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Line Pattern Removal and Enhancement Technique for Multichannel Passive Millimeter Wave Sensor Images

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ABSTRACT

Passive millimeter wave (PMMW) imaging systems have attracted an increasing interest over the past years due to their superior poor-weather performance compared with visible and IR systems. In passive imaging, the spatial information acquired is strictly band-limited. A major drawback to PMMW images is their poor angular resolution. Also, another problem of single-channel PMMW imaging systems is the slow response time due to the lack of thermal sensitivity. The imager could operate at TV (television) rates using a number of parallel channels which may reduce the extent of this problem. In multi-channel, differences between the responses of individual channels can introduce noise into the image, which can obscure details of interest. The proposed noise-removal technique is a two-pass combined method of two techniques. One technique is for removing the DC component in the frequency domain and the other one is statistical filtering based on homogeneous region in the image (spatial) domain, followed by high-boost filtering by 3×3 mask for enhancement the image. High quality images are presented to demonstrate the potential of this technique.

Keywords: Passive millimeter waves, image processing, image enhancement technique, dc component, signal processing, line pattern removal, imaging systems, passive imaging

1. INTRODUCTION

The detection, acquisition, classification, aim point selection of ground mobile, high value targets in high clutter, and adverse weather environment are critical issues in development of smart weapons. Advanced signal/image processing algorithms will be the major element for the success of the smart weapons. A significant problem that affects the successful realisation of the goals of many tactical missions is the poor resolution of images collected from the sensors used to assist guidance operations. The problem is particularly prevalent in autonomous missile guidance applications where diverse mission requirements, such as reliable target acquisition, its classification, track and aim point selection, and precision kill, critically depend on the quality of sensed data collected from missile seekers.

Passive millimeter wave (PMMW) sensing offers adverse weather capabilities due to easy penetration through fog, dust, smoke, etc. Also PMMW images are particularly useful for navigation, guidance, and surveillance because millimeter waves penetrate heavy rain and objects radiate their signature at night as well as during daylight. PMMW imagery is also useful in battlefield condition. Furthermore, the passive nature of this imaging also has

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countermeasures. PMMW imaging also has a number of potential civilian applications, including aircraft landing, collision avoidance, and airport security screening.

The PMMW signatures of metallic objects like vehicles are highly stable because these are invariant to the vehicle temperature, vehicle-operating state, and vary slowly as a function of viewing angle. Metallic objects appear to be very cold to a PMMW sensor due to low emissivity (high reflectivity) relative to terrain and other non-metallic objects in the image. As the metallic objects are almost totally reflective, so any type of countermeasure will have little effect on their detection. However, PMMW image acquisition sensors suffer from poor angular resolution. Resolution is inversely proportional to the wavelength and proportional to the size of the aperture. The resolution is much lower for PMMW radiation because it has a comparatively long wavelength relative to visual radiation. Furthermore, the use of very large apertures is not usually an option due to platform constraints. It is very much required to improve the image quality by advanced image processing techniques.

Early techniques[1-5] in image processing were concentrated mostly on procedures carried out computationally in the frequency domain and that was a natural extension of one-dimensional linear signal processing theory. It is well known that the computing of a 2-D transform for a large data array is a time-consuming activity even with fast transform techniques on large computers. Lee[6] has developed noise-filtering algorithms for both the additive and multiplicative noise cases. The techniques based on local mean and local variance does not require image modelling, like Kalman or Wiener filtering techniques[1-5]. Applying local statistics to image processing is not a new idea. Ketcham[7], *et al*. used the entire local histogram for real-time image enhancement and Wallis[8] applied local mean and variance to filter out scan line noise with striking results.

The present paper aims to improve the image quality by removing the line patterns for multichannel PMMW images. In multichannel, differences between the responses of individual channels can introduce noise into the image that can obscure details of interest. There are various methods for improving the quality of PMMW images by super-resolution technique[9]. But there are some limitations of super-resolution technique. Reeves[9] discussed the difficulties for super-resolution techniques of PMMW images. Also, according to the existing knowledge, there are no super-resolution techniques for removing the line patterns of multichannel PMMW images. Lettington,[10,11] *et al*. have used a statistical method for removing the line patterns of PMMW images. Bernstein[12], *et al*. developed the noise-removal technique to remove both kinds of noises-striping and herring bone noise pattern, formed due to coherent noise from the satellite's 32 kHz switching power supply superimposed on the detector signal. Our proposed noise removal technique is similar to Bernstein,[12] *et al*. method. The basic difference between th author’s method and the Bernstein,[12] *et al*. method is the noise-removal technique in spatial domain. Also the proposed line pattern removal technique is a two-pass combined method of two techniques (i.e., frequency domain technique and spatial domain technique) which gives better result than the individual methods. The first technique is for removing the DC component in the frequency domain and the other one is statistical filtering based on homogeneous region statistics in the spatial domain. Since PMMW image acquisition sensors suffer from poor angular resolution, so a high-boost filtering technique was introduced to improve the image quality.

