The Preliminary Processing of Images and Object's Identification in Thermo-Optical Set for Reconnaissance of Coastal Zone

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***Abstract*—**The paper presents conception of thermo-optical set, which will processing information acquired from two optical cameras and thermal camera. The set will perform the continuous inspection on observed coastal zone and will carry out recognition and identification of sailing and low-flying objects basis on its classification features and thermal characteristics. The module of preliminary image's processing and module of object's identification were described. There were presented the methods of preliminary processing of optical and thermal images which were used in module of filtration and processing of thermal and visional images. Next the method of object's identification on images acquired from thermo-optical set for reconnaissance of coastal zone using Hough Transform was presented. This method was used to create module of reconnaissance and identification in worked out system. More over the results of preliminary processing and filtration of images by created module were presented on the paper. At last the results of object's identification for example images were presented.

***Keywords*—** visional and thermal observation systems, object's identification and recognition, images processing.

I. Introduction

The assurance of effective protection sea border, requires the possession of system which guarantee effective monitoring of sea situation in grounds of national sole economic zone.

The experiences of states of pool Baltic Sea shows, that to effective protection of sea border as well as the protection of businesses of state on the sea, it is indispensable to equipment the border services in modern observational systems which permits to quick identification of swimming and flying objects basis on information gain from optical and thermal sensors.

Actually exploited the System of Safety of Exchange Navigation's Information, though they contributed to considerable improvement of situation in range of control of chosen area, then they do not be adapt to realize the tasks of tightness the sea border. Special meaning has detection of smuggling and terroristic acts which can be made using fast small motorboats and low flying small planes and unmanned flying or sailing vehicles. This is why there is need to develop systems which will support national services in realization its tasks.

The main source in real systems of observation and recognition is mainly radiolocation station. But same object can't be seen by radars. Therefore the presently legacy observation equipment ought to be extend by set which will allow to discover and recognize object in area invisible for radars.

The set is designed to acquiring, processing and visualization the data from thermo-optical sensor on monitors of operator console in form of visional images as well as the presentation of detected objects on the electronic map of observed zone [10], [11]. The set, using the information which will be gained from optical and thermal sensors installed on Observation's Technical Points will execute the recognition and identification swimming marine objects and low flying aerial apparatuses. This is very important task on the ground of protection from military threats and terroristic risk the coastal zone, approaches to harbors and ports basins.

This set has possibility of recording data from thermo-optical sensors about detected objects in real time. These data will be archived in system's data base. Data's archiving allows to replay chosen situations for further analysis and training of system's operators. According to needs the data can be send to other systems located outside [16].

II. General Description of Set

The structure of thermo-optical set is presented on figure 1. The basic module of sensors in thermal-optic set consist of thermal camera and two colorful CCD cameras to day-night observation for the average and far distances. These cameras are characterized be optical and digital zoom which assuring the total coefficient of increase 260 times. These sensors are mounted on common turn-table which allows to circular or sector observation of chosen area depending on mode of work. The turn-table control is realized basis on signals worked out by algorithms implemented on computer. Communication between cameras, turn-table and computer is realized by Ethernet. This set, thanks to two CCD cameras, allows on creating the stereoscopic images of observed zone and the presentation result on one from three monitors which belongs

Manuscript received December 30, 2010. This work was supported by the Ministry of Science and Higher Education under development project realized in years 2009-2011.

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to the set. These cameras are used to calculations distance to observed moving object as well as to calculate the object movement parameters. On second monitor the information from thermal camera about object appeared in observed zone is presented. The information gained from cameras is used to identification and the classification of detected objects. Identification is made basis on thermal and visional object's features [16].

