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A Comprehensive Review on Image Enhancement Based on Image Fusion

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Abstract

The human inability to see clearly in dark/night times has been a research challenge for many decades. Night vision equipment have been extensively used in the defense sector for carrying out hassle-free operation in low visibility or dark operating conditions, but with a limitation that they are essentially monochrome (green/grey) in colour. The comprehension ability using such images is reduced and results in poor situation awareness (SA). Fusion of multispectral images has therefore been seen as a solution to the problem. Various researchers have come up with different ideologies/algorithms over the time. In this paper, the focus is to discuss about techniques developed in recent past with a vision to explore best upcoming multispectral image fusion solutions for combining visible and infrared images, which could lead to a better target detection/ recognition and SA.

Keywords: Infrared image, Multispectral image fusion, Situation awareness, Target detection/recognition.

I INTRODUCTION

Human beings are considered to be one of the most intelligent species in the animal kingdom. Humans, through their five sensory inputs _ eye, ear, nose, tongue, and skin, receive all kinds of external stimuli and respond to them accordingly. The perception of stimulus and generation of appropriate reaction for it is a complex task which occurs in the brain. Although all five sensory inputs have their diverse and vital roles, the foremost analysis of the situation is done through visual analysis. Visual activity helps in identification of objects around or even at some distance where other sensory inputs may not be able to catch a stimulus. For example, while driving the driver tends to estimate the depth of pits present on the road by making a depth perception depending on his/her sight. This ability of comprehension gets dramatically reduced in the total dark or poor visibility conditions. In case of defense services, having a good eye sight is even a compulsory criterion for selection of the candidate. While considering defense services, the significance of the said ability intensifies during critical military operations carried out in dark. There has been major research work carried out all around the world for providing means which could help in visualizing through the dark. In many recent US military expeditions, night vision devices have been extensively used by the soldiers for countering their enemies during night-time. Also, a major challenge is to have clear visibility even when it is not completely dark but the ambient luminance is so low like at time of dusk/dawn that visibility is very poor. Displaying imagery having enhanced information contents during dark or poor visibility situations may help humans to process this type of imagery faster and better, helping in improving SA and reducing detection/ recognition times. The "definition of situation awareness is classified in three levels: (1) the perception of the elements in the environment within a volume of time and space; (2) the comprehension of their meaning; and (3) the projection of their status in the near future" [1]. In this paper, a review of various techniques proposed recently for fusion of multispectral images, which could enhance poor visibility, is presented. Also, the paper highlights present research gaps followed by a discussion about future possibilities in this area. The next section gives a brief about night vision followed by Sections 3, 4, and 5, in which various techniques for fusion of visible and infrared images are discussed. Section 6 illustrates the results of fusion by using different techniques for subjective evaluation, and, a comparison of the pros and cons of reported fusion techniques is also discussed in detail.

II VISION THROUGH THE DARK

Although, human eye has a very highly adaptive mechanism to adjust from bright daylight to dark environment, the maximum contrast sensitivity at any time is limited to 1:1000. What enables wider response of the human eye is its ability to adapt its definition of what is black. The retinal region of human eye is sensitive to light. It is composed of many nerve ganglions, rods, cones, etc. Rods are more sensitive towards intensity of light whereas cones are colour sensitive in nature. These characteristics of rods and cones are majorly responsible for the difference in day and night vision. Thus, when entering from bright sunny daylight to a dark room eye takes some amount of time to adjust to the lighting conditions. It is realized by the changing diameter of the pupil, which acts as a gate controlling the amount of light entering into the eye. Human eye can take few minutes to adapt from bright sunlight to complete darkness. The adaptability of human eye is commendable but when compared with the ability of common pets to see in dark, human ability is still found to be lacking. This difference occurs due to difference in the biological structure of the retina. The retina of pets contain a layer of tapetum lucidum which amplifies the amount of collected light in the dark and helps the animals to see in dark. Mimicking the nature is often found to be a successful option for technological challenges. The two important techniques which are being employed for night vision are image intensification and thermal imaging. While the image intensifiers work on the principle of enhancing the available ambient light (moonlight/starlight), thermal imaging senses the radiation emitted due to the heat produced by any object. Although these two techniques have been judiciously providing night vision means, there still persist some issues. The night vision using image intensified tubes (IITs) is green black in colour and the one provided by thermal imaging is essentially in greyscale. Being kind of monochrome images, these devices lack in providing a natural feel of the night scene. Also, there are issues situation. Enhancing the target detection/recognition at night times (or extremely low lighting conditions) for military operations/remote sensing applications will be a great help to the human operators by virtue of better situation awareness. When there are high brightness light sources present in the scene. The glare of these devices is also magnified which may cause a person to be left flash-blind for few moments. At times, the glare may not totally obscure the vision of a person but may be seen as a bright source with halo around. This may lead to missing of events or objects around such high brightness sources. The natural colour appearance of the scene will help in better perception and quick understanding of the situation. Enhancing the target detection/recognition at night times (or extremely low lighting conditions) for military operations/remote sensing applications will be a great help to the human operators by virtue of better situation awareness.

