ASYMMETRIC THREAT ASSESSMENT USING ELECTRO-OPTICAL IMAGING SYSTEMS

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ABSTRACT

Asymmetric threat assessment from military platforms, including early detection and classification by electro-optical means, is a complicated matter. These threats can be for instance explosives-packed rubber boats, mine-carrying swimmers and divers in a marine environment or terrorists, improvised explosive devices and small vehicles in land or urban environments. Detection is hampered by the threat optical characteristics, as well as the local environment, such as atmosphere and background, which impact on contrast and signal-to-noise ratio. This is true for applications on board of naval platforms in coastal environments, at open sea, for the present-day threat of piracy and observation of hostile activities from the air as well as from land. Background variability as well as target variability are important issues to address. These lead to large amounts of spatial and temporal clutter, which need to be taken into account in the detection and classification processing. For detection as well as classification in visible light and infrared imagery, it is essential to have efficient processes that make use of sophisticated clutter rejection schemes. To have large spatial coverage, because threats can appear from everywhere, a wide field-of-view search system is required. The detection process is performed on the search system, in which clutter rejection is adapted to the environmental conditions. It is an automatic process, generating areas of interest for further classification. Threat classification requires high resolution images to make use of full spatial information. Classification is a combined human and automatic task, operator aided, in which many different feature extraction processes, such are central moments and key point features, can be performed autonomously. The final threat classification assessment is a task for the human in the loop, optionally supported by automatic behaviour analysis.

The key note concentrates on information extraction in naval and UAV approaches for detection and classification of small threats. It discusses the need for enhancing spatial resolution as well as the signal-to-noise ratio. Automatic detection is discussed in terms of kinematics' differences between various objects and threats, as well as with respect to background clutter rejection. The discussion of classification approaches focuses on the assessment of automatic feature extraction. We discuss the application of local descriptors, such as key points and central moments, as well as global shape descriptors, such as silhouettes. For all the techniques different examples will be shown in the scenario of asymmetric threats. Earlier detection and more accurate classification will be demonstrated in this way. Abnormal behaviour detection and classification are new areas of research of which initial results will be given. Combination of additional information from different sensors can be used to enhance the classification capability, thus enhancing the situational awareness and information extraction of the operators.

1. INTRODUCTION

Present-day naval and anti-piracy operations take place in coastal environments as well as narrow straits all over the world. These coastal environments around the world are exhibiting a number of threats to naval forces. In particular, asymmetric threats can be present in these environments. Additionally these environments contain complex and cluttered backgrounds as well as rapidly varying atmospheric conditions. In these conditions the threat contrast may be low and also varying, and the amount of background clutter can be severe, hampering detection. In coastal environments electro-optical means of detection and classification should be optimized in order to have more time to act against threats. In particular the assessment of classification means is an important issue. Electro-optical sensor suites can be used for diverse tasks as detection, classification and identification. By means of passive electro-optical systems, such as infrared and visible light sensors, improved situational awareness can be achieved. High elevation sensor masts are required for long range observation.

As part of the littoral scenario, beside the naval ocean scenario the observation of threats in land scenarios is also essential. Detection algorithms typically make use of different kinds of target features, such as hot spots, motion, and structure. Due to the variation in environment, algorithms that make use of adaptive processing are beneficial in the surveillance process. Incorporation of these algorithms into new types of electro-optical (EO) system concepts, based on infrared and visible light systems as well as integrated systems, is envisaged.

In Figure 1 we present typical examples of present-day asymmetric threats. Note the high intensity levels (i.e. warmer) of the coastal background, as well as the higher intensities of the object's wakes at sea. The first one may hinder detection, but the wake may also support detection performance.

