposed. First, source images are decomposed into image blocks. Next, a fuzzy criterion is employed to measure the sharpness of each block. Then, the sharper image block is transferred to the fused image. The proposed method is compared with the region based pixel level method. Experimental results demonstrate that the proposed image fusion method is better in both quantitative and subjective evaluations.

Keywords: Multi-focus, image fusion, fuzzy inference systems, spatial frequency

1. Introduction

In recent years, image fusion has become an important topic in image analysis and computer vision [1-4]. Image fusion refers to the methods that integrate complementary information from two or more sensors. Multi-focus image fusion denotes fusion of images of a same scene that have diverse focuses. The fused image, in which all relevant objects appear in focus, is more suitable for human visual and machine perception.

A simple image fusion method is achieved by averaging corresponding pixel values of the source images. However, this method decreases the contrast and resolution of the image. In recent years, several methods have been proposed for image fusion: Laplacian pyramid [5], the gradient pyramid [6], the ratio-of-low-pass pyramid [7], morphological pyramid [8], wavelet transform [9-11], region based pixel level [12] and neural networks [13].

In this paper, images that contain two or more objects placed different distances from the camera are considered. It is almost impossible to obtain everywhere-in-focus image with a camera due to the limited depth of field of the lens used in cameras. The aim of the image fusion technique is to obtain the everywhere-in-focus images using the source images that are focused on different objects [14]. In this paper, a synergistic combination of two traditional criterion function achieved by a fuzzy inference system (FIS) is proposed for region based multi-focus image fusion. The experimental results demonstrate the better performance than the region based pixel level multi-focus image fusion using spatial frequency (RBIF-SF) method [12].

2. Image Fusion using Region Based Fuzzy Method

Fuzzy logic is suggested by Zadeh and based on fuzzy set and subsets [15]. In traditional set theory, an entity is either a member of the set or not. Fuzzy reasoning offers an alternative to Boolean logic such that the truth value of a proposition can take any value between 0 and 1. In a fuzzy set, each entity has a membership degree represented by $\mu(x)$ [16,17]. Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The process of fuzzy inference involves: membership functions, fuzzy logic operators and if-then rules.

In region based pixel level image fusion, several criterion functions can be used to determine the sharper regions of an image. However, criterion functions do usually depend on the spatial information of the image which causes miscalculation of the sharpness in some cases. Therefore, this paper

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proposes a criterion function which is a cooperative fuzzy combination of two common criterion functions: Spatial frequency (SF) and Tenengrad (TNG) function.

2.1 Proposed method

Schematic diagram of the proposed method is given in Figure 1. Region based fuzzy method uses the sharpness criterion of the fuzzy system for distinguishing the focused and defocused regions. The decision for choosing the sharper region is made with respect to the higher values of the sharpness criteria.

First, the input source images are decomposed into blocks. Corresponding blocks of the decomposed source images are compared with the proposed FIS. The sharper block is then copied to the intermediate fused image. After then, a consistency check is applied: if a particular block in the fused image is copied from *f1* but the majority of its surrounding blocks are from *f2*, this block will be replaced with the corresponding *f2* and vice versa. In the implementation, the size of the consistency check filter employed is 3×3.