III MULTISPECTRAL IMAGE FUSION

With the advent of multiple types of sensors, domain of available information has increased many manifolds. Each sensor has its own specialty and provides information of specific content. Fusing the information from different sources into one enhances the information content of the resultant image. A general definition of image fusion is given by Genderen and Pohl (1994) as "Image fusion is the combination of two or more different images to form a new image by using a certain algorithm" [2]. However, there has been a continuous advancement in the area of image fusion which has also augmented the basic definition of image fusion. The definition has evolved from a simple fusion algorithm based technique to something more thought-provoking. HCL, the leading computer solution providers, in their section about enhanced vision systems have the definition of image fusion as "Image fusion is a process of combining images, obtained by sensors of different wavelengths simultaneously viewing of the same scene, to form a composite image. The composite image is formed to improve image content and to make it easier for the user to detect, recognize, and identify targets and increase his situational awareness" [3]. The main goal of image fusion is to integrate complementary multi-sensory/multi-temporal and/or Multiview information into a new image containing information, the quality of which cannot be achieved otherwise.

IV INITIAL EFFORDS TOWARDS MULTISPECTRAL IMAGE FUSION

The night vision modalities being efficient in their operation still face some challenges. To overcome the limitations of these modalities fusion of complementary images have been taken up as a scientific dare by researchers all over the world. Toet et al. presented an approach of merging the thermal and visual images for enhancing the target detection ability by using a contrast or ratio of low pass (ROLP) pyramid which could be fitted upon models of the human visual system [4]. Here the importance of patterns is based on their local luminance contrast. Final image is made with patterns having maximum luminance contrast thus, enhancing perceptual details in the composite image. The disadvantage of this approach lies with the output of the image which still remains in greyscale which could not provide as good target detection as could be done using colour fused images. Further, we discuss the approaches focused on providing colour fused images for night vision. Waxman et al. presented an approach of combining two input images which represent different two dimensional (2-D) view of same scene to produce three processed image signals. These signals could be provided to a colour device to generate red green blue (RGB) images. Processing is done by performing computation pixel-by pixel basis [5]. The images provided a natural looking perception but have limited spatial resolution. Fusing two images may provide more useful information but chances that details of one image hides the details from the other image also exist. In 1996, Toet and Walraven proposed an approach of fused false colour rendering for grey level images captured from two different sensor modalities [6]. The images produced had better information content than the original images but image quality was found to be inferior. Following to this work, Waxman et al. proposed a biological opponent colour based approach where night vision was enhanced through fusion of complementary images captured in the region of low-light visible and thermal infrared spectrum [7]. Further, these authors have extended their understanding from dual band fusion to six-band multispectral imagery for camouflage detection. Also, they have extended the approach for the fusion of visible, medium infrared, and synthetic aperture radar (SAR) imagery collected from various platforms during different times [8]. Many other researchers have also contributed into the field and have proposed several other fusion methodologies. In Figure 1, basic outline of multispectral image fusion is depicted by means of a block diagram.

V TRENDS IN RECENT PAST

Hogervost and Toet presented a method to visualize multi-band night-time imagery with colours as observable in natural daylight. The process involves capturing a reference image of the scene (to be viewed at night) during the day time. After that, the night time image of the scene is mapped to this reference image and a look up table (LUT) is formulated and is used to assign colours in the enhanced image. The algorithm involves fusing multiband image into false colour image followed by indexing of this image with the help of a colour LUT. Some of the advantages of this scheme include object colour constancy and after establishment of LUT application in real time modules could be done. Practically, still it is not always possible to have a reference image for every terrain although it may help in similar scenes [9_11]. Also, the thermal targets were not found to be significantly different from the background which could improve the target detection.

