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Performance Improvement of Electro-Optic Search and Track System for Maritime Surveillance

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ABSTRACT

Surveillance of maritime domain is absolutely vital to ensure an appropriate response against any adverse situation relating to maritime safety or security. Electro-optic search and track (EOST) system plays a vital role by providing independent search and track of potential targets in marine environment. EOST provides real-time images of objects with details, required to neutralise threats. At long range, detection and tracking capability of EOST degrades due to uncertainty in target signatures under cluttered scenario. Image quality can be improved by using suitable sensors and enhancement using the target/background signature knowledge. Robust tracking of object can be achieved by optimising the performance parameters of tracker. In the present work, improvement in the performance of EOST subsystems such as sensor, video processor and video tracker are discussed. To improve EOST performance in terms of detection and tracking, sensor selection criterion and various real time image processing techniques and their selection criteria for maritime applications have been also discussed. Resultant improvement in the quality of image recorded under marine environment has been presented.

Keywords: Maritime surveillance; Electro optic search and track; EOST; MWIR; LWIR; Video tracker; Contrast enhancement; Detection

1. INTRODUCTION

Electro-optic search and track (EOST) systems operate in passive mode and are similar to surveillance radar. They allow passive detection and identification with precise line-of-sight target tracking. Low jamming susceptibility makes EOST system a popular choice for maritime surveillance. It can also be efficiently used for surveillance at night and navigational support under very low ambient light. Typically, EOST system detects the potential target on the basis of differential contrast w.r.t. background or discontinuity being sensed by the imaging sensor.

The available imaging sensors for maritime surveillance operate in wavelength bands from visible band, short wave InfraRed (SWIR), medium wave InfraRed (MWIR), long wave InfraRed (LWIR)[1]. To collect complementary information, combinations of imaging sensors operating in two or three different wavelength bands are used. The target signature gets attenuated due to atmospheric absorption and scattering phenomena[2]. The degradation affects the quality of information being collected through EOST system. Several image processing modules are available to improve the image quality; however the effectiveness of the same heavily depends on the cause and type of degradation. Therefore, before implementing the mitigation plan to overcome these degradations, detailed study to examine the cause of degradation[3].

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2. CONFIGURATION OF EOST SYSTEM

EOST system has three main components namely, a set of electro optic (EO) sensors mounted on stabilised electro optic director and system control electronics. The system electronics is comprised of operator control console (OCC), video processor (VP) and video tracker (VT). Block diagram of a typical EOST system considered for the present case study is as shown in Fig. 1.

For 24x7 maritime surveillance, a set of two sensors each operating in different bands are used. High resolution visible band sensor is the primary choice for better detection, however the performance is limited to clear day-time. To supplement this limitation, additional sensors operating in InfraRed band either MWIR or LWIR are used.

VT enables operator to automatically follow the target of interest by updating its position continuously. The image collected through the EO sensor is a primary input to the VT. It eases the process of dealing with the threats in an effective manner and also improves the accuracy of the neutralisation mechanism, if integrated with fire control system. The factors affecting the performance of VT and suggested improvements are discussed in the following sections.

3. MWIR Vs LWIR IN MARITIME SURVEILLANCE

For night-time surveillance, sensors operating in MWIR and LWIR are natural choice. These sensors are not used together as it makes system costlier and bulky. Due to the higher

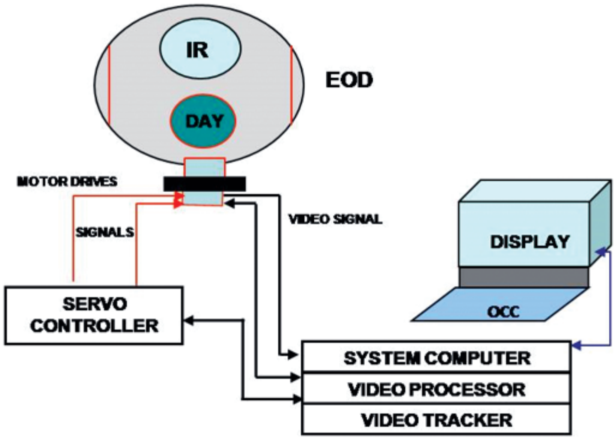


Figure 1. Block diagram of a typical EOST system.