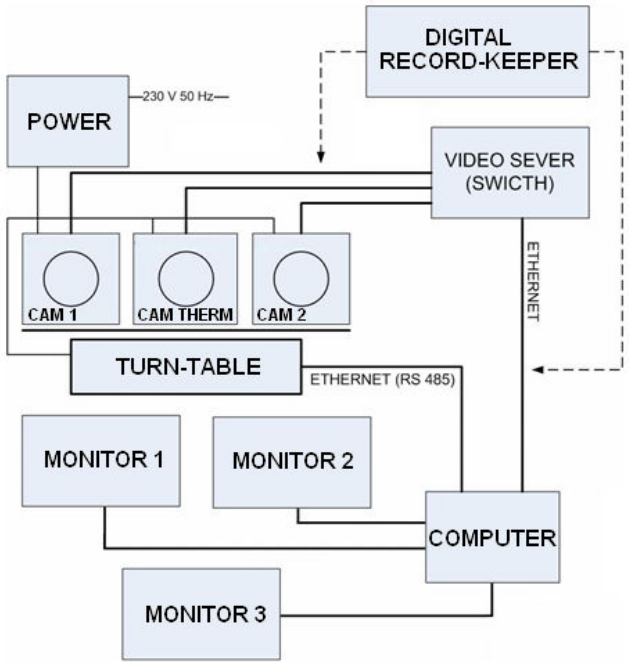

Fig. 1 Structure of thermo-optical set

The set has possibility to record visional and thermal signals from sensors. It allows to educe marine and low flying objects' thermal and visional signatures which should be individual for every object. This is useful to creating the data base and the same allows for quick identification and classification of detected objects basis on theirs thermal and visional signatures.

This set using the information from sensors, about objects present in observed zone, their position and the parameters of movement will be presented on foundation of electronic digital map of observed area. This visualization will be realized on third monitor. The map of observed area will be presented according to standard S-57.

This set allows for creating the visional stereoscopic and thermal images of observed area and automatic following and recognitions the chosen elements on this images. This set will make the recognition and identifications of marine sailing and low flying aerial objects appeared in supervised sea area basis on information from thermal and optical sensors. The acquired information according to data from radiolocation system will allow to follow and control the movement of own and strange objects positioned in regions of interest of Polish border services. This set will assure enlargement of effectiveness of protection before such threats terroristic acts as well as smuggling using small and quick vessel as well as hostile recognition using unmanned flying apparatuses.

III. Functional Structure of Set

The thermo-optical set for recognition and identification of marine sailing and low flying objects, will assure the filtration of visional and thermal images as well as creating the stereoscopic images of the observed zone which will be used for automatic detection and tracking of objects being in field of observation. Basing on received images the set will assure tracking in real time the chosen objects using their classifying features. It also allows for presentation of tracking object position on background of electronic digital map of observed zone. To the basic functions of thermo-optical set should be numbered [16]:

- searching of the observed zone and creating its stereoscopic and thermal presentation,
- the broadcast of visional information form point of technical observation to the system of creating the stereoscopic and thermal presentation,
- the creating of stereoscopic and thermal presentation using two visional CCD cameras and thermal camera,
- the recognition, tracking and identification of chosen elements on acquired images in real time,
- the recognition, classification and identification of chosen objects, basis on their classifying features, on created stereoscopic and thermal images in real time,
- the tracking the chosen objects using the stereoscopic and thermal cameras,
- the presentation of detected objects by thermo-optical set on the background of electronic digital map of observed zone,
- the acquisition and archives the thermal and visional signatures of marine sailing and low flying objects in data base,
- the generating information, in form of standard telegrams compliance to NMEA 0183, about detected objects and sending information to other Automatic Command and Control Systems.
- the assurance of repeatability of situation for training aims and analysis of tactical-navigational situation.

In aim of assurance the realization of introduced above functions by thermo-optical set the functional structure which consist of block which are realizing individual functions and cooperating each other was worked out. The functional structure of set was introduced on figure 2.

The communication interface allows for sending the information and communicating with different systems of recognition as well as assure his proper starting and software initiations and gives possibility of controlling working's parameters of set. The operator can take from data base the thermal and visional signatures as well as saving them to data base using other recognition systems. He can also replay situations in aim of analysis or to training the service crew.