2. INTERCHANNEL NOISE REMOVAL TECHNIQUES

A major problem of single-channel PMMW imaging systems is the slow response time due to the lack of thermal sensitivity. The imager could be operated at TV (television) rates to reduce the extent of this problem using a number of parallel channels. Any PMMW imager that is able to operate at a frame rate comparable with a thermal imager will require several detectors that are scanned or a starting array. Differences between the responses of individual channels can introduce noise into the image that can obscure details of interest. An intuitive observation is that in a multichannel system, each receiver when scanned over the scene will, on an average, see the same integrated value. The integrated intensity for each receiver may be used to provide a measure of the dc errors between the channels. It is necessary to correct this inter-channel noise before further enhancing the images. Several methods described baloew have been devised for removing this form of noise[10,12].

2.1 Noise-Removal Technique

Bernstein,[12] *et al*. developed the noise-removal technique to remove both kinds of noises–striping and a herring bone noise pattern, due to coherent noise from the satellite's 32 kHz switching power supply superimposed on the detector signal. There are the following two methods to remove a coherent noise source of a known frequency:

(i) Transform the incoming signal to the frequency domain and filter out the noise frequency, and then transform the signal back to the spatial domain.

(ii) Process the signal in the spatial domain by subtracting a waveform of the noise frequency directly from the incoming signal.

The first method requires an extensive amount of processing without special Fourier transform hardware. The second method, although requires much less processing, is very sensitive to the relative phases of the subtractive noise waveform, and if not done carefully, the actual noise in the data may be doubled rather than zeroing. So, determining the phase of the noise in the data is a key factor in successfully reducing or removing it by the second method.

They developed an algorithm for eliminating the 3-pixel (32 kHz) noise from the images based on the above-mentioned second method. In this algorithm,[12] they arbitrarily partitioned the incoming signal line into adjacent cells containing three pixels each. Within the cells, the pixels are called A, B and C. The algorithm then attempts to determine, for each cell, whether the noise signal is in synchronisation with the A, B or C pixel. To do this, they differentiated the signal by subtracting each pixel from its left-hand neighbour. The noise signal typically looks like a "+2 –1–1" pattern. Then the cells are assigned to one of the following four states[12].

(a) "A sync" - a positive transition was found in the A position only

(b) "B sync" - a positive transition was found in the B position only

(c) "C sync" - a positive transition was found in the C position only

(d) "Undecided" - either no positive transition was detected in the cell or more than one transition was detected.

Initially, because the phase of the noise signal does not change rapidly, they proposed that the cells would tend to be in the same sync as their neighbours. Therefore, the cells will be grouped in regions of similar sync, and between the regions, the cells will be predominantly undecided. Also, the cells whose sync has been incorrectly assign, will scatter throughout the line.

Next, they entered an iterative algorithm that attempts to grow the regions of sync by assigning the undecided cells to one of the three definite sync states. The decision for an undecided cell depends on the state of its neighbouring cells. If neither its left nor the right neighbour is decided on a sync, then a cell remains undecided. If only one is decided on sync, then the cell decides to be in sync with it. If both are decided on sync, then the cell arbitrarily decides to be in sync with its left neighbour.

Each time the decision algorithm is applied to the cells, more cells become decided. The regions of sync grow as these convince their undecided neighbours to be in sync with them. The decision algorithm can be applied iteratively until all undecided cells have become decided.

After synchronisation is determined, the magnitude of the noise can be estimated by averaging the signal of all the pixels in the first position, the second position, and the third position after the sync point (A, B, and C). These correlated averages are subtracted from the signal average to determine the difference due to the noise. Then this difference is subtracted from the original signal, using the synchronization points determined for each cell. If a cell is still decided, no noise correction is done for that cell.