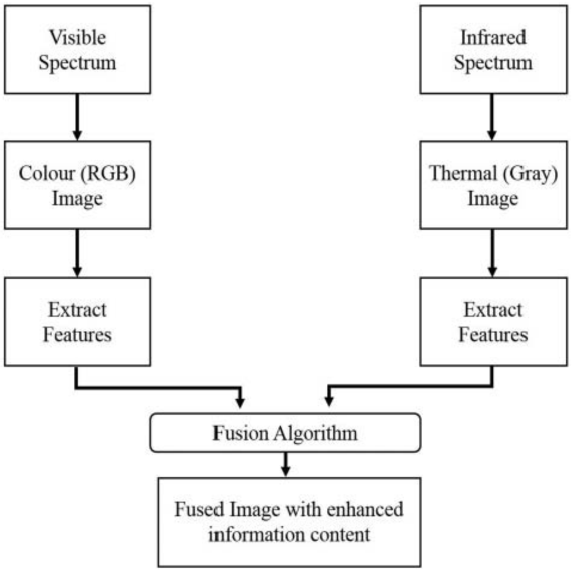

Figure 1: Basic scheme of multispectral image fusion for enhancing situation awareness.

Xiaojing et al. proposed a solution for the above-mentioned problem by proposing a different means of formulating the LUT. Authors derive the colour LUT by combination of visible-thermal image and its day light background- highlight-targets fused representation which was based on natural colour transform, luminance component, and feature level fusion. Feature level optimization of the target region in thermal image was performed utilizing the K-means clustering and fusion of visible and infrared (IR) images were done using discrete wavelet transform [12].

Siyue and Leung suggested a statistical signal processing approach based on expectation maximization (EM) and covariance intersection (CI) for IR and visual image fusion. More specifically, the ideal IR and visual images are estimated by EM along with the covariance matrices of the estimation error. Then, CI method is used for combining the two images and providing a consistent estimate of the fused scene [13]. The authors treat the process of image fusion as a statistical estimation problem.

Toet and Hogervorst presented a tri-band colour lowlight observation (TRICLOBS) system. The system comprises two digital image intensifiers and a long wave IR thermal camera along with a 3-D digital position information system. The system spans the range of visible (400_700 nm), near IR (700_1000 nm), and long wave infrared (LWIR) (8_14 mm) spectrum. The colour LUT formation is based on the information extracted from visible and near IR (NIR) spectrum ranges [9, 14]. The authors also employ bottom-up statistical visual saliency mode for preliminary optimization of the colour mapping. Later, it was followed by a top down visual saliency model to improve the representation of information for surveillance and navigation purposes. The authors have reported this system as a prototype for real time colour mapping system and rigorous observer field trials are required to further optimize the systems [15].

Anwar et al. have proposed another system, which they call by an acronym Scarf (semi-automatic colorization and reliable image fusion), to produce enhanced nighttime images which could be conformal to human vision. Here also, the images from visible and infrared sensors are fused on a pixel level basis using advanced feature extraction techniques followed by semiautomatic colorization [16]. The method used by authors for pixel level fusion of images is contourlet transform and gradient-based structural similarity. Contourlet transform was used because of its advantageous nature in terms of directionality and anisotropy. The semiautomatic colorization technique adopted in this paper works with hue saturation intensity (HSI) colour space due to its computational benefits. The algorithm is implied with a constraint condition, i.e. if neighboring pixels are having similar intensities then they are likely to have similar colors.

Makwana et al. describe an approach of colour transfer method utilizing colour-map clustering and colour similarity based cluster recognition [17]. The lab colour space has been identified for colour-map clustering operations and the cluster based colour transfer is Hamam et al. reported a texture-based technique for colouring of IR images. They used single band IR images in the study due to the low cost of single band sensors. A database of true daytime colour images was created initially. The IR image of night-time scenery is then matched with colour images present in the database based on textural features. Processing is done on three successive levels, i.e. image level, segment level, and pixel level. Selection of source image is done automatically by matching the texture properties of scenery in the given IR image with the images of database. After the selection of source image in the second level, segments of source image are matched with those of IR image having similar texture. Finally for every matched colour segment, IR pixel is matched to the colour image pixel in the matched segment [18].