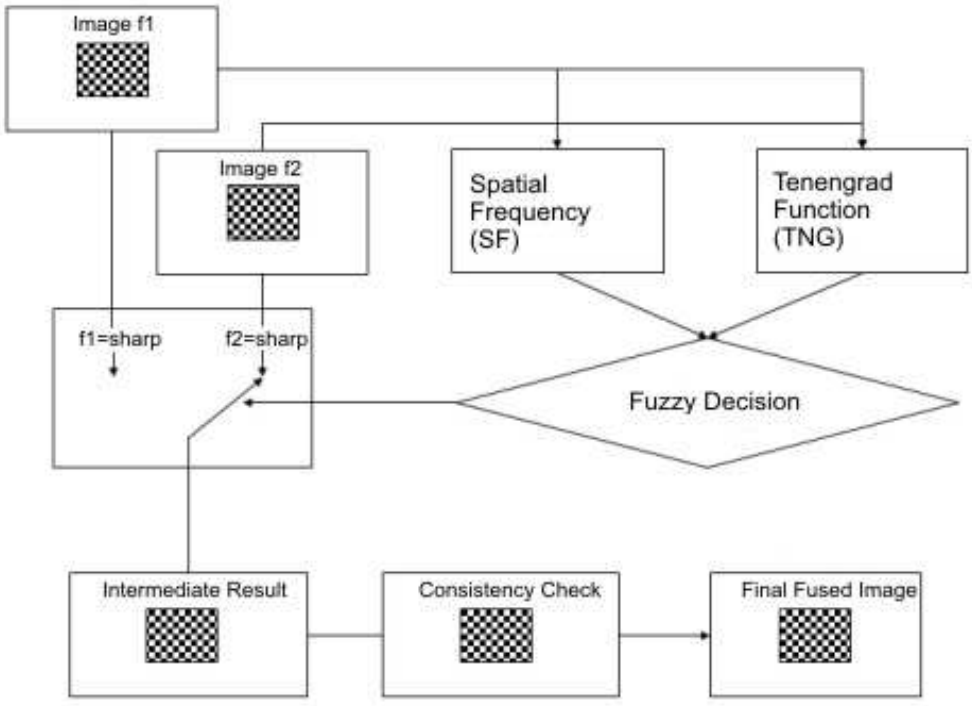


Figure 1.Shematic diagram of the proposed image fusion method.

2.2 Sharpness Criterion Functions

Several focus measures are proposed in the literature by researchers. These functions usually depend on the gradient of the image, edge characteristics and statistical information such as variance. In this paper, the proposed fuzzy system does not directly measures the sharpness of the image block. It evaluates the information about the sharpness of the image and produces a value that represents the sharpness value for that image. A fuzzy inference system produces an output by evaluating several different information. Spatial frequency and Tenengrad function are employed to obtain a fuzzy criterion function for image fusion.

2.2.1 Spatial Frequency (SF)

SF indicates overall activity level in an image [18]. In this method, the gradients are computed by measuring the first intensity differences between adjacent pixels along horizontal and vertical lines. The gradients are squared so as to enhance the contributions of the larger gradients more than those of the smaller gradients. The criterion is then computed as:

$$SF = \sqrt{C^2 + R^2} \tag{1}$$

where *C* and *R* are the row and column gradients:

$$C = \left[\frac{1}{M \times N} \sum_i \sum_j [f(i,j) - f(i-1,j)]^2 \right]^{1/2}$$
$$R = \left[\frac{1}{M \times N} \sum_i \sum_j [f(i,j) - f(i,j-1)]^2 \right]^{1/2} \tag{2}$$

2.2.2. Tenengrad Function (TNG)

Edge characteristics are affected by the quality of focus. Since defocusing tends to decrease the gradient of an edge, the criterion function involves measuring the magnitude of the gradients in the region of interest. The criterion estimates the gradient at each image point, and simply sums all their magnitude from operator.

$$TNG = \sum_i \sum_j [\nabla f(i,j)]^2 \text{ for } \nabla f(i,j) > T \tag{3}$$

where *T* is a threshold value and $\nabla f(i, j)$ is the gradient magnitude given as:

$$\nabla f(i,j) = \sqrt{f_x{}^2 + f_y{}^2} \tag{4}$$

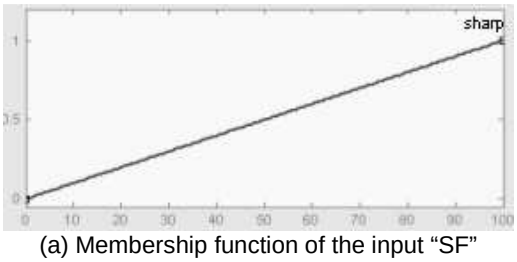
where f_x and f_y are gradients along the horizontal and vertical direction, respectively. There are many discrete operators which can estimate f_x and f_y. Tenengrad uses Sobel operators to approximate gradients in the horizontal and vertical directions as shown below:

$$\begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \qquad \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}$$

