



Effect of Homomorphic Filter on Infrared Images for Exposure Fusion

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Abstract: An important factor to improve the visual quality of an image is contrast enhancement. The more the value of contrast, the simpler it is to identify and compare between different objects in an image. This paper focuses on experimenting how efficient different contrast enhancement techniques developed for visual images work for infrared images. It also determines which technique suites well to site a weapon hidden beneath a person's clothing application of infrared imaging. We have compared Homomorphic filtering to the classical technique of histogram equalization using metrics of entropy, sharpness and user observations. These metrics provide both qualitative and quantitative analyses of the implemented work which has relevance to the end user application of concealed weapon detection using infrared imaging.

Keywords: Infrared images; contrast enhancement; homomorphic filter; histogram equalization; entropy; sharpness; concealed weapon detection CWD.

I. Introduction

There are a number of imaging sensors for CWD based on their portability, proximity and whether they use active or passive illumination. Though most of the illuminations required are low-power radiation, legal issues such as posting warnings or seeking consent from people being screened may alert carriers of concealed weapons and diminish the value of the CWD system. Infrared imagers utilize the temperature distribution information of the target to form an image [1], [2]. Normally they are used for a variety of night-vision applications, such as viewing vehicles and people. The underlying theory is that the infrared radiation emitted by the human body is absorbed by clothing and then re-emitted by it. As a result, infrared radiation can be used to show the image of a concealed weapon only when the clothing is tight, thin, and stationary. Before an image sequence is presented to a human observer for operator-assisted weapon detection or fed into an automatic weapon detection algorithm, it is desirable to preprocess the images to maximize their exploitation. The preprocessing steps considered in this section include contrast enhancement and filtering for the removal of shadows, wrinkles, and other artifacts.

A considerable amount of research has been done in the field of contrast enhancement. The field of contrast enhancement can be broadly divided into two major areas of research: (1) Global contrast enhancement techniques and (2) Local contrast enhancement techniques. Global contrast enhancement techniques are simple and powerful but cannot adapt to the local brightness features of the input image because these techniques use only global information collected over the entire image [3]. Local contrast enhancement techniques adjust picture element (pixel) values are over smaller regions of an image to improve the visualization of structures in both the darkest and the lightest portions of the image at the same time. The purpose of image enhancement is to improve the interpretability or perception of information contained in the image for human viewers.

Histogram equalization (HE) is a commonly used global contrast enhancement technique for both color and grayscale images. HE spreads out and flattens the histogram of the number of image pixels at each gray level value, thus stretching the intensity values in the image over more of the available dynamic range of gray-levels and increasing the apparent contrast in the image [4]. This method is especially useful when an image is represented by close contrast values, such as images in which both the background and foreground are both bright, or else both are dark at the same time. While easy to implement and not very computationally intensive, HE has several known drawbacks. First, HE does not preserve the average brightness of the input image in the output image. Therefore, the processed output image will often appear unnaturally bright or "washed out." Also, the method is indiscriminate. It may increase the contrast of background noise, while decreasing the usable signal. To overcome these drawbacks, numerous variations of the classic HE technique have been published [5], [6], [7]. Homomorphic filtering is a frequency domain method for contrast enhancement [8]. It has been used in a variety of applications like shadow identification [9], underwater image pre-preprocessing [10], [11], contrast enhancement for raised or indented characters [12], and seismic data processing [13]. Homomorphic filtering sharpens features in an image by enhancing high frequencies and sharpening object edges [12]. It also flattens lighting variations in an image, bringing details out of shadows. It provides simultaneous dynamic range

compression (reducing illumination variation) and contrast enhancement (increasing reflectance variation). Homomorphic filtering can thus prove to be most effective on images that have large variations in lighting. This paper integrates the results from two different approaches of contrast enhancement techniques. Section II discusses the Histogram Equalization method. Section III covers contrast enhancement by homomorphic filtering. Section IV provides a comparison of the two techniques using metrics like entropy, sharpness and user observations.

II. Histogram Equalization

Histogram equalization is a technique for adjusting image intensities to enhance contrast [7]. It is accomplished by linearizing the cumulative density function of the image intensity levels. Consider a discrete grayscale image and let n_i be the number of occurrences of gray level i . A normalized histogram of the image shows the probability of occurrence of a pixel of level i in the image, and would be given by a collection of probability values for each pixel level:

$$p(x_i) = \text{probability that pixel } x \text{ has gray level } i = n_i / n$$

where n = the total number of pixels in the image. The cumulative density function for this histogram would be given as in Eq. 1:

$$\text{cdf } x(i) = \sum_{j=0}^i p(x_j) \quad (1)$$

Histogram equalization seeks a transformation of input pixel values to output pixel values that will make this cumulative density function as nearly linear as possible across the range of pixel gray levels. That is

$$\text{cdf}_x(i) = K i \quad (2)$$

For the purposes of this experiment, global histogram equalization is chosen as the “gold standard” for comparing alternative methods of contrast enhancement. The Matlab function *histeq* was used as the particular reference method for contrast enhancement implementation. The *histeq* function enhances the contrast of images by transforming the values in an intensity image, or the values in the color map of an indexed image [14].