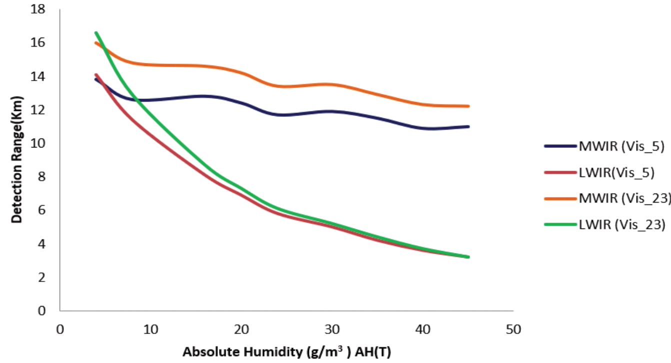


Figure 2. Range performance of MWIR and LWIR sensors for tropical region.

wavelengths LWIR sensor has better atmospheric penetration and therefore longer detection range is expected in comparison to the MWIR sensor[4].

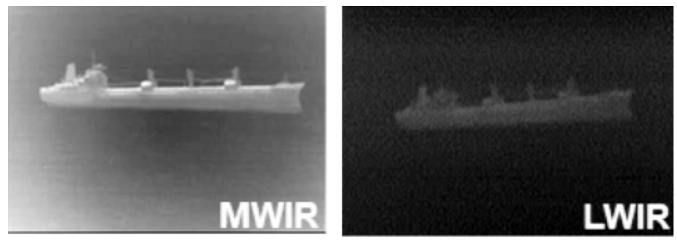
Range performance of sensors operating in MWIR and LWIR band can be predicted by various theoretical models. For range performance analysis, MODTRAN (MODerate Resolution TRANsmission) atmospheric transmittance calculations have been carried out using[5]. The atmospheric transmittance studies have been carried out in MWIR and LWIR spectral bands taking the atmospheric model (tropical), visibility and water vapour contents, into consideration[7]. Based on atmospheric model (tropical), detection range performance of MWIR and LWIR sensors for a target of size 2.3 m x 2.3 m with $\Delta T = 2$ °C under 23 km visibility have been given as a function of Absolute Humidity *(AH)* in Fig. 2. Under 23 km visibility, the reason for sharp dip in LWIR imaging sensor curve is due to high content of water vapour in atmosphere.

Comparative performance parameters of MWIR and LWIR spectral bands are as defined in Table 1.

Table 1. Comparative performance in MWIR and LWIR spectral band

Parameter	MWIR	LWIR
Photon flux	Less	More
Peak detectivity	More	Less
Range performance under dust and fog	Less	More
Range performance under hot and humid	More	Less

It was observed during the trials that the range performance of MWIR sensor was considerably better than that of LWIR imager in marine environment, as described in Table 2. The target at 8 km is merged with the background in LWIR band while the same target could be recognised distinctly in MWIR band[8].



(a) (b)

Figure 3. Ship image captured using MWIR and LWIR imaging sensors at 8.0 km.

The images captured from MWIR and LWIR sensors during trials are as shown in Fig. 3.

The choice of MWIR imaging sensors for long range (> 8 km) maritime surveillance improves the performance of EOST system drastically[9].

4. FACTORS AFFECTING THE DETECTION AND TRACKING PERFORMANCE OF EOST SYSTEM

Target in EOST system declare the presence on the basis of difference of target to background contrast. Therefore the image contrast becomes a key factor during subjective or qualitative evaluation of the system.

For imaging sensors operating in visible bands, sensed contrast depends upon reflectivity of the object in presence of background. The perceived contrast is defined as:

$$C = \left(\frac{L_{target} - L_{background}}{L_{target} + L_{background}} \right) * 100 \qquad (1)$$

where, L_{target} is target luminance and $L_{background}$ is background luminance.

Further, for imaging sensors operating in IR bands, an

Table 2. Maximum recognition ranges achieved in sea and desert environment

Target type	RH (%)	Temperature (°C)	AH	Visibility (in km)	Range performance
Merchant ship (L≈130m)	68-73	34-36	25-30	15-18	7.5 km NFOV(LWIR) 17.0 km NFOV(MWIR)
Cargo ship (L≈110m)	73-80	36-38	30-37	10-12	7.0 km NFOV(LWIR) 13.0 km NFOV(MWIR)

approximate value for thermal contrast of blackbody is given by:

$$C = \left(\frac{W_{target} - W_{background}}{W_{target} + W_{background}} \right) * 100 \qquad (2)$$

where, W_{target} is radiant emittance from target, $W_{background}$ is radiant emittance form background and T is absolute temperature.