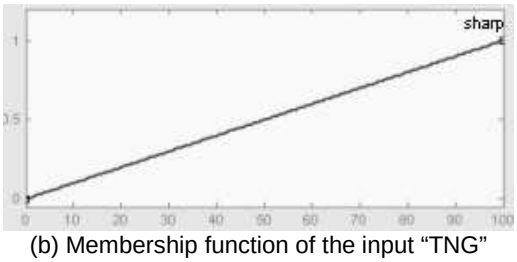
2.3 Fuzzy Criterion Function

In the implementation of a FIS, the parameters of the system need to be determined. These parameters are: number of input and output variables and membership functions, fuzzy rules, fuzzy inference method and defuzzification method.

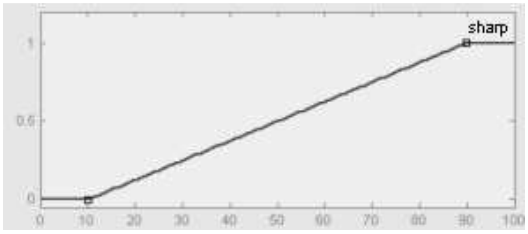
As previously mentioned, the proposed structure has two input variables: SF and TNG. The output of the inference system is named “sharpness”.



(a) Membership function of the input “SF”



(b) Membership function of the input “TNG”



(c) "Membership function of the output "sharpness"

Figure 2. Membership functions of the inputs and the output of the proposed FIS.

As can be seen from Figure 2, all membership functions are linear increasing functions because of the relation between criterion function value and the sharpness.

Another issue that has to be addressed is the value range of input parameters. However, the criterion functions produce values according the intensity of the image and these values usually depends on the image content. Therefore, a normalization process should be realized.

The if-then rules of the proposed system are given below:

1: If SF is sharp, sharpness is sharp

2: If TNG is sharp, sharpness is sharp

With these rules, the FIS always evaluates the two independent input variables. If one of them makes a miscalculation, proposed system determines the sharpness with the help of the other variable. The fuzzy output of the system is shown in Figure 3. The proposed fuzzy structure is a Mamdani type FIS and centroid based defuzzification method is used in the implementation.

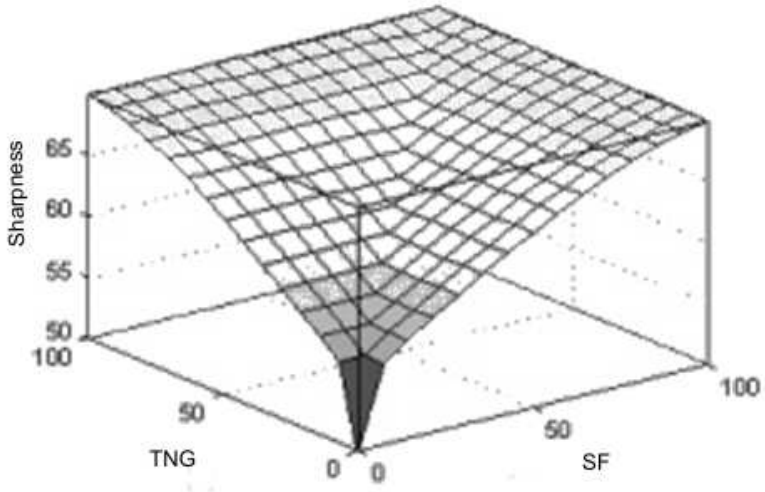


Figure 3. Input-output diagram of the proposed FIS.

