The Method for Generating High Resolution Images in Low Light Conditions

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Abstract: This method through fusion of edges detected in an electro-optic image with a corresponding transformed infrared image and the original infrared image. Alternatively, the method generates high resolution images in low light conditions when an electro-optic image is not available by edge detection of an infrared image, transformation of the infrared image and fusion of the transformed infrared image with the edges detected in the infrared image. The method is particularly useful for night vision applications.

1 INTRODUCTION

Electro-optic ("EO") imaging techniques are capable of achieving high-resolution images when the object to be imaged is illuminated by adequate light of an appropriate wavelength, as during the day. Electro-optic imaging devices are less useful at night or in other low light conditions. Infrared ("IR") imaging technology is dependent upon heat emitted by the object to be imaged and is not dependent on incident light reflected by the object. Infrared imaging techniques hence can be used in conditions of complete darkness. Infrared imaging is inherently of lower resolution that electro-optic imaging and suffers from noise in the signal. Infrared imaging is also poor at discriminating between object having a similar temperature. Night vision systems are known. For example, it is shown that a night vision system in which edge detection is applied to an infrared image and the detected edges fused with an image-intensified visible light image (U.S. Patent 7,864,432 to Ottney issued 2011). See literature (U.S. Patent 7,864,432 to Ottney issued 2007, U.S. Patent 7,864,432 to Ottney issued 2003) for the same disclosure and teaches a head worn night vision system include image intensifiers operating in the near infrared. In the literature, see "Cognitive Image Fusion and Assessment," Alexander Teot, chapter of Image Fusion, edited by Osamu Ukimura (Ruzic, Pizurica 2012). See also "Experimental Tests of Image Fusion for Night Vision," Y. Chen and R. Blum, available (huang, Netravali 2012, Huang, Man, Lawrence 2012). Copies of the Teot and Chen articles are attached to this provisional application and incorporated by reference herein. Using current imaging techniques, it is not possible to distinguish the edges of objects in low light conditions, such as at night, where the objects have a similar temperature and a similar background, or tiny parts of any objects.

2 THE RESEARCH METHOD

2.1 First Innovative Method

The first method involves the following steps: (a) capturing an electro-optic image of objects; (b) processing the electro-optic image by applying edge detection technology to detect the edges within the electro-optic image; (c) collecting an infrared image of objects corresponding to the electro-optic image; (d) transforming the infrared image by applying a Wiener filter or an inverse filter based on the point spread function of the thermal imaging method; (e) registering the infrared and electro-optic images to match features of one image with the other; and (f) fusing the transformed infrared image and the detected edges of the electro-optic image to create a composite image. The composite image features better resolution among objects than the original infrared image.

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The step of capturing the electro-optic image may occur at a time different from the time that the infrared image is captured. For example, the electro-optic image may be captured during daylight hours so that the object to be imaged is adequately illuminated to create a high resolution, low noise image having readily identifiable edges. The corresponding infrared image may be captured during periods of low light when the electro-optic detector is not effective.

The step of transforming the IR image may occur in any of several ways, either alone or in combination. For example, the IR image may be transformed by applying an inverse filter using a Fourier transform based on the theoretical point spread function ("PSF") of the infrared detector. The IR image transformation may be based on the measured, rather than theoretical, point spread function for the infrared imaging system. The inverse filtering process utilizing either the theoretical or measured point spread function of the IR imaging system reduces the noise in the image and makes the transformed infrared image look “sharper” than the original one. The IR image may be filtered by applying the Wiener filter as an alternative to transform the IR image if noise is not neglectable. The inverse filter is a special case of the more general Wiener filter.

The step of edge detection of the EO image involves applying an edge detection algorithm to the EO image. The resulting edge-detected image comprises the detected edges. The step of registering the transformed IR image and the edge-detected EO image may be as simple or as complex as the data require and involves the identification and matching of corresponding features on the IR and EO images. The step of blending the edge-detected EO image and the transformed IR image involves overlaying the detected edges on the corresponding locations of the transformed IR image. The blending step may include blending of the original, un-transformed IR image with the transformed IR image and the detected edges.

2.2 B. Second Innovative Method

The method of the method can generate images of improved resolution when only an IR image and no corresponding EO image is available. In this second method, the steps include (a) capturing an IR image, (b) transforming the IR image by applying a Wiener filter or an inverse filter using a Fourier transform based on either a theoretical point spread function or a measured point spread function of the infrared image, (c) applying an edge detection algorithm to detect the edges in the IR image, and (d) blending the edge-detected IR image, the original IR image and the transformed IR image to form a fused IR image.