While easy to implement and not very computationally intensive, HE has several known drawbacks. First, HE does not preserve the average brightness of the input image in the output image. Therefore, the processed output image will often appear unnaturally bright or “washed out.” Also, the method is indiscriminate. It may increase the contrast of background noise, while decreasing the usable signal. To overcome these drawbacks, numerous variations of the classic HE technique have been published [3].

III. Homomorphic filtering

Homomorphic filtering is a frequency domain method for contrast enhancement. Homomorphic filtering sharpens features in an image by enhancing high frequencies and sharpening object edges [6]. It also flattens lighting variations in an image, bringing details out of shadows. It provides simultaneous dynamic range compression (reducing illumination variation) and contrast enhancement (increasing reflectance variation). Homomorphic filtering can thus prove to be most effective on images that have large variations in lighting. This model consider the image is been characterized by two primary components. The first component is the amount of source illumination incident on the scene being viewed $i(x,y)$. The second component is the reflectance component of the objects on the scene $r(x,y)$. The image $f(x,y)$ is then defined as :

$$f(x, y) = i(x, y) * r(x, y) \quad (3)$$

In this model, the intensity of $i(x,y)$ changes slower than $r(x,y)$. Therefore, $i(x,y)$ is considered to have more low frequency components than $r(x,y)$. Using this fact, homomorphic filtering technique aims to reduce the significance of $i(x,y)$ by reducing the low frequency components of the image. This can be achieved by executing the filtering process in frequency domain. In order to process an image in frequency domain, the image needs first to be transformed from spatial domain to frequency domain. This can be done by using transformation functions, such as Fourier transform. However, before the transformation is taking place, logarithm function has been used to change the multiplication operation of $r(x,y)$ with $i(x,y)$ in Eq. 3 into addition operation. In general, homomorphic filtering can be implemented using five stages, as stated as follows:

STAGE 1: Take a natural logarithm of both sides to decouple $i(x,y)$ and $r(x,y)$ components as in Eq. 4

$$z(x, y) = \ln i(x, y) + \ln r(x, y) \quad (4)$$

STAGE 2: Use the Fourier transform to transform the image into frequency domain as in Eq. 5

$$FFT \{z(x, y)\} = FFT \{\ln i(x, y)\} + FFT \{\ln r(x, y)\} \quad (5)$$

or

$$Z(u, v) = F_i(u, v) + F_r(u, v)$$

STAGE 3: High pass the $Z(u, v)$ by means of a filter function $H(u, v)$ in frequency domain, and get a filtered version $S(u, v)$ as the following Eq. 6

$$S(u, v) = H(u, v)Z(u, v) = H(u, v)F_i(u, v) + H(u, v)F_r(u, v) \quad (6)$$

STAGE 4: Take an inverse Fourier transform to get the filtered image in the spatial domain as shown in Eq. 7.

$$\begin{aligned} s(x, y) &= FFT^{-1}\{S(u, v)\} \\ &= FFT^{-1}\{H(u, v)F_i(u, v) + H(u, v)F_r(u, v)\} \end{aligned} \quad (7)$$

STAGE 5: The filtered enhanced image $g(x, y)$ can be obtained by using the following Eq. 8.

$$g(x, y) = \exp\{s(x, y)\} \quad (8)$$

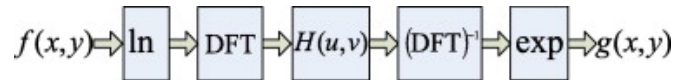
The typical filter for homomorphic filtering process has been introduced in [8]. This filter has circularly symmetric curve shape, centred at $(u, v) = (0, 0)$ coordinates in frequency domain. This filter is modified from Gaussian highpass filter, which is known as Difference of Gaussian (DoG) filter. The transfer function for DoG filter is defined as in Eq. 9.

$$H(u, v) = (\gamma h - \gamma l) \left[1 - \exp \left\{ -c \left(\frac{D(u, v)}{D_0} \right)^2 \right\} \right] + \gamma l \quad (9)$$

Where, constant c has been introduced to control the steepness of the slope, D_0 is the cut-off frequency, $D(u, v)$ is the distance between coordinates (u, v) and the centre of frequency at $(0, 0)$.

For homomorphic filter to be effective it needs to affect the low- and high-frequency components of the Fourier transform in different ways. To compress the dynamic range of an image, the low frequency components ought to be attenuated to some degree. On the other hand, to enhance the contrast, the high frequency components of the Fourier transform ought to be magnified. Figure 1 depicts the algorithm used to implement the homomorphic filter used in this paper. The algorithm is based on the equations above.

Figure 1 Block Diagram for Homomorphic filtering



IV. Metrics and Results

Test images have been chosen carefully to represent a wide variety of challenging contrast situations. The infrared images used here represent real imaging situations and challenges for IR image applications like night vision, security cameras, fire fighting and automobile night vision. A variety of images depicting low contrast, high contrast, features in shadows and features in highly saturated areas have been selected. The variety of the test images will prove to be useful while testing the effectiveness of the implemented methods.