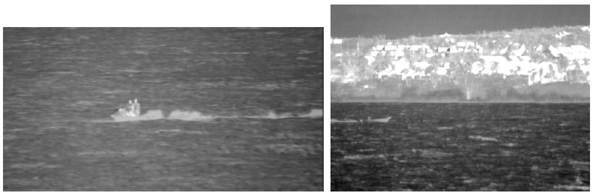


Figure 1. Infrared imagery of potential coastal threats, a small vessel and jet-ski in a warm coastal environment.

In this paper we present essential techniques for naval surveillance system concepts. These should combine the processes of detection, recognition and identification (DRI) of small objects at sea, as well as on shore. We will discuss system concepts, the suite of algorithms required, the system block diagram, as well as some typical examples of image processing in the maritime and land environment, in particular to counter turbulence and enhance contrast. We also discuss the topic of automatic classification.

2. IMAGE ENHANCEMENT

Beside automatic detection processing, final operator use of information depends strongly on the images obtained on the targets. For this purpose, as well as for improved detection, image enhancement of visual data is important. Our first processing stages incorporate these so-called signal conditioning aspects.

2.1. Signal conditioning

Signal conditioning concerns with image enhancement procedures, such as artefact (non-uniformities due to detector and optics) reduction, noise reduction, resolution enhancement, contrast enhancement, stabilisation as well as turbulence correction. In our approach we aim to improve the imagery for two purposes. First of all improving the data for data processing, and second improving the imagery for detection and recognition by human operator. In this pre-processing stage of signal conditioning, the signal to noise ratio (SNR) should be enhanced at the spatial scales that are of interest for the processing and for the human operator separately.

2.2. Contrast enhancement

During several experiments in a naval environment we have tested the Local Adaptive Contrast Enhancement (LACE) module on-board naval frigates. LACE is operating on all types of imagery, from visual CCD, Low-Light-Level-TV (LLL-TV) and infrared. These experiments took place in a harbour environment and several passages though narrow straits. Some results are presented in figures 2 and 3 below. In these figures the left images are the original images from the sensor. After processing with the LACE module the right image shows the effect of an increased contrast on these images. The results show clearly that situational awareness is improved in these conditions. This is visible in the imagery of the figures by the presence of more details in the coastal and harbour background as well as on the larger ships. Hence structure information is better visible in the processed imagery, hence providing improved operator aided classification and also improved classification ranges.

Figure 2. Coastal area during Suez channel passage (left original LLL-TV, right enhanced contrast).

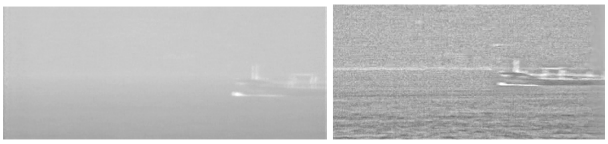


Figure 3. Ship, sea surface and coastal background during passage near Gibraltar (daylight camera left without and right with LACE applied).

2.3. Turbulence correction

For long optical paths over sea turbulence is a dominating factor. To obtain correct classification in these situations turbulence correction is therefore essential. The effects of turbulence in the atmosphere can become problematic when one is interested in obtaining a highly detailed image. When safeguarding harbours such a detailed image is required to be able to tell if there are any threats in the vicinity. The turbulence in the atmosphere can distort the images, making it hard to see details. There are several possibilities to correct for the effects of turbulence in images. We have looked at the possibility of image restoration after the images are recorded. In this way we also maintain the sensitivity of the (infrared) system. Especially after image stabilisation turbulence is clearly visible and dominating the image sequence and limits classification. We have applied the standard image enhancement suite of TNO [1] extended with turbulence compensation. The image enhancement suite contains dynamic super-resolution (DSR), local adaptive contrast enhancement (LACE), image stabilisation and moving object detection. In Figure 4 input images from the image sequences are shown together with an output images obtained after applying turbulence compensation. The amount of detail visible in the images, such as antennas, has grown and the scintillations have disappeared. Moving objects, like birds, are detected and preserved in the output images, and names on the ship can be read easier. For slow moving objects the smearing effect due to temporal integration is negligible and these objects are well visible in the output images.