Fu et al. proposed a new algorithm to colour night-time images which they have titled colour estimation model (CEM) based on a Dark to Day (D2D) prior followed by an image restoration using sparse representation.

The proposed CEM model was essentially a transform which harmonizes the dark areas and light areas of night-time images and day-time images, respectively using mathematical formulas described in the paper [19]. For performance optimization, they have used a parameter D2D prior which authors have claimed to be based upon large statistical observations. The transformed image is found to be blurred, so a sparsity based algorithm was employed by the authors to restore image quality.

Yin et al. introduced another method based on the use of non-subsampled contourlet transform (NSCT) for capturing geometric details of the image and fuzzy logic for setting appropriate weights during the fusion of visible and thermal image. The source images are decomposed into its high and low frequency components using NSCT. Coefficients are calculated for low frequency components by using fuzzy logic based adaptive averaging. The low frequency components are important for preserving contrast details of the image and target recognition. The formation of fused image is accomplished by taking the inverse NSCT [20].

Saeedi and Faez reported fusion of infrared and visible images using wavelet transform, fuzzy logic, and population- based optimization method. The authors employ a combination of pixel-based and region-based fusion for combining the thermal and visible images. Segmentation map for all source images are obtained using watershed algorithm, followed by decomposition using dual tree-discrete wavelet transform (DT-DWT) algorithm. Using these, pixel-based decision maps are generated which are then used to generate region-based decision maps. Integration of high frequency wavelet coefficients was done using fuzzy logic and that of low frequency wavelet coefficient by population-based particle swarm optimization technique. Finally, an inverse DT-DWT fetches the fused image [21].

Qian et al. has discussed another approach for highlighting targets with respect to the background for easy detection/recognition. Colour contrast enhancement is performed over the visible and infrared images and then a reference pallet is drawn from both the source and fused images. This reference pallet is then used for differentiating the targets from background in the fused imagery [22].

VI DISCUSSION

Various methods for fusing visible and infrared images to produce an informative colour image have been reviewed. The said objective has been achieved by mainly two pathways either by fusion or mapping of colour. Colour fusion is fusing pixel intensity of visible and IR images in different colour spaces while colour mapping is done with an aim to map the colours of source reference image over the targeted image [23]. Fusion of visible and infrared [24] images using different fusion techniques is shown in Figure 2.

These fused image results provide a subjective evaluation measure to assess different fusion methods. It can be seen that in Figure 2(c) and (d), fused images have unnatural appearance with spectral distortions; in Figure 2(e), it is seen that PCA-based fusion have lesser clarity; and in Figure 2(f), fused image based on DWT fusion provides better natural appearance result. The detailed inferences are summed up in Table 1.

Toet and Hogervost also presented a review of the progress made by them in the area of fusing visible and IR images [25]. The authors started the discussion with the method proposed initially by MIT Lincoln Laboratory, which was based on centre-surround opponent-colour fusion (OCF) [26] followed by the pixel-based opponent colour fusion [27], statistical analysis for colour transfer [28], and others. These methods developed initially had their merits like centre-surround OCF achieved better depth perception and increased target detection. The pixel-based OCF was a step ahead in the direction of centre-surround OCF and had the ability to retain features helpful in obstacle avoidance. The statistical colour mapping process in its basic form was able to develop a false colour night vision image which used to map the natural daylight colour but the method took high computation time and could not have been a viable option for real time dynamic system. Thus, LUT-based approaches came into picture for mapping natural colours over the night time images in a lesser span of time. Zheng et al. [23] also compared different colour mapping techniques based on histogram matching, joint histogram matching, LUT-based technique and statistical matching qualitatively and quantitatively. Best results in terms of image quality and computation time were reported when the combination of statistic matching and joint histogram matching was applied, with latter applied after the application of statistic matching. Using a combination of techniques for colorization of night vision images thus seems to be a promising opportunity. While using an LUT may be convenient, but it is not always possible to have reference imagery available at hand. On a broader scale, it could be said that the techniques proposed either rely on a pixel-by-pixel basis computation or region-based feature extraction process or multi-scale transforms [21].