3 METHOD DESCRIPTION

Figs. 1 and 2 are schematic diagrams illustrating the first method of the method. Fig. 1 shows the flow of information in the first method while Fig. 2 shows the method of the first method. As shown by Figs. 1 and 2, an EO sensor captures an EO image. An IR sensor captures an IO image, either at the same or at a different time from the capture of the EO image. The IR and EO images are registered to match features of the IR and EO images for use in blending the processed images. The EO image is analyzed using an edge detection algorithm to detect differences in hue, color or intensity that may indicate an edge of an object. The result of the edge detection is an edge-detected EO image comprising the detected edges. The other information in the original image generally is omitted in the edge-detected EO image. As indicated by Fig. 7, the edgedetected EO image may be further processed by applying a small-size low pass filter to the edgedetected image. The IR image is transformed using either a Wiener filter or an inverse filter based on the point spread function of the IR sensor. The inverse filter is a particular application of the Wiener filter and comprises transforming the IR image using the point spread function of the IR sensor. The selection of either the Wiener filter or the inverse filter may depend upon the noise level in the original IR image. If the original IR image has a high noise level, then the Wiener filter will be adopted to reduce that noise level. If the original IR image has little or no noise, then the inverse filter is the filter of choice. The method of the method may be configured to select the appropriate filter based on the noise level of the original IR image. The point spread function of the IR sensor applied in either the Wiener filter or the inverse filter may be either a theoretical point spread function or a point spread function determined by measurement. As an optional step, the transformed IR image and the edge-detected image may be registered to match the detected edges in the edge-detected image to the edges shown by the transformed IR image.

The edge-detected EO image, the transformed IR image, and the original, un-transformed IR image

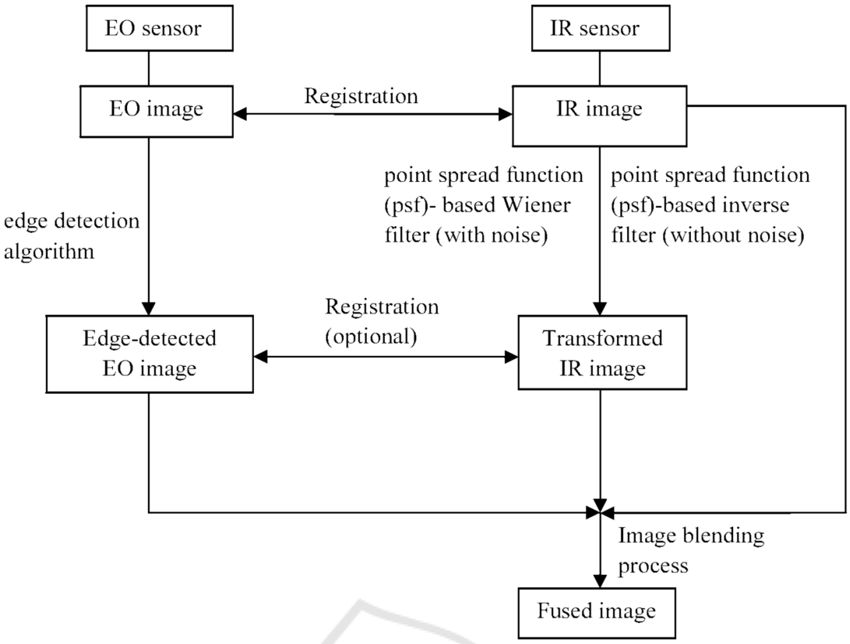

Figure 1: Flow of information(self-created).

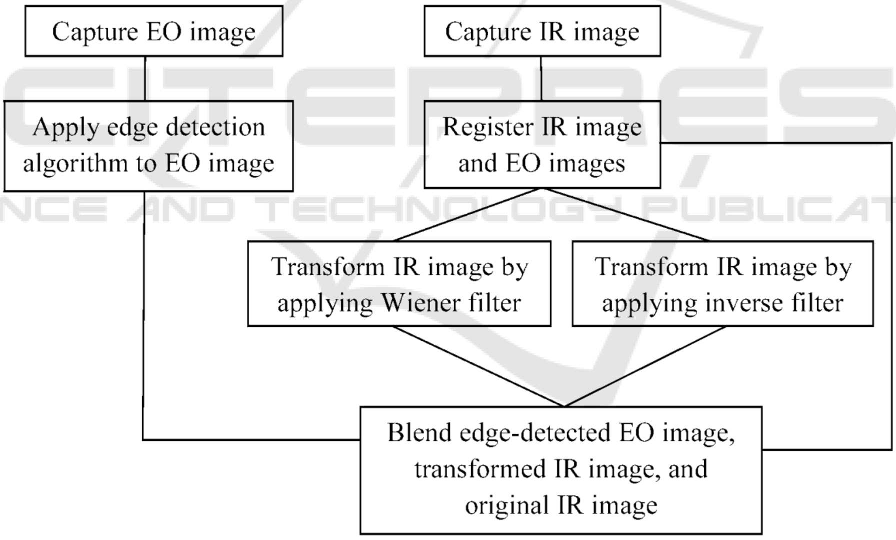

Figure 2: Flow chart(self-created).

then are blended to define a fused image. The resulting fused image demonstrates a better resolution among objects shown by the images than either the IR image or the EO image alone. For further explanation, see the attachments.