For very small temperature, the thermal contrast can be defined as

$$T_{target} \approx T_{background} = T \qquad (3)$$

$$C \approx \frac{\Delta W}{2W} \qquad (4)$$

Using Stefan-Boltzmann law, i.e.

$$W = \sigma T^4 \qquad (5)$$

So, $\Delta W = 4\sigma T^3 \Delta T$ (6)

Therefore,

$$C = \frac{4\sigma T^3 \Delta T}{2\sigma T^4} = \frac{2\Delta T}{T} \qquad (7)$$

If the object having 2 °C temperature difference with respect to background at ambient T = 300 K i.e. $\Delta T = 2$ °C , the apparent thermal contrast would be equal to 1.33 percent. It is very low contrast situation.

To improve the perceived visual contrast and apparent thermal contrast, a suitable image processing algorithm is required.

The purpose of VT is to provide continuous and stable line of sight (LOS) with target[10]. The design parameters of a typical VT are as under:

- Video input : 1V V_{p-p} , 625 lines
- Update rate : 50 Hz
- Minimum target contrast : 5 per cent
- Minimum signal to noise ratio : 4
- Minimum Target Size : 6 x 3 pixels
- Tracking algorithm : Edge/ centroid/ correlation
- Tracking rate : ± 4 pixels/field
- Output (error signal) : 8 (both in X and Y axis)

It is evident from above that the performance of VT heavily depends upon target contrast w.r.t. background, track update rate and user selectable tracking algorithms.

Target contrast: Military targets are small in size with low reflectivity and emissivity. Therefore, for tracking such targets, the minimum contrast required for processing is 5 per cent. Therefore, scene captured through EOST needs to be improved before it fed to VT, as unprocessed image suffer from lack of requisite target contrast.

Track update rate: In order to track high speed targets, track update rate becomes deciding factor for VT. For a typical EOST system having 0.01 mrad instantaneous field of view, requirement of track update rate for fast patrol boat has been worked out for surveillance ranges from 2 km to 10 km. Same is as shown in Table 3.

Table 3. Track update rate requirement for fast patrol boat

Range →	2 km	3 km	4 km	5 km	8 km	10 km
Target speed ↓	Target movement in 20 ms (pixels/field)					
30 km/h	6	4	3	2	2	1
40 km/h	11	7	6	4	3	2
56 km/h	16	10	8	6	4	3

It is evident that at shorter ranges, large track update rate is required, that impose the limitation on VT and thus, overall system performance. Block diagram of video tracker is as shown in Fig. 4.

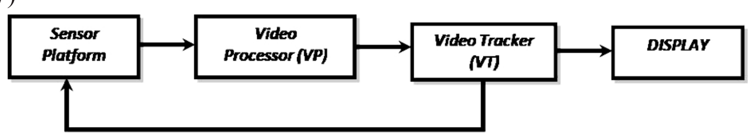


Figure 4. Block diagram of a typical video tracker.

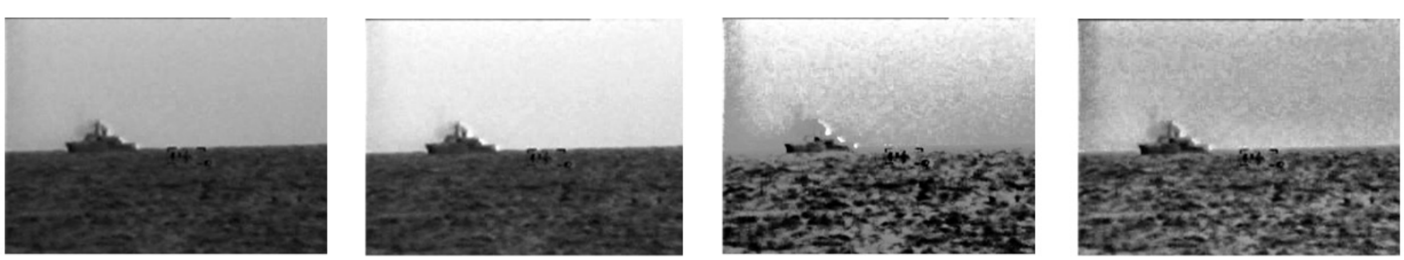
Input video received from sensor payload is pre-processed to make it suitable.

5. ANALYSIS OF IMAGE PROCESSING TECHNIQUES FOR VP MODULE OF EOST SYSTEM

The VP module processes the image for two basic functionalities, one is the detection of object by operator and secondly, the pre processing of the image for VT[11]. Analysis of following image processing technique is discussed in brief for real-time implementation on VP modules.

5.1 Contrast Stretching Algorithm

Contrast stretching (CS) improves the contrast by stretching the desired range of intensity values. The result produced by the contrast stretching algorithm has a soothing effect on the eye and performs best on the hardware for real-time implementation as shown in Fig. 5(b).



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

Figure 5. (a) Input image, (b) CS processed image, (c) HE processed image, and (d) MMHE processed image.