The following metrics have been chosen for the purpose of this investigation:

1. User Observations
2. Entropy
3. Image Sharpness and

A. User Observation

A set of users were chosen to carry out this investigation. The users represented a variety of occupations from software and computer engineers to science and management. The users rated the images based on how well the objects in a particular image could be seen and the contrast and quality of the image. While making a decision the users were not informed about which image represented which technique of contrast enhancement. A set of 14 users gave their feedback and the rated the images on a scale of 1 to 5 where 1 represented the 'best output' according to the user.

Based on an average of user observation outputs [15], homomorphic filtering was selected by users as providing the best results for contrast enhancement. Output images of homomorphic filtering were seen to have higher quality of contrast while not deleting information from the original test images but enhancing the details in the test images.

B. Entropy

Entropy is a measure of information content of an image and is usually applied in image processing methods as a mean for measuring the information and complexity of images [16].

The Entropy of an image can be calculated by:

$$E = \sum_{i=0}^{255} -p_i \log(p_i) \quad (10)$$

Where, p_i is the probability that an arbitrary pixel in the image having intensity ' i '. Assuming the number of pixels having intensity i is n_i and the image contains n pixels, $p_i = n_i/n$. It is obvious that when no change occurs in information content of images or both input images (initial and contrast enhanced image) are the same.

C. Image Sharpness

The Prewitt operator from Matlab was used for detecting the sharpness of the output images compared with the input images. This is a discrete differentiation operator, computing an approximation of the gradient of the image intensity function. The Prewitt operator value therefore shows how "abruptly" or "smoothly" the image changes at each point in an image. This metric helps in analyzing how blurry the output image gets while enhancing the contrast [17]. Since contrast enhancement is used to enhance the overall visual clarity of the image, if in the process the output image becomes blurred then the contrast would not be prominent and effective. This metric helps understand the overall visual quality of the output image after the enhancement techniques have been applied. The higher the value of sharpness the better the contrast enhancement technique has preserved sharpness. The Prewitt operator is based on convolving the image with a small, separable, and integer valued two-dimensional filter [18]. Figure 2 and fig. 3 show the kernel used for horizontal and vertical edge detection for the Prewitt operator.

Figure 2 Prewitt kernel for horizontal edge detection

-1	-1	-1
0	0	0
1	1	1

Figure 3 Prewitt kernel for vertical edge detection

-1	0	1
-1	0	1
-1	0	1

D. Image Results

The test image data set was carefully chosen to include infrared images of the same scene that have different ranges of contrast as well as various exposure conditions for concealed weapon detection. The test images have been categorized as low exposed, medium exposed and highly exposed images of the four scenes respectively. The test results along with the respective histograms are presented subsequently.

Figure 4 Image Results: (a) Low exposed original Image (b) Histogram of (a) (c) Homomorphic filtering applied (d) Histogram of (c) (e) Histogram equalization applied (f) Histogram of (e)

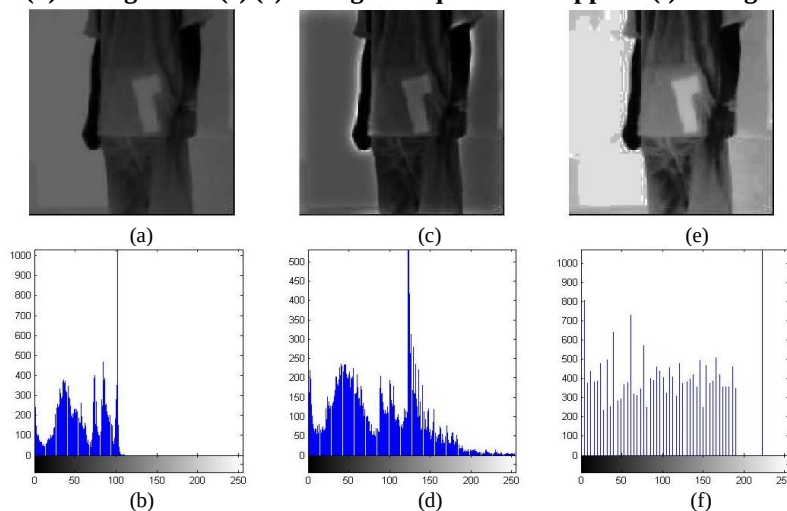


Figure 4 serves as a low exposed image with few details in the test image. In the histogram equalization output, left hand corners the output image are brighter and thus do not provide more contrast in that region whereas for the homomorphic filter output, better contrast is obtained in the entire output image and also in the weapon area. This technique also succeeded at bringing hidden objects and details.