The steps of the algorithm can be summarized as:

Step 1- Decompose the source images *f1*and *f2* using a particular KxK sized blocks.

Step 2- Calculate the SF and TNG values of each block in *f1* and *f2*.

Step 3- Evaluate the SF and TNG values of the corresponding blocks using the proposed FIS

Step 4- Compare the output of the fuzzy system and copy the block to the intermediate fused image using Equation 5.

$$f_{result}(M,N)=\begin{cases} f_1(M,N), & sharpness_1(M,N) > sharpness_2(M,N) \\ f_2(M,N), & sharpness_1(M,N) \le sharpness_2(M,N) \end{cases}, \quad (5)$$

Step 5- Repeat the steps 2-4 for all blocks.

Step 6- Apply a consistency check filter for the intermediate fused image to obtain the final fused image.

3. Experimental Results

3.1 Performance Metrics

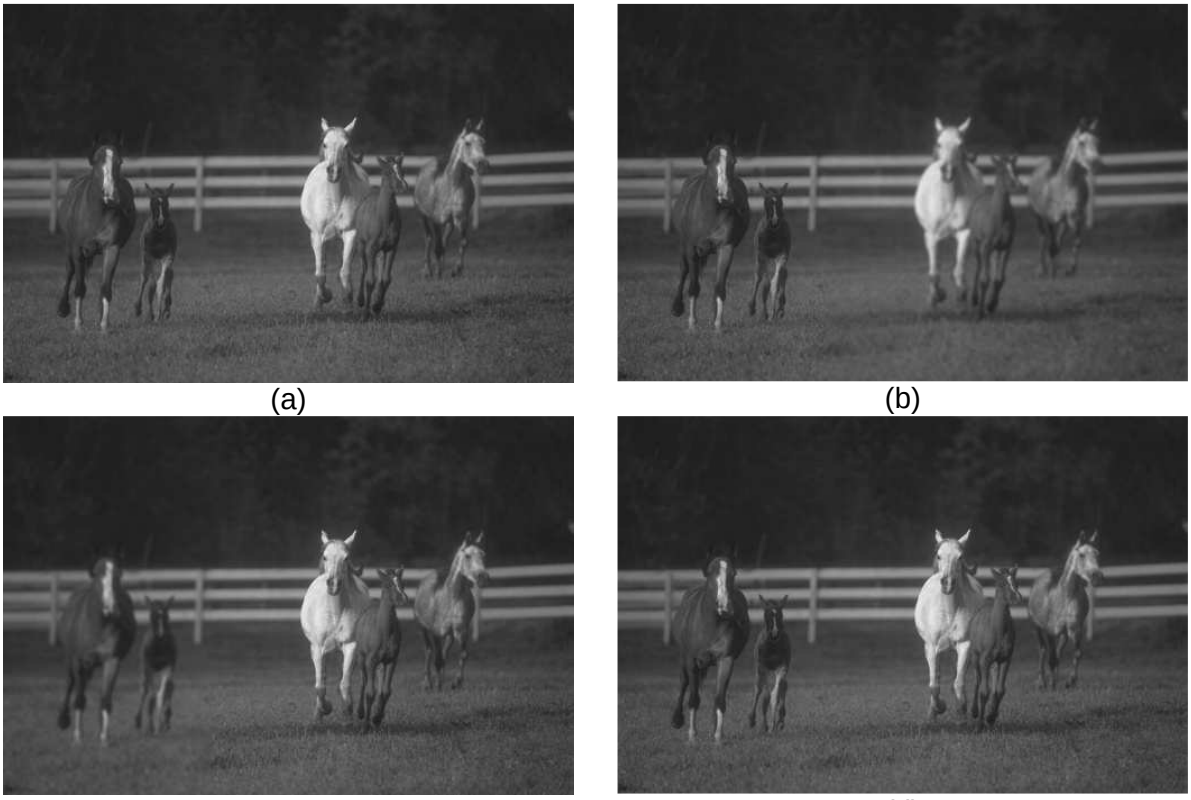
For the simulations, the image in Figure 4(a) and its blurred versions (Figure 4(b), (c)) are used. The reference image is 476x719 in size and focused in everywhere. The blurred versions of the reference image are generated artificially by convolution with an average (5X5) filter. One of these images is focused on the right and the other one is focused on the left. Root Mean Square Error (RMSE) and SF are used as evaluation metrics.