5.2 Histogram Equalisation Algorithm

Unlike CS algorithm, histogram equalisation (HE) processes the image using non linear function. It works well for low contrast images but due to nonlinear processing, HE produces generally oversaturated image. In maritime environment it produces a noisy pattern of water particles underneath the object, as shown in Fig. 5(c).

5.3 Multi-modal Histogram Equalisation

Unlike HE, Multi-modal histogram equalisation (MMHE) divides the input histogram into number of sub-histograms to overcome the issue of saturated image. MMHE overcomes the limitation of HE of over-saturation by partitioning the image histogram and produces better contrast image under maritime environment as shown in Fig. 5(d).

The CS and MMHE processed image of input image is processed as binary image required for edge and centroid based tracking algorithm as shown in Figs. 6(a) and 6(b), respectively.

(a) (b)

Figure 6. (a) Binary image of CS processed image and (b) Binary image of MMHE processed image.

6. IMPLEMENTATION METHODOLOGIES

The image quality of EOST system can be improved by the image processing module. It requires real-time implementation of same in VP module, as delayed performance will severely affect the performance.

Real time performance of above enhancement algorithms is achieved by exploit inherent parallelism of partitioned data and control paths using Field Programmable Gate Array (FPGA)[12]. The architecture of CS based VP module is designed for FPGA based hardware implementation as shown in Fig. 7.

The incoming digital data (Data_in) is fed for computing the minimum and maximum values present in the image frame. The user defines selection of threshold are provided for minimum (Th_MIN) and maximum (Th_MAX) threshold. The incoming data gets subtracted with stored minimum value and gets multiplied with data from LUT. The delay of 4 clock cycles with latency of one frame is achieved through the presented architecture. To achieve real-time implementation, resulted clock cycle delay is mitigated using 4X DLL inside FPGA. FPGA implementation of CS based module on Xilinx FPGA XC5VSX50T requires 25 per cent resource utilisation, whereas MMHE based module requires 34 per cent resources.

Similarly, to achieve real time performance from MMHE based VP module, architecture designed for FPGA based hardware implementation is as shown in Fig. 8. Intensity Level

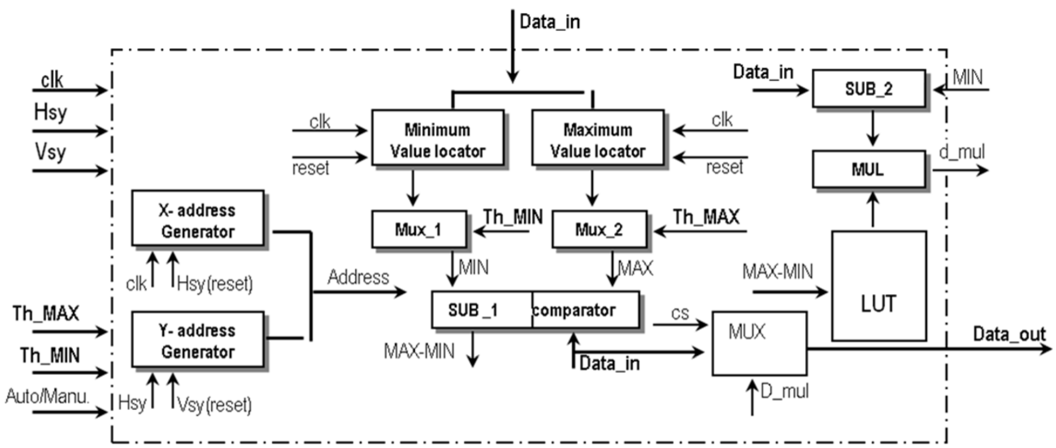


Figure 7. Architecture for CS based VP module.

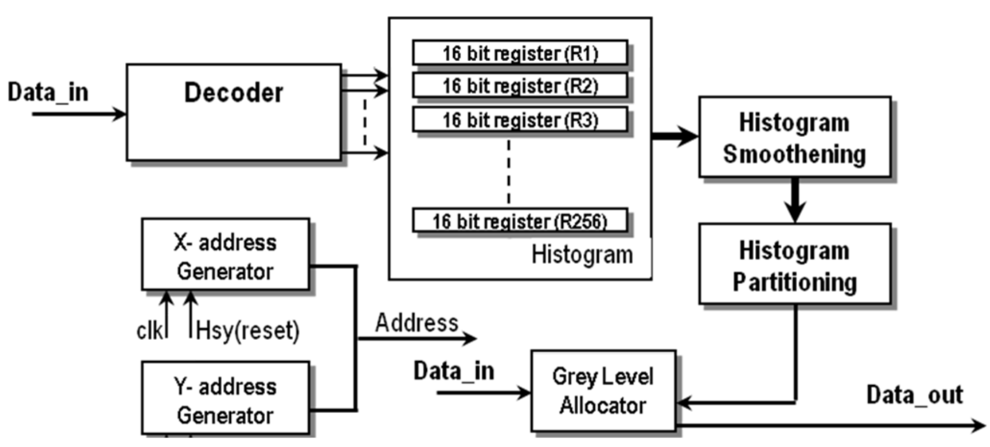


Figure 8. Architecture for MMHE based VP module.