Figure 4. Originally recorded maritime visible light image (top) and image processed with turbulence corrector (bottom). The ship's range is 12.5 km. Images were recorded with the TNO SPITS [2] system.

3. DATA PROCESSING

The signal processing determines for a large part the quality of the imagery, the detection and clutter rejection capability, as well the classification probabilities. In Figure 5 we present the system block diagram of the system processing concept of our proposed surveillance system. The overview shows system areas of image enhancement pre-processing (labelled block number #2 in the figure), detection (#3), classification (#4) and adaptive sensor management (#6). For reasons of clarity only a single (search) camera is specified in this figure (block #1). In practice additional classification cameras can be used in combination with the surveillance search sensor to support the classification process. With classification we define several steps that need to be taken for adding labels to detected objects. These steps are e.g. clutter rejection, feature extraction, object classification. The features of interest can be target features, such as dimensions, and also threat types as go-fast or jet-ski. Beside these blocks additional user interface blocks are drawn.

The goal of our surveillance approach is to make use and adapt existing algorithms for image enhancement, detection, classification and sensor management, in order to create a robust real-time maritime demonstrator, which supplies enhanced imagery for the operator and automatically detect small surface targets, such as jet-skis and fast inshore attack crafts.

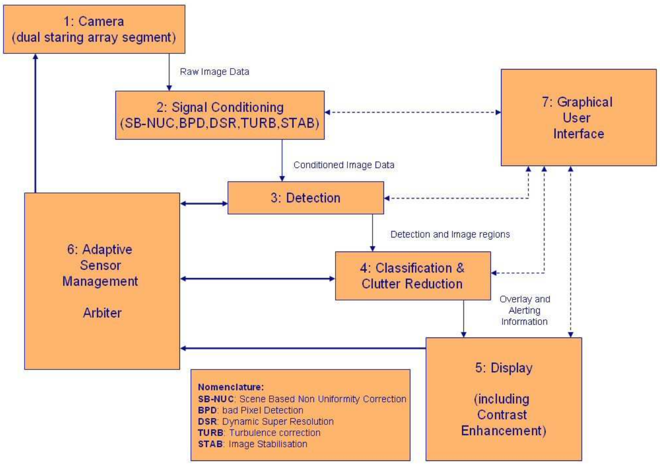


Figure 5. Block diagram of the algorithms system concept in a surveillance system [3].

4. AUTOMATIC DETECTION

The detection process makes use of detection of hot spots (the SURFER hot spot detection algorithm is presented in van den Broek et al.[4]) and detection of moving targets (Schutte et al.[1]). It is foreseen to use the existing TNO M6T tracker [5] to do temporal correlation and confirmations of potential detections. An important stage in the detection pre-processing is the background removal, especially in close-by situations with large amounts of sky reflections and other variations (such as white caps) in the background levels. In Figure 6 we show the positive results of background removal making use of a model of the background radiance slope. The original image is presented at the left. The middle image shows the effect of removing the average background for each elevation line, which is a standard approach. Here the contrast is enhanced on average, but clearly not optimum on the more extended targets. By using a model that corrects each elevation line separately by subtracting a background radiance model the local target contrast is enhanced with respect to the contrast that is visible in case the average background is removed.

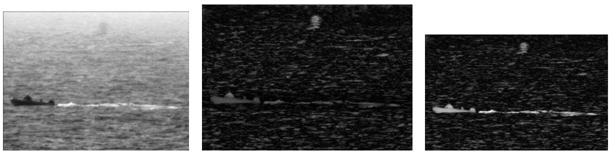


Figure 6. Original daylight image (left); image after subtraction of the line average (middle); image after subtraction of elevation line model (right).