RMSE is described as follows:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{I}\sum_{j=1}^{J}[R(i,j)-F(i,j)]^2}{I \times J}}, \quad (5)$$

where R is reference image, F is fusion result, $R(i,j)$ and $F(i,j)$ are the pixels of the R and F images located in the (i,j) position, respectively.

SF can also be used as a global sharpness metric for the final fused image since it does not require the reference image.



(a) (b) (c) (d)

Figure 4. Reference image, the blurred versions and the fused image. (a) reference image; (b) source image focused on the right; (c) source image focused on the left; (d) fused image using FIS (block size 66x66).

3.2 Affects of the block size

Table1 shows RMSE and SF values which are obtained by using different block sizes. There is not much difference between the results. As can be observed from the tables, the block size should not be too large or too small. Besides, a proper block size for each image has to be chosen. 33x33 and 38x38 block sizes demonstrate better results for the image used in the simulation, however these block sizes may not be suitable for another image.

Table 1. RMSE and SF values for the fusion of Fig. 4(b) and (c) with different block sizes using proposed method.

RMSE									
3x3	**8x8**	**13x13**	**18x18**	**23x23**	**28x28**	**33x33**	**38x38**	**43x43**	**48x48**
1.1181	0.75153	0.3049	0.3599	0.5001	0.4950	**0**	0.2032	0.3305	0.7749
SF									
3x3	**8x8**	**13x13**	**18x18**	**23x23**	**28x28**	**33x33**	**38x38**	**43x43**	**48x48**
8.8744	8.9244	8.9713	8.9662	8.9498	8.9495	**8.9822**	8.9776	8.9682	8.905

3.3 Comparison with region based pixel level image fusion method

In this section, fusion results of the RBIF-SF method [12] with different threshold values are presented and compared with the proposed method. RBIF-SF method is selected for the comparison because it is a region based pixel level method, as the proposed fuzzy method. For different threshold values, RMSE and SF values of RBIF-SF method shown in Table 2. As shown in Table 1 and 2, RMSE and SF values of proposed method are better than those of RBIF-SF method. RBIF-SF method gives the best result with 33x33 block size and the threshold level of 0. In some cases, threshold level significantly affects the fusion performance. However, determining a threshold level usually requires heuristic choices.

Tablo 2. Fusion results of RBIF-SF method with different block sizes and threshold values.