Allocator assigns the mapped value similar to classical HE algorithm to all partitioned histograms.

Both the image processing modules i.e. CS and MMHE modules have been implemented and ported on VP. Contrast of incoming images is improved with both the techniques, however clear binary image is obtained through CS module for VT. Fig. 9 shows the implementation scheme on VP hardware and selection criterion of image processing modules for object detection and tracking using VT.

Improved image can be obtained using MMHE for better visual quality required for detection. Similarly, CS module produces better results in generating binary image required for VT.

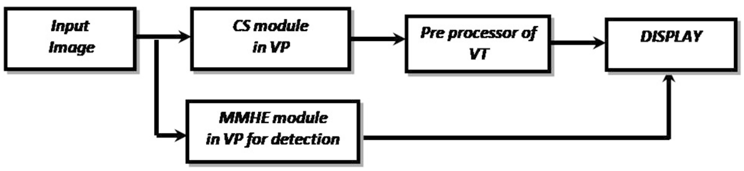


Figure 9. Implementation scheme of image processing module for detection and tracking.

7. RESULTS AND DISCUSSION

Selection of sensor suite in IR band and the performance comparison is discussed in detail under section 3. It is observed from the range prediction model shown in Fig. 2 that MWIR scores over LWIR in marine environment having 5 km or 23 km visibility condition. The same was practically validated during trial process, and the captured images are as shown in Fig. 3. The range performance of MWIR camera was found better than that of LWIR camera in marine environment. The target at 8.5 km could be recognised distinctly through thermal camera operating in MWIR. The target signature degrades as it travels through atmosphere before being collected by the EOST system. The possible improvements in terms of contrast enhancement using CS, HE and MMHE algorithms have been discussed in detail. The real-time performances of these algorithms with improved hardware architecture have been presented. The enhanced images are as shown in Fig. 5. The distinct improvement in visual quality is observed using MMHE algorithm as shown in Fig. 5(d). It improves the detection of ship at distances around 12 km due to 15 per cent increase in differential contrast of object. The same is implemented in VP module to process the incoming image before being projected to operator for detection.

Improving the tracking performance of the detected object at longer ranges, the involved process has been discussed and presented in Fig. 4. It is evident from the discussion that the real-time performance of the VP module is required to ensure the requisite update rate. Implementation scheme for image processing module developed for improved detection and tracking performance has been shown in Fig. 9. The input image is processed with CS and MMHE based algorithms; CS output is passed through the tracker module to generate binary image suitable for edge or centroid based tracking algorithms. It is observed that the binary image generated by CS processed image is speckle free as shown in Fig. 6(a). Binary image generated by MMHE processed image has speckle noise, which is not suitable for VT module. For object detection, MMHE algorithm produces enhanced image suitable for the operator to detect the presence of any threat, easily as shown in Fig. 5(d). A suitable implementation methodology for target detection and tracking used in the present is as shown in Fig. 9.

8. CONCLUSIONS

EOST system is widely employed for day and night surveillance for maritime security. The performance of EOST system heavily depends on the choice of sensor suite. In the present work, the selection and performance criterion of MWIR and LWIR camera have been discussed. Comparative performance of same through theoretical modelling and practical evaluation are presented. It was observed that in the marine environment, using MWIR camera improves the detection capability of EOST system. The performance of EOST system can be further improved by suitable implementation of image processing module designed for contrast enhancement of atmospheric degraded images.

Performances of contrast enhancement techniques such as CS, HE and MMHE have been analysed under marine environment. It was observed that MMHE improves the visual quality of image required for manual detection of object. Though CS also improves the image quality, MMHE scores over HE and CS. The tracking performance can be improved by providing the enhanced imagery to VT module. It was observed that CS processed image generates better binary image than MMHE processed image. The performance of EOST system is improved by adopting MWIR imaging sensor and real-time implementation of image processing algorithms for improved detection and tracking of the object.

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Contribution in the current study, he has contributed in comparative analysis of MWIR and LWIR band thermal imagers.

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Contribution in the current study, he has guided and supervised the work presented in this paper.