For longer range infrared imagery of small vessels the detection threshold has to be quite low in order to maintain detection capability. In particular for uncooled detectors and complex sea and harbour conditions, this results in substantial sources of clutter. These sources can be removed by correlating the spatial detections in the temporal domain. This is done in the M6T tracker process. An example of tracking results is presented in Figure 7.

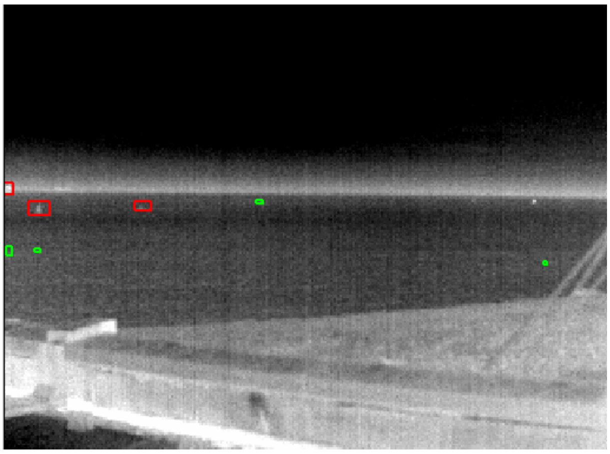


Figure 7. Tracking results. Older tracks in red are detected as potential objects (threats). From left to right a ferry, a buoy and a RHIB. The green tracks are considered friendly.

5. AUTOMATIC CLASSIFICATION

The automatic classification process consists of several stages. It supports the surveillance system in the post detection stage to reduce false alarms, extract target features, and determine object class information. Examples are clutter reduction where simple features are used to classify between clutter and non-clutter detections, resulting in lower false alarm rates for comparable detection probability. Tracking may further reduce false alarms, making use of consistency in target features. Two approaches are executed in our research:

- Information enhancement by using simple features (such as size) and specifying extra information to an operator, possibly including general classes (large/medium/ small, or containership, fishing vessel, …)
- Aided target recognition: After a selection based on earlier steps, more complicated features (such as possibly profiles, input from an operator) are used to specify a few possible types of ships, with reliability.

These two approached are related to the separation of human-in-the-loop versus automatic detection. In the case of automatic classification, a step-wise approach from aiding the operator with more-and-more information will result eventually in a final “fully automated” approach.

The inputs for classification are detections with specific additional image information from which features can be derived. Clutter reduction can be considered in this sense as a form of classification, which is used early in the process to limit the processing load for further, more complicated methods. Tracking adds the possibility to look at changes of features in time, or to determine features more accurately. It also provides kinematics information such as velocity. Classification may be done in steps, for example repeating several feature extraction and classification steps. In this way more complicated steps, need not be applied to all detected objects. The output of the process will often be object information or class information being presented to an operator.

Some features that can be used in classification may be obvious, such as size related features. Others types of features were derived in earlier projects (such as features based on intensity variation in SURFER [4]), or are common choices in pattern recognition (such as profiles, or moments). Our process starts with examining different features, using a limited set of available images. Figure 8 shows some examples of images with segmentation masks that were used to derive some basic features. More complicated features, such as central moments and key points, are also being looked at in parallel.

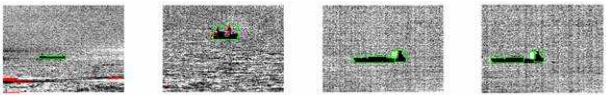


Figure 8. Classification as a means of clutter rejection for a number of different surface targets.

The targets in Figure 8 are indicated in green, and the non-target related segmented areas are indicated in red. Typically red areas are related to clutter that should be discriminated more strongly. There are also some areas defined on the vessels that are not associated directly with the target. This is an association issue that needs to be taken care of. Therefore the combination of the parallel approaches, make more efficient use of the image information. This makes the classification algorithm more robust.