Figure 5 Image Results: (a) Medium exposed original Image (b) Histogram of (a) (c) Homomorphic filtering applied (d) Histogram of (c) (e) Histogram equalization applied (f) Histogram of (e)

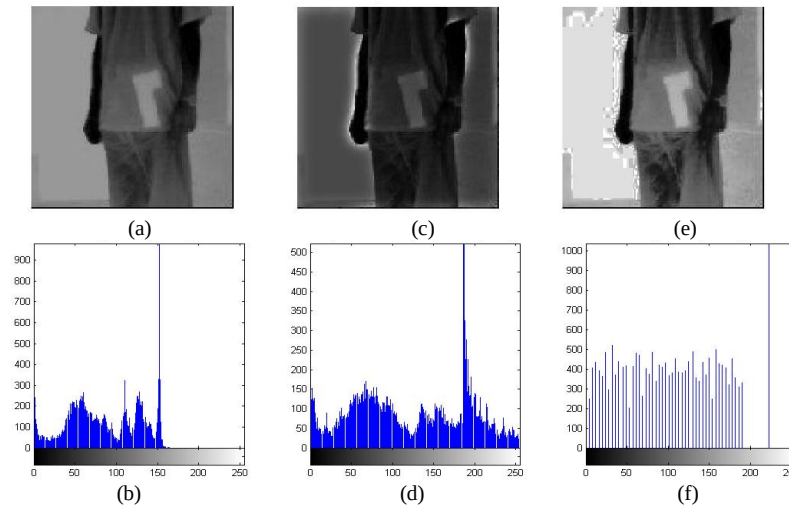


Figure 5 is a medium exposed test image with a lot of details and objects that are enhanced after the implementation of the contrast enhancement techniques. For this test image homomorphic filtering provides a crisp output image without loss of details.

Figure 6 Image Results: (a) Highly exposed original Image (b) Histogram of (a) (c) Homomorphic filtering applied (d) Histogram of (c) (e) Histogram equalization applied (f) Histogram of (e)

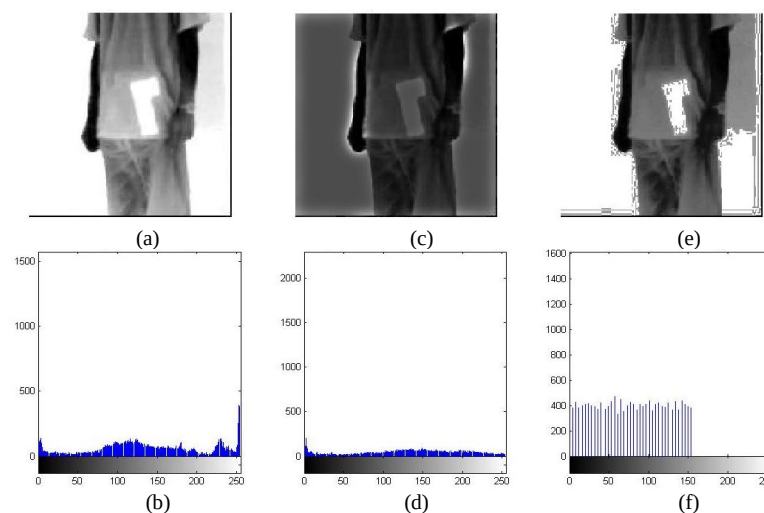


Figure 6 is a highly exposed image. The person and the hidden weapon are the only details in the image with the background being a plain. The output of histogram equalization as shown Figure 30(e) has a white washed effect near the weapon area. In homomorphic filtering, the weapon can be seen prominently.

Figures below are some more examples of other low exposure, medium exposure and high exposure infrared images. Figures 7, fig. 8 and fig. 9 are examples of low exposed infrared images of different scenes. Figure 7(a), fig. 8(a) and fig. 9(a) are original low exposed infrared images of different scenes with hidden objects. Figure 7(b), fig. 8(b) and fig. 9(b) are the Homomorphic filtering outputs on the input images. Figure 7(c), fig. 8(c) and fig. 9(c) are the Histogram equalized outputs on the input images with their respective histograms.

Figure 7 Image Result of Image set 2(Chair front) (a) Low exposed original Image (b) Histogram of (a) (c) Homomorphic filtering applied (d) Histogram of (c) (e) Histogram equalization applied (f) Histogram of (e)

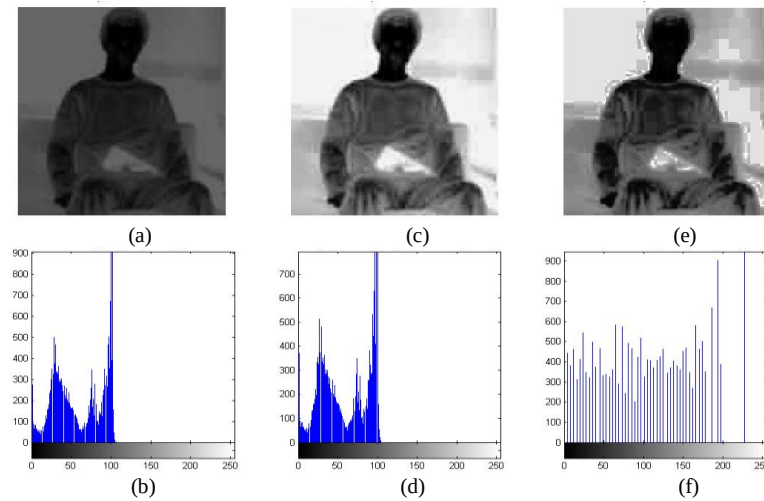


Figure 8 Image Result of Image set 3(Chair) (a) Low exposed original Image (b) Histogram of (a) (c) Homomorphic filtering applied (d) Histogram of (c) (e) Histogram equalization applied (f) Histogram of (e)