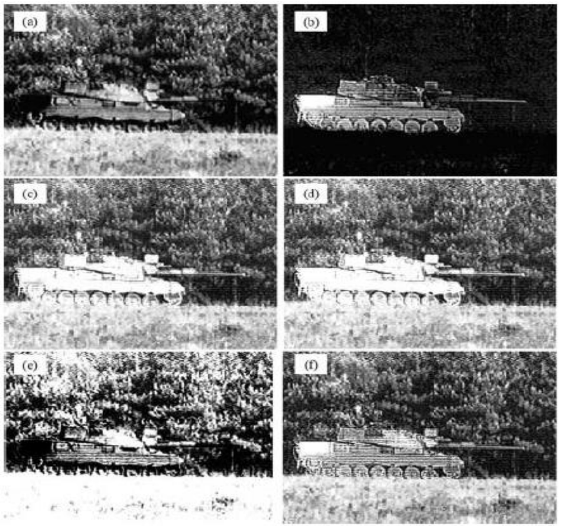

Figure 2: (a) Visible image, (b) LWIR image, (c) fused image using pixel-by-pixel fusion approach, (d) fused image using color space transform, (e) fused image using principal component analysis (PCA), and (f) fused image using DWT fusion approach.

The methods based on performing a pixel level fusion or arithmetic computation have found to be causing spectral and spatial distortion in the fused imagery as shown in Figure 2(a). Statistical methods with better results are more on the side of computationally expensive nature. False colour mapping may require specific training for achieving better comprehension while the user is already having a divided attention between many activities. Automatic target recognition in a SAR imagery by using Fourier descriptors and shadow contour approach has also been reported in the literature [29]. Such techniques may also be studied further for enhancing situation awareness in case of poor visibility conditions.

From the above discussion it could be inferred that multi-scale or multi-resolution transforms have been found to be a better solution for the purpose of fusion of visible and infrared imagery. They have many advantages like: less spectral and spatial distortion, less blurring of edges, flickering and more stable inverse transforms, as is seen in Figure 2(e). Even in case of multi-resolution transforms, wavelet approaches have been found out to be better performer than the pyramid based approaches viz. Laplacian, Gaussian, contrast or ROLP, etc. Basis of functioning of wavelets is quite similar to the way human visual system works. Wavelets work by decomposing an image into its low and high frequency components.

The low frequency components are basically the approximation of background details and high frequency components give the information about the foreground details like edges, lines or boundaries. Literature provides an insight that initial use of wavelets started with Mallat algorithm which also had some limitations in form of shift invariance, fusion of images being not size independent, etc. Trous algorithm succeeded the Mallat algorithm with advantages of redundancy allowing dominant feature detection, lesser artifacts and, image size independence but at the cost of computation time and more memory usage [30]. Besides these basic algorithms, use of multi-band wavelet theory is seen as the solution for overcoming some of the basic problems associated with the traditional dyadic wavelets since more than one scaling function are generated here which results in having much more flexibility in the design of fusion rules related when used for multispectral image fusion. This is an area of research under investigation extensively and authors are working in this direction for evolving an algorithm using this approach to fuse visible and IR images for enhancing situation awareness.

VII CONCLUSION

This paper presented recent advances in the field of combining multispectral images viz. visible and IR for enhancing situation awareness. It also reports subjective evaluation of few known techniques to bring forth their merits and demerits. The initial works using contrast pyramids, opponent colour fusion, etc. laid a strong foundation in the area. With recent advances in the field of data processing and manipulation followed by many statistical techniques, optimization algorithms, artificial intelligence methods, combinatorial algorithms, there are new approaches coming into play for fusion of multispectral images. The use of these new approaches has proved to be a fast computing solution with further improved target recognition and better fused image quality. The use of optimization approaches like genetic algorithms, population based approaches can be predicted as the major players in the coming times. The advances in this field are essential for development of real time solutions for enhancing poor visibility operating capabilities especially for the area of remote sensing and military surveillance. A promising solution could be the efficient use of both soft computing techniques and traditional image processing based techniques for reaping the benefits of both.

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