For automatic classification of vessels, a database is required containing information relating features to specific classes. For clutter reduction, a 2-class process, this is simple, but for using more classes, defining the database is much more complex. Not only does it require much data to fill the database, but separating classes may get difficult for other reasons, as classes may overlap. Additionally class separation can be quite different in other operational domains. It is expected that accurate classification processes could bring much more results in clutter rejection, as well as classifying ships.

6. SENSOR IMAGE FUSION

Figures 9 and 10 show images of a patrol boat, jet-ski and Rigid-Hull Inflatable Boat (RHIB) in the harbour of Den Helder taken on the October, 9th 2008 [6]. The left image of the figure was acquired by a long-wave infrared wide field-of-view ‘panoramic’ camera. The targets are located within the projected circle. The right image shows images of the targets acquired by the mid-wave narrow field-of-view camera. Figure 10 shows long-wave infrared narrow field-of-view images of a Landing Craft Rubber Motorized (LCRM) (at the left) and two twin kayaks taken outside the harbour (i.e. in a littoral scenario) on October, 8th 2008.

For each run the images were taken at almost the same time with partly overlapping fields-of-view. This allows for (new) sensor fusion techniques and approaches such as image stitching and image fusion. One should keep in mind that, due to differences in sensor frame rates, latencies, fields-of-view and parallax errors in target pixel positions between the different images can occur. The lowest frame rate realized was 9 frames per second for the Merlin EM-247 visible light camera. Given a maximum (lateral) speed of 70 km/h for the RHIB or jet-ski in the harbour, this resulted in a horizontal target displacement of 2 m per frame which equals to 5 image pixels at 1 km. The trial that we discuss here [6], and at which the data was recorded, was defined to collect data in order to demonstrate the feasibility of new techniques and approaches to detect, track, recognize and identify small surface targets in and near a harbour environment, as well as to demonstrate the newly developed detection, classification and cueing techniques in real-time. Additionally a combination with radar and AIS data in a sensor data fusion approach would be supported (see below). For the purpose of the trial a sensor network had been set up consisting of a heterogeneous set of cameras with panoramic observation capabilities, radar and an automated identification system (AIS). The sensor network was used to collect data of small surface targets in and near the New Harbour of Den Helder, in the Netherlands, in October 2008.

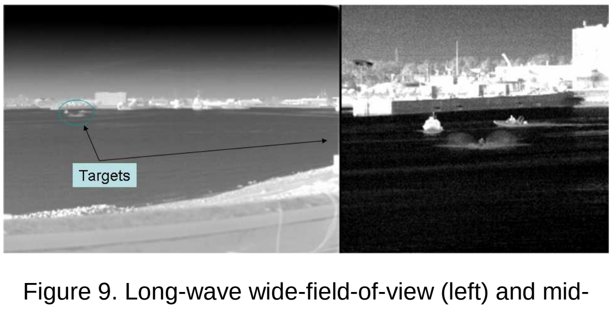


Figure 9. Long-wave wide-field-of-view (left) and mid-wave infrared narrow field-of-view (right) images of patrol boat, RHIB and jet-skis.

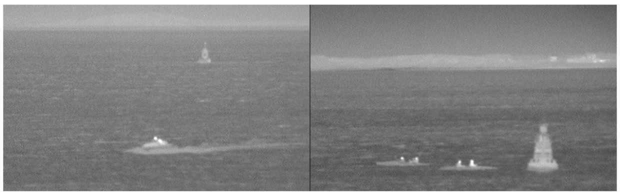


Figure 10. Long-wave infrared narrow-field-of-view image of LCRM (left) and two twin kayaks (right) in littoral scenario North of Den Helder New Harbour.

Figure 11. Colour representation of a multiband image. The multiband image combines a near infrared, mid-wave infrared, long-wave infrared and colour image. In the image the hue and saturation is obtained from the colour image; value is obtained from the multiband.