The basic sensor of set, which allows to acquire data about object in observed zone are visional CCD and thermal cameras. They will change visional information into digital data. This images, depending on external conditions especially weather conditions, will characterize different quality. Having acquired images it will exist need to improve or make another operations which allows on gaining possibly a lot of visual or quantitative information from them. In aim of making possible to improvement of image's quality there is a whole scale of images' operations and methods of transformations. Digital filtration will have in this stage of images' processing the biggest meaning. With this regard acquired visional and thermal images will be digitally processed in aim to eliminate the influence of noises on its quality. This processing will be realized by filtration and processing of visional and thermal images modules.

The task of filtration and processing of visional and thermal images modules is to improvement the quality of acquired images using digital filtering which will reduce the unimportant elements according to recognition elements of images. Filtration is realized on pixels of source images in which result the new, transformed image will be obtain. According to such processing the noises will be removed and edges will be set off, so the useful, on other stages of processing, information from original painting will be obtained.

The task of creating stereoscopic presentation is to get the information about images depth and the same information about distances to chosen elements on images [7]. Problem which will be solved by this module is to obtain the map of depth, so called 2.5 dimension images, because during mapping images from 3D in 2D by cameras the information about depth is lost.

Having so worked out visional and thermal images of observed zone it will be displayed on monitors and simultaneously send to the thermal and visional presentation modules where it will be quantitative analysis it means recognitions as well as finding on images selected elements. The need of automatic recognizing and analysis of images is presently very common and is joined with strongly developing computer science which the object of interest are the methods of images' processing in peculiarity the detection of selected