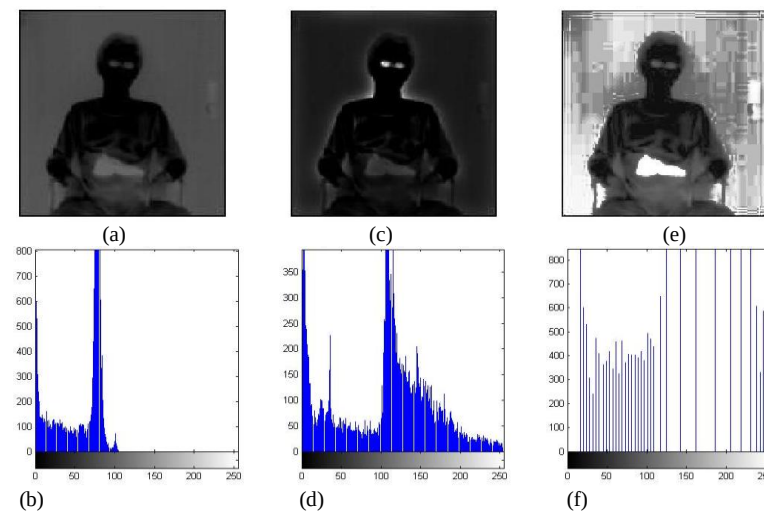
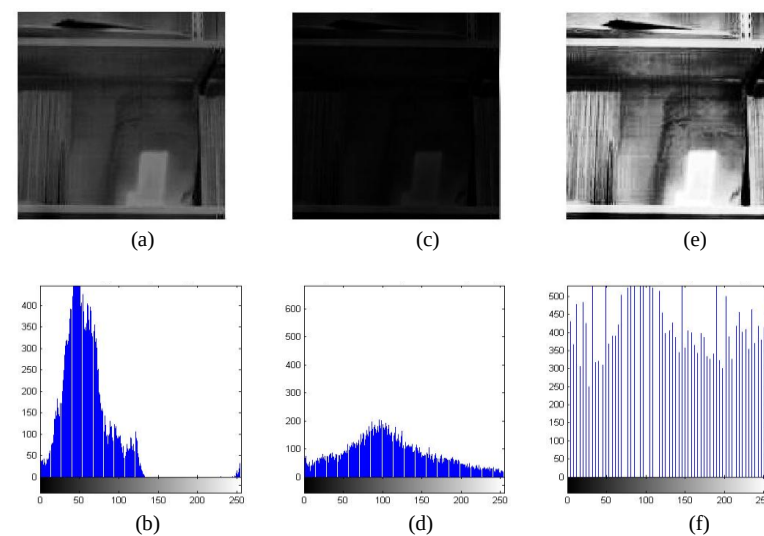


Figure 9 Image Result of Image set 4(Envelope) (a) Low exposed original Image (b) Histogram of (a) (c) Homomorphic filtering applied (d) Histogram of (c) (e) Histogram equalization applied (f) Histogram of (e)



Figures 10, fig. 11 and fig. 12 are examples of medium exposed infrared images of different scenes. Fig. 10 (a), fig. 11(a) and fig. 12 (a) are original medium exposed infrared images of different scenes with hidden objects. Figure 10 (b), fig. 11 (b) and fig. 12 (b) are the Homomorphic filtering outputs on the input images. Figure 10 (c), fig. 11(c) and fig. 12 (c) are the Histogram equalized outputs on the input images with their respective histograms.

Figure 10 Image Result of Image set 2(Chair front) (a) Medium exposed original Image (b) Histogram of (a) (c) Homomorphic filtering applied (d) Histogram of (c) (e) Histogram equalization applied (f) Histogram of (e)

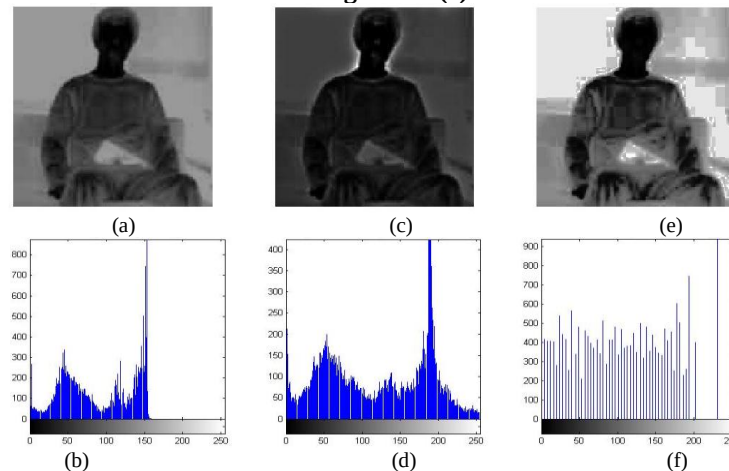


Figure 11 Image Result of Image set 3(Chair) (a) Medium exposed original Image (b) Histogram of (a) (c) Homomorphic filtering applied (d) Histogram of (c) (e) Histogram equalization applied (f) Histogram of (e)