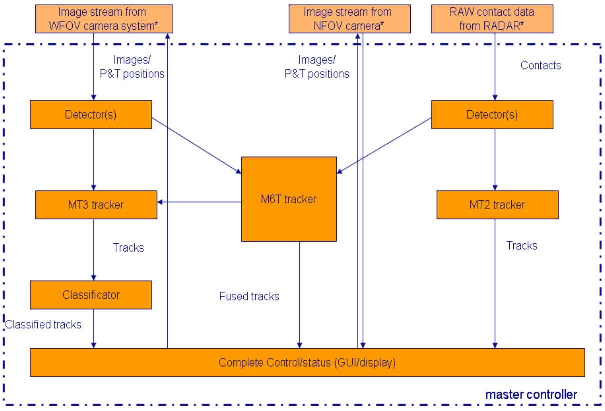
The simultaneously recorded multi-sensor image data was combined in a single image to enhance the operator's situational awareness. By making use of a TNO process that generates colour imagery, with colours that closely resemble true colours, improved target and scene visibility is obtained. The process starts with combining several sources of multiband data. We have used the combination of near infrared, mid-wave infrared, long-wave infrared and colour image. By taking a specific choice for the hue, saturation and value from these data, improved object and background recognition is obtained. In Figure 11 we present an image generated in this way. The image contains small vessels in a harbour environment. We observe the natural, and soft, colours of the background, while the vessels are clearly visible in the water.

7. SENSOR DATA FUSION

In sensor data fusion [6] we make use of data from different sensors that generate complementary information from objects in the scene. Typically cameras generate 2-dimensional image data, without range. In a surface scene, when we know the observational positions, we are able to generate rough distance information from the scene based on (infrared) images. We can then combine this range information with the range information generated by the radar. The radar generates range and azimuth and is less well equipped to generate accurate elevation data.

Our detection processing has generated infrared plots and tracks, which we have combined with radar plots and tracks. In Figure 13 we show some results obtained in this way. Different radar track can be seen to merge with the infrared information, and single tracks can be obtained from this process. When applying the fusion technique on these dim targets in cluttered environments, it is essential to have accurate positioning, pointing and timing of all sensors. Furthermore care must be taken to maintain stability of the data covariance.

The collected data from the trial [6] has been used in studies involving the target detection, clutter reduction, classification, fusion and cueing based on infrared images and radar measurements. The first approach uses the wide field-of-view infrared images and radar to produce plots (detections, contacts) that will be sent to their individual trackers (MT3, MT2, both earlier version of M6T) to build target tracks. The second approach uses the plots to send to another tracker (M6T, [5]) that first builds infrared and radar tracks and secondly fuses them. The final approach uses both infrared and radar plots first to fuse within the M6T tracker (i.e. plot fusion) and secondly to build the fused tracks. This approach is depicted in Figure 12.



*denotes a separate subsystem, which connects though Gig-E to master controller (dashed signal perimeter)

Figure 12. Cueing, contact and track fusion scheme: Cueing of narrow field-of-view camera based on fused radar and wide field-of-view camera plots (or tracks).

Figure 13. This sensor data fusion harbour scenario contains a patrol boat, RHIB and other opportunity vessels. Radar tracks (in blue) and infrared tracks (in red) (with green GPS/AIS).

8. APPLICATIONS

Systems for obtaining long range sensing capability require elevated sensor masts or (low-) flying platforms. These platforms are ideally suited for the surveillance and autonomous detection task and equipped to improve the operational picture. A primary issue is how to incorporate new electro-optical technology and signal processing into the new system concepts. Of great importance is the derivation of information from the high spatial-resolution imagery created by the sensors. As electro-optical sensors do not have all-weather capability, the performance degradation in adverse scenarios should be understood, to support the operational use of adaptive sensor management techniques. In particular in coastal regions, relatively fast changing conditions can occur, that may hamper sensor performance.