RMSE ***Block Size***

Threshold	**3x3**	**8x8**	**13x13**	**18x18**	**23x23**	**28x28**	**33x33**	**38x38**	**43x43**	**48x48**
0,00	1.4601	0.6529	0.3122	0.3841	0.4625	0.4839	**0.0522**	0.2032	0.3477	0.6982
0,25	1.524	0.7047	0.4065	0.4591	0.4366	0.5021	0.2668	**0.2510**	0.4268	0.5683
0,50	1.6008	0.8037	0.5399	0.5615	0.5523	**0.5094**	0.5140	0.5111	0.5128	0.6231
0,75	1.6815	0.9624	0.7787	0.8700	0.8693	**0.7485**	0.8270	0.9141	0.7933	0.7671
1,00	1.7454	1.0375	0.8986	0.9935	0.9587	0.8613	0.9734	1.0059	**0.8398**	0.9791
1,25	1.7811	1.0766	1.0443	1.0523	1.1057	1.0062	1.0442	1.1952	**0.9466**	1.0132
1,50	1.8197	1.116	1.0715	1.1045	1.18	1.0363	1.1429	1.2738	1.0176	**1.0125**
1,75	1.8534	1.1374	1.0894	1.1158	1.2112	**1.0793**	1.1622	1.3035	1.1186	1.1999
2,00	1.8998	1.1748	1.0931	1.1391	1.2456	**1.083**	1.1787	1.3229	1.1652	1.4251
2,25	1.9563	1.196	1.1306	1.1695	1.2806	**1.0994**	1.2191	1.3966	1.2102	1.573
2,50	2.0068	1.2521	1.1793	1.1863	1.2922	**1.1552**	1.2191	1.4184	1.2257	1.8347
2,75	2.0502	1.3156	1.2133	1.2385	1.3264	**1.1524**	1.2515	1.4333	1.2533	1.8606
3,00	2.1006	1.365	1.2808	1.2854	1.3664	**1.2069**	1.355	1.4932	1.3374	1.8958

SF ***Block Size***

Threshold	**3x3**	**8x8**	**13x13**	**18x18**	**23x23**	**28x28**	**33x33**	**38x38**	**42x42**	**48x48**
0,00	8.8301	8.9521	8.9709	8.9643	8.9537	8.9504	**8.982**	8.9776	8.9672	8.9162
0,25	8.8187	8.9463	8.9639	8.9588	8.9485	8.9473	8.9753	**8.9761**	8.9621	8.8769
0,50	8.8024	8.9361	8.9543	8.9469	8.9359	8.9451	8.9558	**8.9566**	8.9541	8.8706
0,75	8.7779	8.9117	**8.9253**	8.9092	8.8864	8.9189	8.9165	8.9006	8.9214	8.848
1,00	8.7521	8.8857	8.8919	8.8721	8.8545	8.8889	8.8779	8.8704	**8.901**	8.8161
1,25	8.7283	8.8658	8.8542	8.8491	8.8157	8.8496	8.8495	8.8239	**8.8805**	8.8088
1,50	8.7033	8.8491	8.8321	8.825	8.7856	8.8336	8.822	8.794	**8.8657**	8.8077
1,75	8.6827	8.8362	8.8222	8.8134	8.7641	8.821	8.8176	8.7849	**8.8383**	8.7597
2,00	8.6596	8.8182	8.8174	8.8062	8.7538	8.8192	8.8137	8.7764	**8.8212**	8.6908
2,25	8.6312	8.8064	8.8087	8.7987	8.7444	**8.8152**	8.8021	8.7557	8.8067	8.6362
2,50	8.6067	8.7909	8.7958	8.7942	8.7413	8.7982	8.8021	8.7482	**8.8024**	8.5721
2,75	8.5826	8.7712	8.7858	8.7804	8.7327	8.7703	**8.7939**	8.7439	8.7936	8.5114
3,00	8.5554	8.7566	8.7677	8.7674	8.7206	8.7564	8.7599	8.7248	**8.7718**	8.4981

3.4 Subjective Evaluation

The proposed method and RBIF-SF method are used to fuse images including objects with different distances obtained by a real lens. This type of images has no reference image therefore the evaluation has to be subjective. For example in Figure 5(a) camera is focused on the nearby clock and in Figure 5(b) camera is focused on the bookcase. The fused images using RBIF-SF method and the proposed method are shown in Figure 5(c) and (d), respectively. Also the fused image obtained by the proposed method is better than the RBIF-SF when they are visually interpreted. Another simulation is realized by using different natural multi-focus images shown in Figure 6.

4. Conclusion

In this paper, a new region based image fusion algorithm based on fuzzy logic is proposed. With this method, fusion of multi-focus images is performed and everywhere-in-focus image is obtained. Several experiments and simulations are performed to measure the performance of the proposed method. As a result of the comparison with RBIF-SF method, proposed method has better performance in terms of quantitative and subjective analysis. Proposed method is computationally simple and can be used in real time applications. Also, the proposed method does not require heuristic threshold choices. In this study, only fusion of two source images are considered, but it can be extended straightforwardly.