Figs. 3-5 illustrate the second method of the method. The second method applies when an IR image, but not an EO image, is to be processed. Fig. 3 illustrates the information flow of the second method. Fig. 4 illustrates the method of the method. From Figs. 3 and 4, an IR sensor captures an IR image. The IR image is processed along two different paths and the results of the processing are blended to form a fused image. In the first method, an edge detection algorithm is applied to the IR image to determine an edge-detected image. The edge-detected image comprises the detected edges and generally does not include the other information in the original IR image. In the second path, the original IR image is transformed by applying either a Wiener filter based or an

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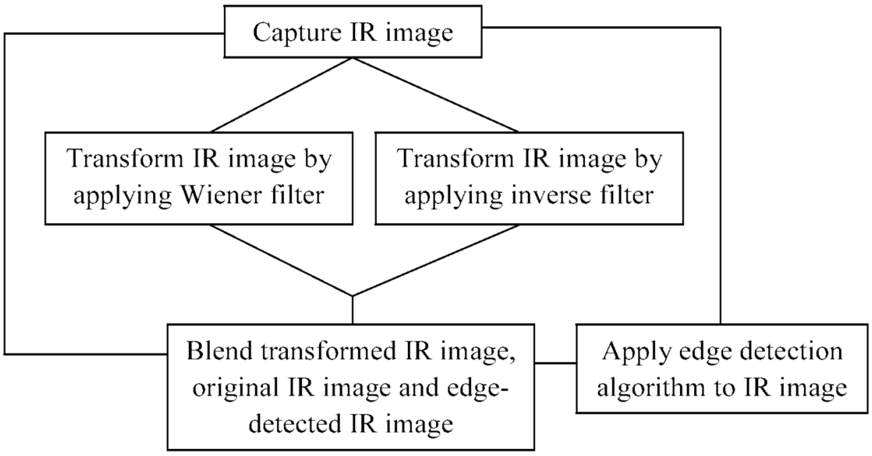

Figure 3: Flow chart(self-created).

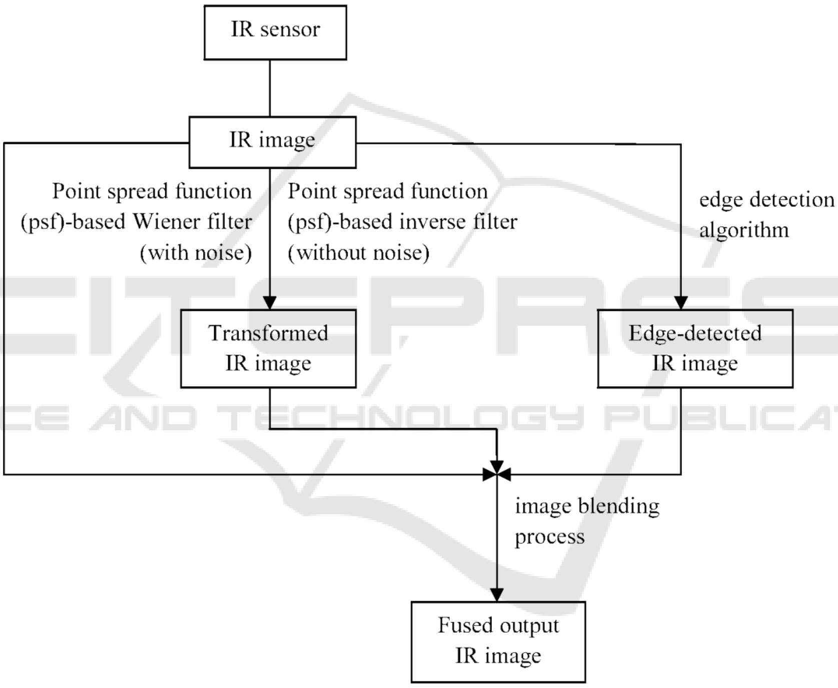

Figure 4: Flow chart(self-created).

inverse filter comprising a Fourier transform based on the point spread function of the IR sensor. The step of transforming the IR image is conducted as indicated above for the first method. The transformed IR image is then blended with the edge-detected IR image and the original IR image to define a fused output image. The fused output image demonstrates a better resolution among objects shown by the images than the IR image alone. Fig. 5 also relates to the second method and illustrates that the filtering of the IR image shown by Figs. 3 and 4 may be based on either a theoretical point spread function of the IR sensor or may be based on an actual measured point spread function of the IR sensor.