The elevated platforms require stabilisation. At sea, on land and in the platform motion may degrade the sensor image. Making use of the DSR algorithm we can make good use of image motion caused by the sensor, and change it into an advantage by increasing the spatial resolution (trading temporal resolution for spatial resolution). Additionally we can then correct for turbulence in order to enhance resolution over long atmospheric paths. These processes provide us with enhanced signal to noise ratios. These items are all beneficial for situational awareness. Without motion of the sensor we can still perform contrast enhancement (LACE) to have a first order of enhanced image. Again an automated approach adaptively judging the sensor motion could adapt the algorithms from DSR to LACE for optimum results. These algorithms are applied in elevated mast systems in operation by the Netherlands Defence force.

During an experiment the automatic classification algorithms were applied in a harbour scenario in the Rotterdam harbour. The good results are presented in Figure 14. Different vessels, such as RHIB, jet-ski and watertaxi are classified as such, buy making use of different features.

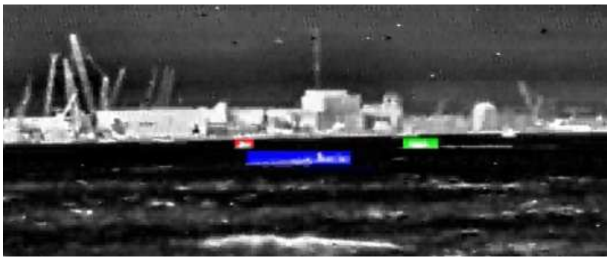


Figure 14. Classified objects during a real-time trial in the Rotterdam harbour. The automatically classified targets are coloured: watertaxi (red), RHIB (green) jet-ski (blue).

9. CONCLUSIONS

In this paper we have shown successful approaches for techniques of use in asymmetric warfare in a naval environment. We have presented results of automatic detection and classification of targets in a harbour environment. The approach is to subsequently detect, track, and classify small surface targets in and near a harbour environment. It was demonstrated that a sensor network, containing search and imaging sensors, could be realized consisting of a heterogeneous set of cameras with panoramic observation and zoom capabilities. The data collected during trials was used to test the performance of the classification and sensor data fusion techniques. We have also shown the image results are improved by application of signal conditioning algorithms, such as LACE and turbulence correction, as well as sensor image fusion by introducing natural “true” colours. This image fusion approach combines different sets of up to six image data sets into a multiband image.

10. ACKNOWLEDGEMENTS

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11. REFERENCES

1. Schutte, K., de Lange, D.J.J., van den Broek, S.P., Signal conditioning algorithms for enhanced tactical sensor imagery, SPIE Proc. Vol. 5076, 92-100, 2003

2. Theil, A., Huizing, A.G., van Heijningen, A.W.P., Single Picture Integration for Territorial Waters Surveillance (SPITS): An initiative to improve situational awareness in littoral waters, MAST (Maritime Systems and Technology) Conference, Nice France, 4-6 September 2006

3. Schwering, P.B.W., van den Broek, S.P., van Iersel, M., EO System Concepts in the Littoral, SPIE Proc. Vol. 6542 paper 100, 2007

4. van den Broek, S.P., Bakker, E.J., de Lange, D.J., Theil, A; Detection and classification of infrared decoys and small targets in a sea background, 2000, SPIE Vol. 4029, 70-80, 2000

5. Bosse, E.; Roy, J., The Canada-Netherlands collaboration on multisensor data fusion and other Canada-NATO MSDF activities, Circuits and Systems, 1998. ISCAS apos; 98. Proc. of the 1998 IEEE, May-Jun 1998, Volume 6, Issue 31, 561-564, 1998

6. Lensen, H.A., Schwering, P.B.W., van den Broek, S.P., den Hollander, R.J.M., van der Mark, W., Kemp, R.A.W., Application of heterogeneous multiple camera system with panoramic capabilities in a Harbor Environment Circuits and Systems, 2009, SPIE Vol. 7305, 73050B-73050B-16, 2009