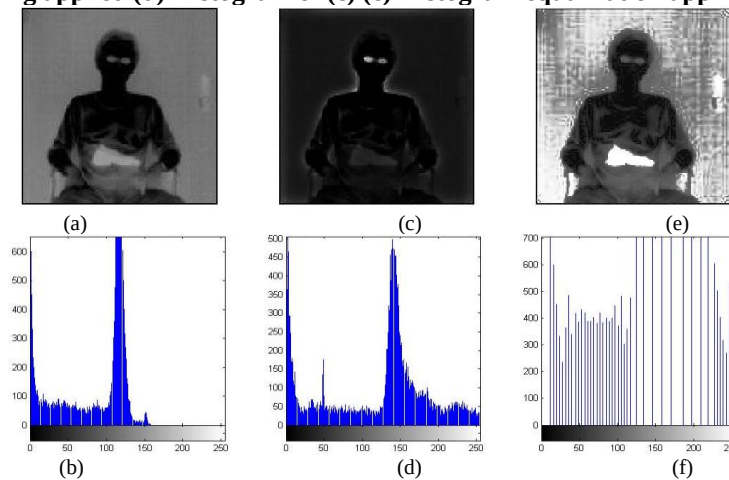


Figure 12 Image Result of Image set 4(Envelope) (a) Medium exposed original Image (b) Histogram of (a) (c) Homomorphic filtering applied (d) Histogram of (c) (e) Histogram equalization applied (f) Histogram of (e)

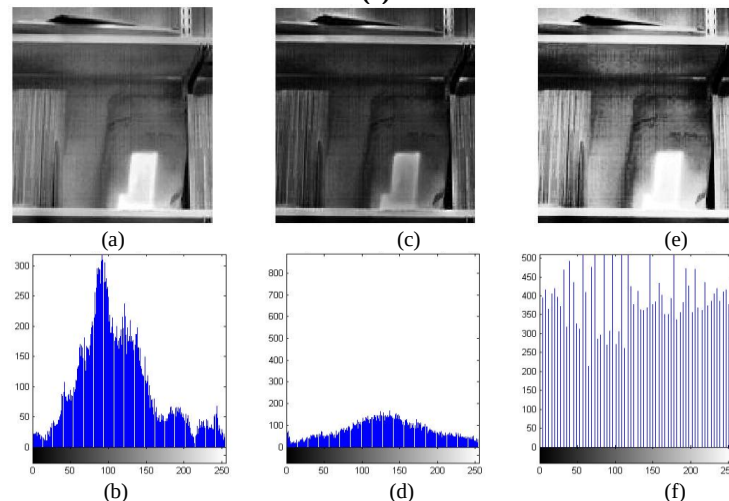


Figure 13, fig. 14 and fig. 15 are examples of highly exposed infrared images of different scenes. Fig. 13 (a), fig. 14(a) and fig. 15 (a) are original highly exposed infrared images of different scenes with hidden objects. Figure 13 (b), fig. 14 (b) and fig. 15 (b) are the Homomorphic filtering outputs on the input images. Figure 13 (c), fig. 14(c) and fig. 15(c) is the Histogram equalized outputs on the input images with their respective histograms.

Figure 13 Image Result of Image set 2(Chair front) (a) Highly exposed original Image (b) Histogram of (a) (c) Homomorphic filtering applied (d) Histogram of (c) (e) Histogram equalization applied (f) Histogram of (e)

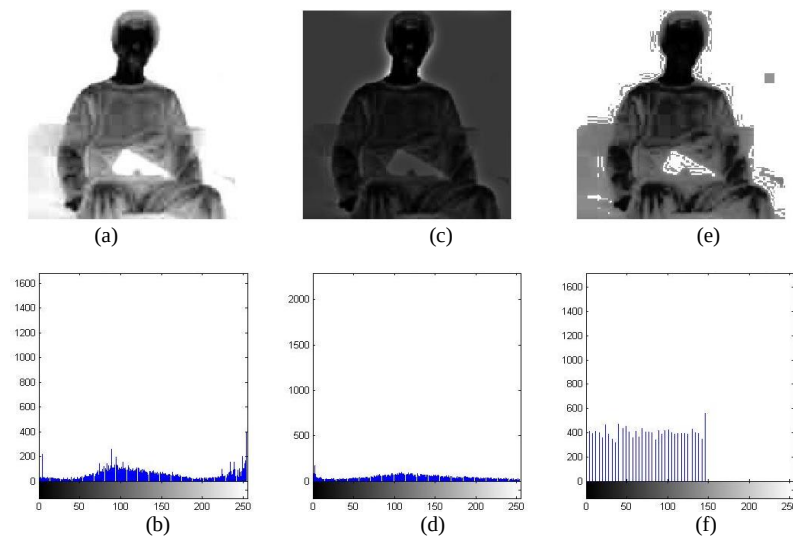


Figure 14 Image Result of Image set 3(Chair) (a) Highly exposed original Image (b) Histogram of (a) (c) Homomorphic filtering applied (d) Histogram of (c) (e) Histogram equalization applied (f) Histogram of (e)