Fig. 6 illustrates the method for the first method of the method. The method comprises a microprocessor operably connected to the IR sensor, the EO sensor, a computer memory and a computer display. The method receives data from the IR sensor defining the IR image and data from the EO sensor defining the EO image. The microprocessor is configured to receive and manipulate the data by programming in the computer memory. The microprocessor is configured to perform each of the steps described above or as

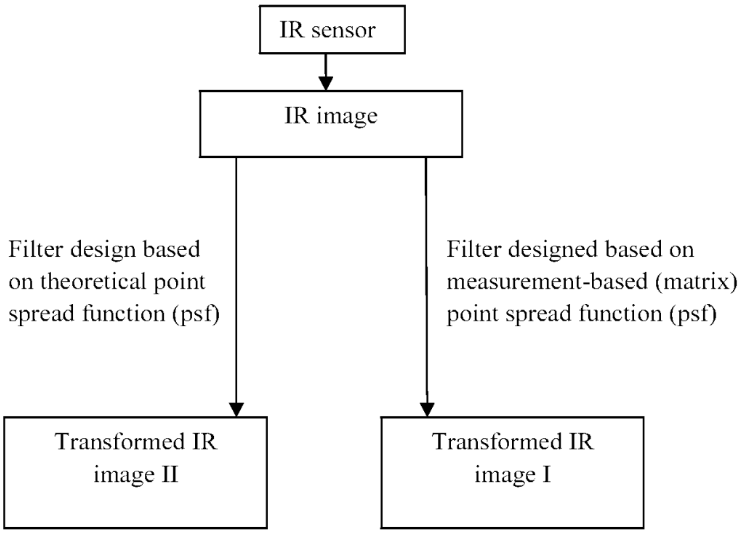

Figure 5: Flow chart(self-created).

shown in the attachments, resulting in the fused image. The fused image is displayed to the user on a display. Also from Fig. 6, the method of the method for the second method of the method has characteristics similar those shown, except that the microprocessor does not receive or does not process EO image data from the EO sensor. The microprocessor is otherwise configured to perform each of the steps set forth above or in the attachments for the second method, resulting in a fused image. The display is configured to display the fused image to the user. Fig. 7 illustrates an additional filtering step that may be applied to an edge-detected image. The additional step is passing the edge-detected image through a small-size low pass filter for the purpose of smoothing the detected edges. The small-size low pass filter, for example a 2 by 2 average filter as known in the art, allows the detected edges to seamlessly match the objects shown by the original IR image and transformed IR image. The low pass filter must be small in size to prevent loss of the edge information in the edge-detected image. While Fig. 7 illustrates the additional filtering step as applied in the first method of the method as shown by Figs. 1 and 2, the technique also may be applied to the edge-detected IR image in the second method, shown by Figs. 3

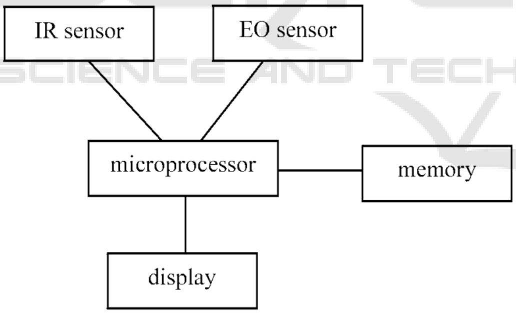

Figure 6: Flow chart(self-created).

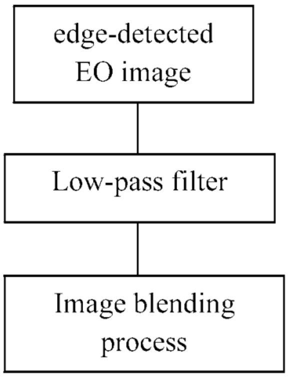

Figure 7: Flow chart(self-created).

4 CONCLUSION

This paper proposes a method of image fusion, with combination of infrared image and the original infrared image. Through the above analysis, we can obtain some useful results: the proposed method generates high resolution images in low light conditions, particularly, edge detection of an infrared image is not available for electro-optic image.

In the future study, our works are mainly focus on multimedia video processing that employ image fusion method proposed in this paper.

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