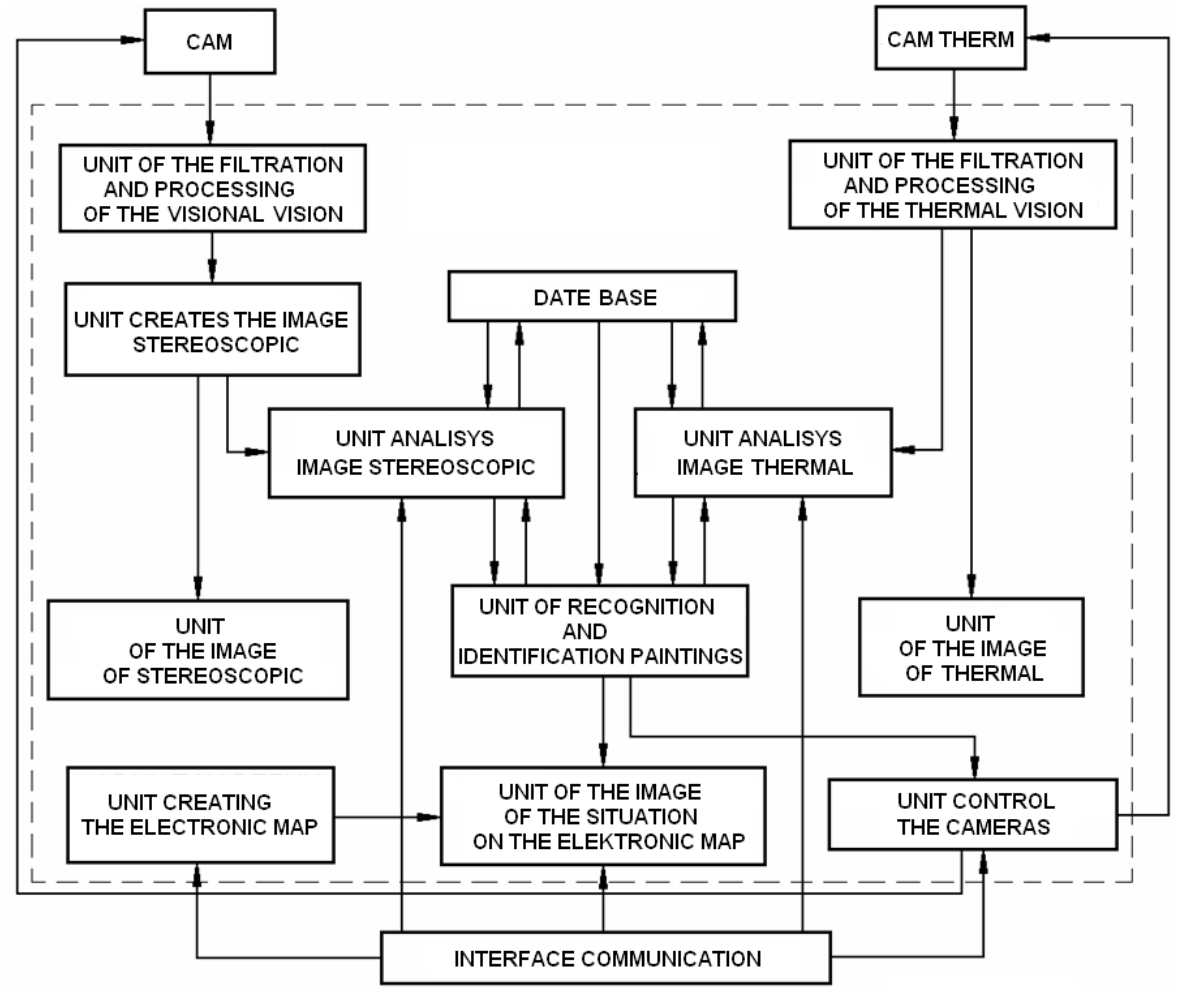

Fig. 2 Thermo-optical set's functional structure

elements as well as their recognizing. The large meaning in analysis of stereoscopic and thermal images has the preliminary processing which task is the preparation of data to final processing, and which also assure the proper analysis of images. These tasks are executed by modules of visional and stereoscopic analysis which cooperates with module of identification and images' recognition.

In this module the processing images into digital description is made. It allows to get conclusions about quantitative and qualitative occurrence of selected element on images and the same it gives possibility to linguistic description of images in automatic process. In this module will be realizing:

- the recognizing, detection, identification, location and description of scene;
- the creating the concise and informative representation of images;
- the selection and construction of features;
- the interpretation of decision and the opinion of classifier;
- the continuous work on images respectively to the time.

In this module one of two possible approaches will be realized in recognizing images it means:

- the direct approaches which example can be applying neural networks, some algebraically such as SVD or some use of SVM. The main advantage of this approach is simplicity of working. To the defects should be number the limited applicability it means rather small images and simple objects;
- the indirect approaches which use representation of indirect images on example of features' vector, the list of objects and their features, vice - count of contiguity of areas. To the advantages of this approach can be numbered the module construction as well as the possibility of using the UM tools. The defect of this approach is firstly larger expenditure of work and secondly the problems with selection of images' representation.

Presently, the way of conclusion in recognition of selected element on images is not determined. The worked out algorithms will use recognizing using features, that means they will use calculated form images features or recognition basis on models it means the similarity will be calculated by comparing with some kind of pattern (for example measurement of similarity of thermal features) [15]. In case of recognizing objects on stereoscopic images it will be realizing the recognition concentrated on objects and recognition concentrated on scene view. First case it is required to knowing the model of recognized object, and the recognition depends on deciding if he could generate the given view. Second case follows decomposition of view onto simply elements and conclusions are made basis on analysis of individual elements. Recognizing stereoscopic images where the depth is well-known, allows on precise identification thanks to additional describing object parameter as well as his precise orientation in space.

This module cooperates with data base where the patterns of objects can be archived as well as their signatures. More over it also cooperates with module of presentation situation on electronic digital map.

In module of situation presentation on electronic digital map the detected and recognized objects will be presented according to the requirements which take placed in case of ACCS. This module will get information from the creating of electronic map module as well as the module of identification and the recognition of images.

The module of sensors' control is communicated with module of identification and recognition of images. Basis on this information it will work out control signals for executing sensors' element what allows the proper mode of work it means the searching according to definite algorithms or the following the chosen of elements on thermal or stereoscopic images of observed zone. This module communicates with operator via entrance interface.