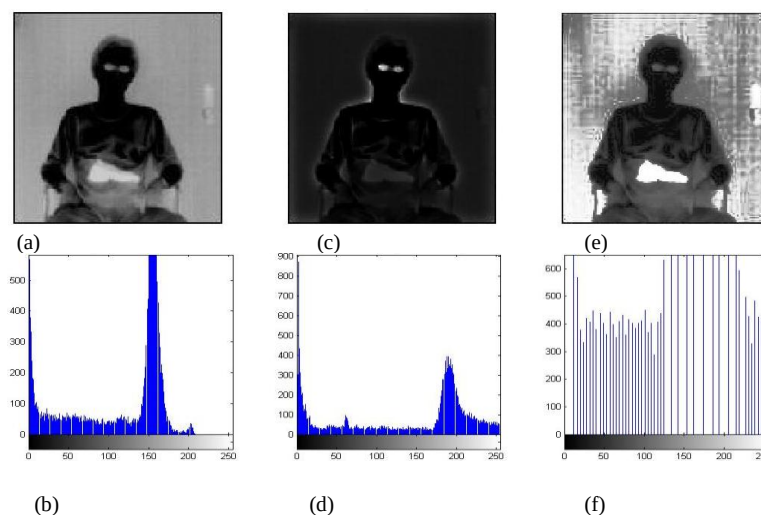
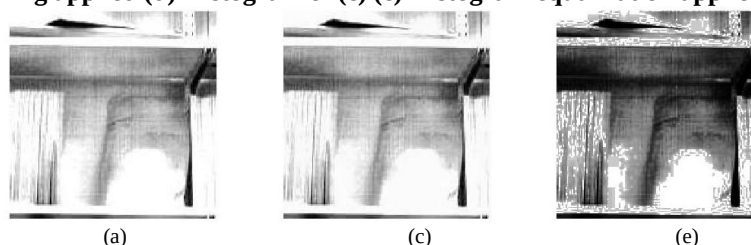


Figure 15 Image Result of Image set 4(Envelope) (a) Highly exposed original Image (b) Histogram of (a) (c) Homomorphic filtering applied (d) Histogram of (c) (e) Histogram equalization applied (f) Histogram of (e)



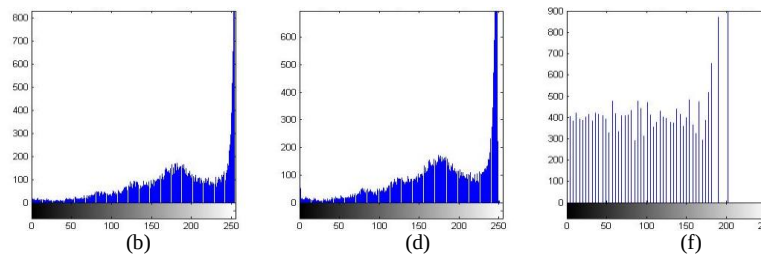


Table I depicts the calculated entropy of the histogram equalized output and homomorphic filtering output for the full test images. This metric provides a view of the overall exposure in the image. It is evident that homomorphic filtering achieves more information content after increasing the contrast in the image.

Table I Entropy of Test Images

		Original image	Histogram Equalization	Homomorphic filtering
Image Set 1 (Stand image)	Low exposed	5.7029	4.9868	7.1015
	Medium exposed	6.1944	5.0633	7.3278
	Highly exposed	5.6384	4.1833	4.3259
Image Set 2 (Chair front)	Low exposed	5.8071	5.1511	5.8918
	Medium exposed	6.2637	5.2091	7.4487
	Highly exposed	5.4258	4.0067	4.3363
Image Set 3 (Chair)	Low exposed	5.4878	4.8498	7.3373
	Medium exposed	6.0804	5.2393	7.1319
	Highly exposed	6.449	5.4097	6.4923
Image Set 4 (Envelope)	Low exposed	6.6202	5.8705	7.16
	Medium exposed	7.5692	5.9715	6.8887
	Highly exposed	6.6074	5.1807	6.7345

Table II depicts the calculated sharpness of the histogram equalized output and homomorphic filtering output for the full test images. It is clearly observed that homomorphic filtering provides better edge detection than histogram equalization.

Table II Sharpness of Test Images

		Original image	Histogram Equalization	Homomorphic filtering
Image Set 1 (Stand image)	Low exposed	22.4931	60.4151	66.6997
	Medium exposed	34.6703	54.6638	90.6113
	Highly exposed	60.0266	65.5797	169.7213
Image Set 2 (Chair front)	Low exposed	23.0628	56.6976	22.6772
	Medium exposed	34.5771	56.5549	76.3614
	Highly exposed	59.2233	67.1537	134.2507
Image Set 3 (Chair)	Low exposed	26.3268	80.9856	92.3004
	Medium exposed	41.6837	98.3211	138.531
	Highly exposed	53.8667	90.3867	189.2905
Image Set 4 (Envelope)	Low exposed	36.8023	96.9863	203.1531
	Medium exposed	65.6682	95.2566	193.8182
	Highly exposed	80.8859	116.7147	78.9767

These image examples again show that homomorphic filtering achieves better results than histogram equalization. In general, the contrast and average brightness results with homomorphic filtering make it subjectively easier to pick out objects in the image.