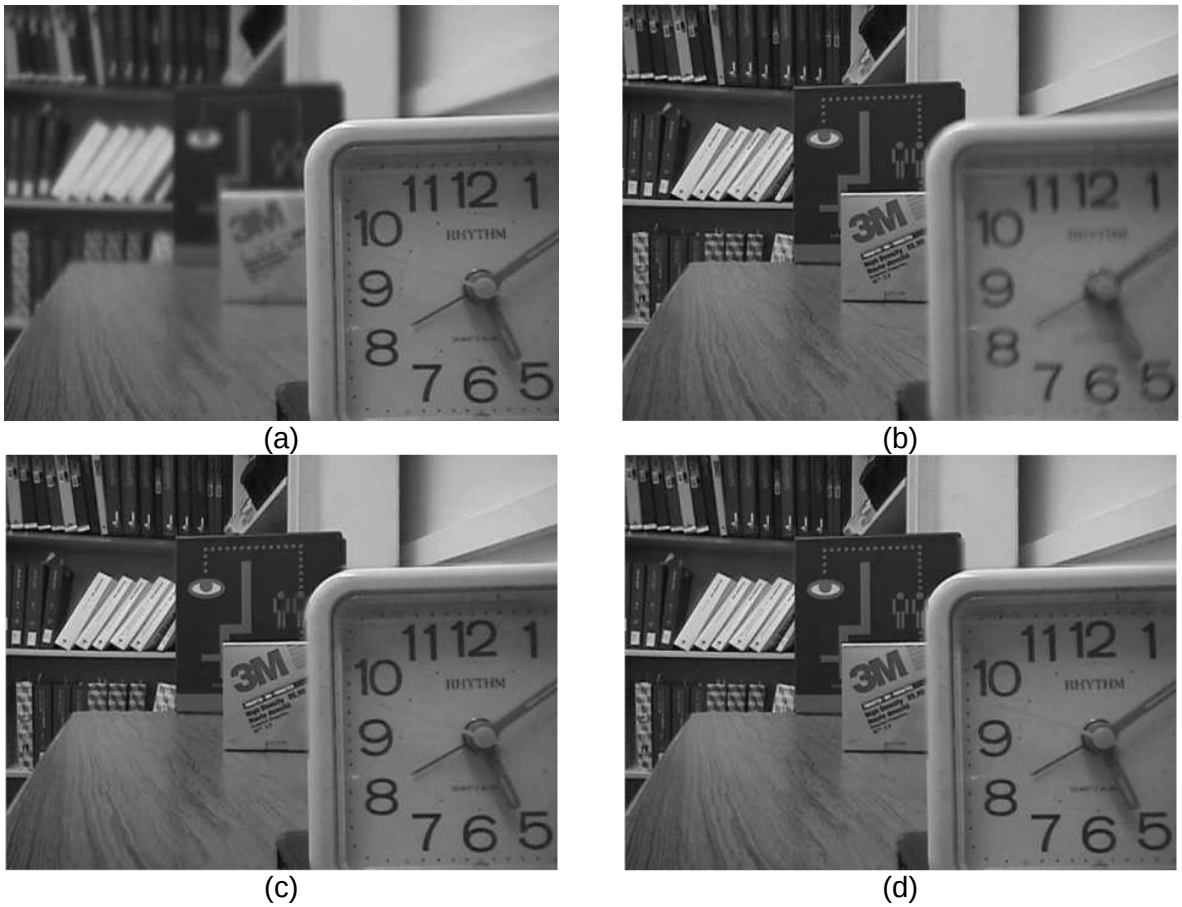
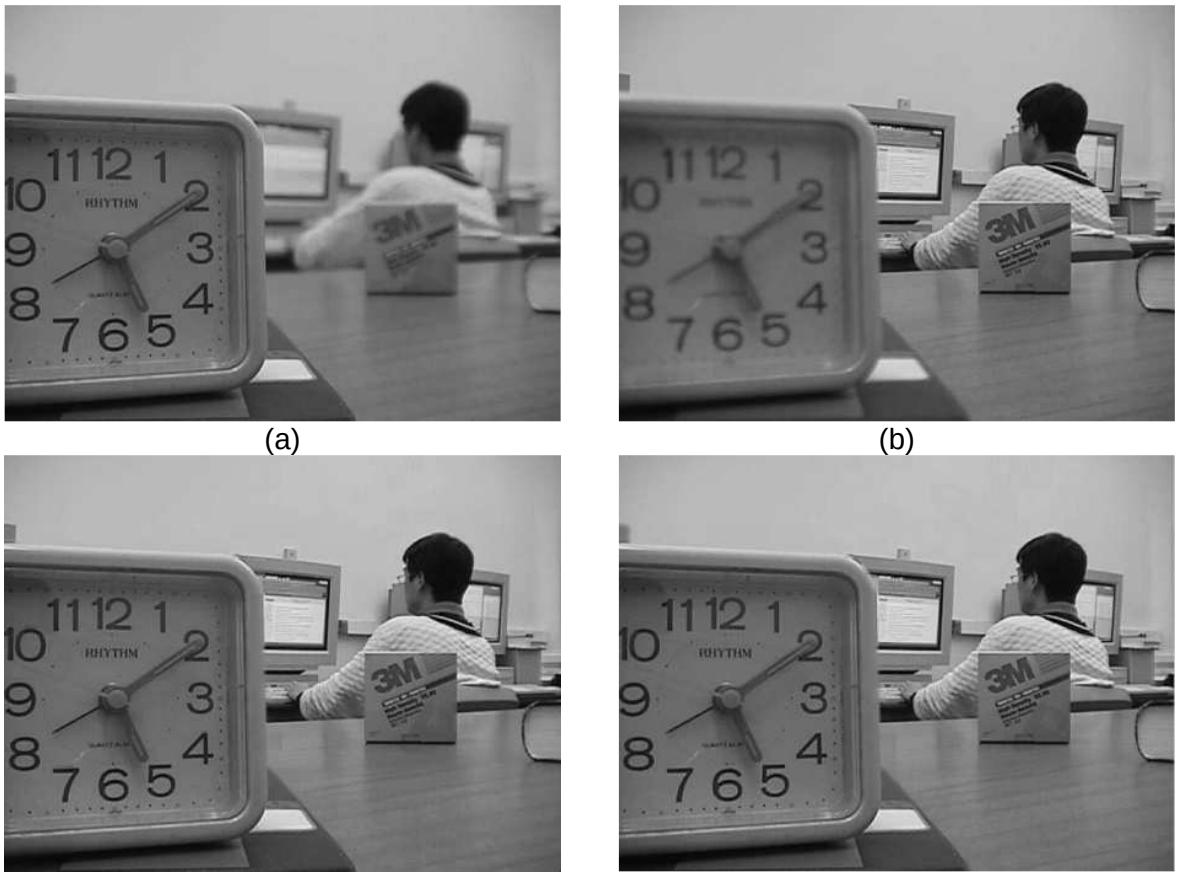


Figure 5. Source images named “disk” (480x640) and fusion results. (a) focused on the right; (b) focused on the left; (c) RBIF-SF method (block size=32x32, threshold value = 0,75) (d) proposed method (block size=32x32).



(a) (b) (c) (d)

Figure 6. Source images named “lab” (480x640) and fusion results. (a) focused on the clock; (b) focused on the student; (c) RBIF-SF method (block size=20x20, threshold value = 0,75) (d) proposed method (block size=20x20).

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