The algorithm by Bernstein[12], *et al*. to remove a coherent noise in the spatial domain has some drawbacks. First, the algorithm arbitrarily partitions the incoming signal line into adjacent cells containing three pixels each. This arbitrary partition may affect the actual signal and noise. Second, the decision algorithm for assigning the undecided cells is an iterative process, which takes much time.

2.2 Noise-removal Technique–the Proposed Method

Here, the proposed noise-removal technique is similar to Bernstein[12], *et al*. method, but the basic difference between the proposed method and Bernstein's method is the noise-removal technique in spatial domain. The proposed technique is used for removing these line patterns based on finding the background mean in the spatial domain. Also, the proposed line pattern removal technique is a two-pass combined method of two techniques (i.e., frequency domain technique and spatial domain technique) which gives better result than the individual methods. The first technique is for removing the dc component in the frequency domain for making the bias to zero and the other one is statistical filtering based on homogeneous region statistics in the spatial domain. Since PMMW image acquisition sensors suffer from poor angular resolution, so a high-boost filtering technique to improve the image quality, has been introduced. Since the proposed method is a two-pass combined method, so first apply the first technique by taking the original image as an input and then apply the second technique by taking the output of the first technique as an input. Here, the incoming signal line is not partitionaed arbitrarily and the process is not an iterative process for removing the noise from the signal. Flow chart for multichannel image enhancement technique is shown in Fig. 1.

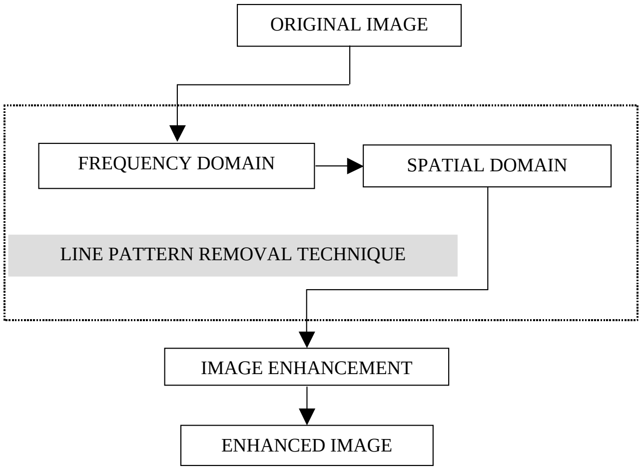


Figure 1. Flow chart for multichannel image enhancement technique.

In the first technique, the image is transformed in to the Fourier domain using Discrete Fourier Transform (DFT)[3], which for a sequence $\{u(n), n = 0,1,\ldots, N-1\}$ is defined as

$$v(k) = \frac{1}{N}\sum_{n=0}^{N-1} u(n) W_N^{kn}, k = 0,1,\ldots, N-1 \tag{1}$$

where $$W_N \overset{\Delta}{=} \exp\left(\frac{-j2\pi}{N}\right) \tag{2}$$

In the Fourier domain, the different frequency components are separated and here the first coefficient or the DC component is equated to zero. Then the image is transformed back to the spatial domain by inverse Fourier transform. The inverse Fourier transform for a sequence $\{v(k), k = 0,1,\ldots, N-1\}$ is given by

$$u(n) = \sum_{k=0}^{N-1} v(k) W_N^{-kn}, n = 0,1,\ldots, N-1 \tag{3}$$

This inverse transformed image is clearer than the original image. The DC removal only makes the bias to zero and does not affect any frequency components. Hence, it cannot remove the line patterns. Also, it has been found experimentally that still line patterns exist after using frequency domain technique [Fig. 2]. Next, one proposed a second method for removing these line patterns.

The second technique that is used for removing these line patterns is based on finding the background mean in the spatial domain. This method may be called as mean scene referencing method. It is a mean subtraction method based on homogeneous region in the image domain. On a close observation of the acquired image in multichannel sensor, It was observed that there was repetition of line pattern after every P scan lines, where the value of P is 2-times the number of channels, and hence, the image has been decomposed into some regions. The methodology of the second technique is as follows:

Step 1: Decompose the image into some (even multiplier of P) regions of size P x Q where Q is the number of column of the image.