The very low contrast images as shown in fig. 6, fig. 7 and fig. 8, demonstrate that while histogram equalization increases the contrast in these images, it also greatly increases the noise in the image. Therefore, while quantitatively better in contrast levels and greatly “improved” in sharpness, these images are subjectively inferior and less useful than those enhanced by other techniques that scored lower on sharpness.

V. Conclusion

Based on the metrics comparison, homomorphic filtering has high values of sharpness on average. This feature might be important in security related applications where precise data is required. Based on user observations, homomorphic filtering was selected by most users in terms of overall better contrast without outputting a grainy or a white-washed effect. This subjective assessment, along with the apparent ability of homomorphic filtering to bring objects and details out of shadows, makes it well suited to most IR imaging applications such as night vision, firefighting, and security surveillance. To the existing methods, post-processing can be investigated in

the future. This could apply global contrast enhancement methods or local contrast enhancement methods based on the application. The same techniques might also be tested with color infrared images.

VI. References

- [1] Devid Hall, James LLians, "Hand book of multisensor data fusion", CRC Press LLC, 2001.
- [2] Dana R. Rauscher, and Michael P. Hartnett, Concealed Weapon Detection Program, Decision-Science Applications, Inc, Dec 1998.
- [3] Al-amri, Salem Saleh, N. V. Kalyankar, S. D. Khamitkar, "Linear and Non-linear Contrast Enhancement Image", Journal of Computer Science (2010) Volume: 10, Issue: 2, Pages: 139-143.
- [4] Kaur Manpreet, Jasdeep Kaur, Jappreet Kaur, "Survey of Contrast Enhancement Techniques based on Histogram Equalization", International Journal of Advanced Computer Science and Applications, Vol.2, No. 7, 2011.
- [5] Eramian, Mark, David Mould, "Histogram Equalization using Neighborhood Metrics", Proceedings of the Second Canadian Conference on Computer and Robot Vision (CRV'05).
- [6] Menotti, David, Laurent Najman, Jacques Facon, and Arnaldo de A. Araujo. "Multi-Histogram Equalization Methods for Contrast Enhancement and Brightness Preserving", IEEE Transactions on Consumer Electronics, Vol. 53, No. 3, August 2007, pp. 1186-1194.
- [7] C. Wang and Z. Ye. Brightness preserving histogram equalization with maximum entropy: A variational perspective. IEEE Transactions on Consumer Electronics, 51(4):1326-1334, November 2005.
- [8] Delac, K., M. Grgic, T. Kos, "Sub-Image Homomorphic Filtering Technique for Improving Facial Identification under Difficult Illumination Conditions", International Conference on Systems, Signals and Image processing (IWSSIP'06), September 21-23, 2006, Budapest, Hungary, pp 95-98.
- [9] Etemadnia, Hamideh, Mohammad Reza Alsharif, "Automatic Image Shadow Identification using LPF in Homomorphic Processing System", Proc. VIIth Digital Image Computing: Techniques and Applications, Sun C., Talbot H., Ourselin S. and Adriaansen T. (Eds.), 10-12 Dec. 2003, Sydney, pp 429-438.
- [10] Bazeille, Stephane, Isabelle Quidu, Luc Jaulin, Jean-Phillipe Malkasse. "Automatic Underwater Image Pre-Processing", CMM'06 – Characterisation Du Milieu Marin, 16-19 October 2006.
- [11] Sujatha, C.M., K. Navinkumar, K.S. Arunlal, S.A.Hari Prasad. "Performance evaluation of Homomorphic filtering, Anisotropic filtering and Autocontrast algorithm", 2009 International Conference on Advances in Computing, Control, and Telecommunication Technologies, pp 27-29.
- [12] Li, Jianmei, Changhou Lu, Fengqin Zhang, Wenke Han. "Contrast Enhancement for Images of Raised Characters on Region of Interest", Proceedings of the 8th World Congress on Intelligent Control and Automation, July 6-9 2010, Jinan, China, pp 6258-6261.
- [13] Oppenheim, A., J. Tribolet. "Application of Homomorphic Filtering to Seismic Data Processing", Massachusetts Institute of Technology.
- [14] Mathworks Product Documentation, 2011, The Mathworks, Inc. December 2011, <<http://www.mathworks.com/help/toolbox/images/ref/histeq.html>>
- [15] K.-Q. Huang, Z.-Y. Wu, and Q. Wang, "Image enhancement based on the statistics of visual representation." Image and Vision Computing, 23(1):51-57, 2005.
- [16] Herwig, J., & Pauli, J., "An Information-Theoretic approach to Multi-Exposure Fusion via Statistical Filtering using Local Entropy," in Proceedings of the 7th IASTED International Conference, Vol. 678, No. 099, pp. 50.
- [17] Nuutinen, Mikko, Raisa Halonen, Tuomas Leisti, and Pirkko Oittinen, "Reduced-reference quality metrics for measuring the image quality of digitally printed natural images." In *Proc. SPIE*, vol. 7529, p. 75290I. 2010.
- [18] R.C. Gonzalez and R.E. Woods. *Digital Image Processing*. Prentice Hall, Upper Saddle River, New Jersey, EUA, 3rd edition, January 2008.