Step 2: Take the first region. Find the mean values of every P row. That is, let $u(i, j)$ be the gray value of $(i, j)^{\text{th}}$ pixel where the pixel (i, j) belongs to the considering region. Then the mean value of each P row is

$$m_i = \frac{\sum_{j=1}^{Q} u(i, j)}{Q} \quad \forall i = 1,2,\ldots,P$$

Step 3: Find the standard deviation of all P rows, i.e.,

$$\sigma_i = \sqrt{\frac{\sum_{j=1}^{Q} \left[u(i, j) - m_i\right]^2}{Q}} \quad \forall i = 1,2,\ldots,P$$

Step 4: Find the set

$$S_i = \left\{ \begin{matrix} u(i, j) : m_i - \sigma_i \le u(i, j) \le m_i + \sigma_i, \\ j = 1,2,\ldots,Q, \forall i = 1,2,\ldots,P \end{matrix} \right\}$$

and find

$$M_i = \frac{\sum_{u(i,j)\in S_i,\, j=1}^{Q} u(i, j)}{\# S_i} \quad \forall i = 1,2,\ldots,P$$

where $\#S$ represents the number of points.

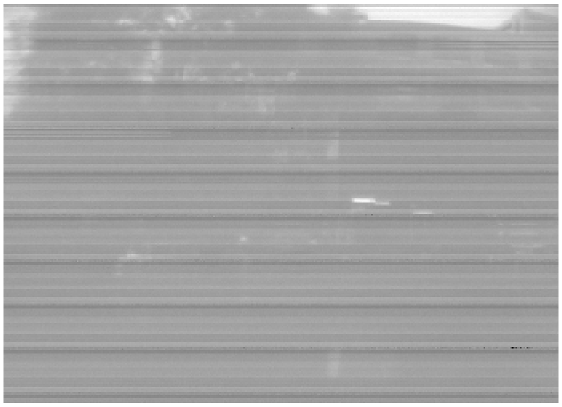
Step 5: Compute $v(i, j) = u(i,j) - M_i$ for $j = 1, 2,\ldots, Q$ and $i = 1, 2,\ldots, P$.

Step 6: Repeat step 2 to step 5 for all regions.

This spatial domain, i.e., mean scene referencing method is clearer and free of line patterns than the original image. Also, the spatial domain technique is free of line patterns than the frequency domain technique. But the resolution or information extraction capability by the spatial domain method is less than that of frequency domain method. This indicates that the frequency domain technique is better for information extraction and the spatial domain technique is better for removal of line patterns. So, two-pass combined method of frequency domain and spatial domain techniques was used for removal of these linear patterns and information extraction. In the first-pass, the frequency domain method is applied on the original image. Then the output image of the first-pass is used as an input of the second-pass. In the second-pass, the spatial domain technique is applied on the output image of the first-pass. After two-pass combined method, high-boost filtering and contrast enhancement techniques were introduced to improve the quality of the image.

3. RESULTS AND DISCUSSION

To test the efficiency of these techniques, several data are considered with different sizes (from 50 x 50 pixels to 450 x 450 pixels). Figure 2(a) shows an original image acquired by 1 x 16 multichannel PMMW sensor at 94 GHz and one can see the visual distortions in the image due to difference in inter-channel responses. It is necessary to correct this inter-channel noise before further enhancing the images. Figure 2(b) shows the result by applying the frequency domain line pattern removal technique, which is based on DFT technique in the Fourier domain. One can see significant improvement in the image quality but still the line patterns are present there. Figure 2(c) shows the result by applying the spatial domain line pattern removal technique, which is based on mean scene-referencing method in the spatial domain. In this method, it has been seen that the line patterns have been removed but the image quality is not good because sufficient information has not been extracted. If two-pass combined method is applied as in Fig. 1 then it gives quite significant and smooth result, which is shown in Fig. 2(d). Still some noise is present in Fig. 2(d) that is removed after applying the image enhancement technique. Figure 2(e) shows the final result after enhancing the image [Fig. 2(d)]. The results show that these techniques are very much suitable for the enhancement of multichannel PMMW images.



(a)

(b)

(c)

(d)

(e)

Figure 2. Image acquired by multichannel 1×16 PMMW sensors: (a) original image of size 401×288, (b) line patterns removed by frequency domain technique, (c) line patterns removed by spatial domain technique, (d) line patterns removed by two-pass combined method, and (e) final enhanced image.

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