IV. The Module of Filtration and Processing Visional and Thermal Images

Having the recorded image a need of improving it or making different operations which assure the success of identification of its elements on it will exist. A whole range of the operation and methods of transformations of images is being using in the aim of improving the quality during preliminary processing [2], [3], [13]. The main aim of preliminary image processing is to prepare data for the last step of identification and assure the correct results of analysis of the picture elements. Images acquired from the optical camera especially at low light level (at night) during occur of rain and fog will be characterized by very weak quality. Therefore the quality of images should be improved by the compensation of vision noise and reduction its influence and the same to bring to close to its original shape. According to this the unplait operation is used which task is to reconstruct original or deliberate appearance of image [9].

Very import thing in images processing is emboss and detection of edges. Emboss of edges using methods of convolution filters founds many application inf automatic classification of chosen element on images. This operation is usually the first step in detection and identification of object on images. After phase of feature detection the process of luminance values thresholding is made due to discard of unwanted datas. Process of edges detection reduce images to contained on its edges and primary form of images disappear, what makes classification process much more easy and faster. The four methods of edge emboss where checked and one method of edge detection. There are respectively: filter of shift and subtract, Laplacea's filter, direction gradient filter, direction filter and Sobel's filter and its variant which is using the Previtt's filter.

A. Unplait Operation

A method which is being practiced in this purpose is the unpalit operation which task is to reconstructing the genuine or planned appearance of the image [14]. It is possible to treat the

observed image $f(x,y)$ which was deteriorated as the plait of original picture $g(x,y)$ with the impulse reply function $h(x,y)$ which described how the point of picture is looking in ideal conditions. It is possible to write that:

$$f(x,y) = g(x,y) * h(x,y) \tag{1}$$

Applying the Fourier transform the above equation will take form:

$$F(u,v) = G(u,v) \cdot H(u,v) \tag{2}$$

From here, if there is a known function of the impulse reply it is possible to perform the image using the equation:

$$G(u,v) = F(u,v) / H(u,v) \tag{3}$$

Fig. 3 The results of unplait operation applied to the image obtained by vision system: a) image recorded by the thermo-optical set, b) image after unplait operation

In practice it is necessary to add the additive noise which is present on the image. Above equation will take form as:

$$G(u,v) = (F(u,v) - N(u,v)) / H(u,v) \tag{4}$$

It should be noticed that if $H(u,v)$ is small both expressions in the equation (4) can become big and the noises can be increased. One of methods of avoiding this occurrence is to apply the Wiener filter which consists in recording the image in his reconstructed figure as:

$$G(u,v) = [F(u,v) \cdot \hat{H}(u,v)] / [N(u,v) \cdot \hat{H}(u,v) + n_u] \tag{5}$$

where:

$\hat{H}(u,v)$ - is the conjugate complex value of $H(u,v)$;

n_u - is the noise to signal ratio and it is the heuristic value which is selected in experimental way.

The result of a unplait operation was introduced on fig.3. The picture was taken by camera which was mounted on the set.

B. Finding Edges

The filters which permit to finding edges are commonly used during classification of object shapes. The basic method of finding edges consist of sum of product of first order but such approach not always is giving the proper results. Therefore the best results are taken by using the first derivative like in Sobel's filter [4], [12]. It works as the gradient method, which means it described the points on picture where the luminosity is changed in highest way. In practice to find edges on picture it is calculated the plait of the picture with horizontal Sobel's filter and next plait of the picture with vertical Sobel's filter what can be written as:

$$I_1 = picture * S_{po}$$
$$I_2 = picture * S_{pi} \tag{6}$$

where: S_{po} – horizontal Sobel's filter with coefficients:

$$S_{po} = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix},$$

S_{pi} – vertical Sobel's filter with coefficients:

$$S_{po} = \begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix}$$

The luminous of the new pixel is calculated as follow:

$$I = \sqrt{I_1^2 + I_2^2} \tag{7}$$

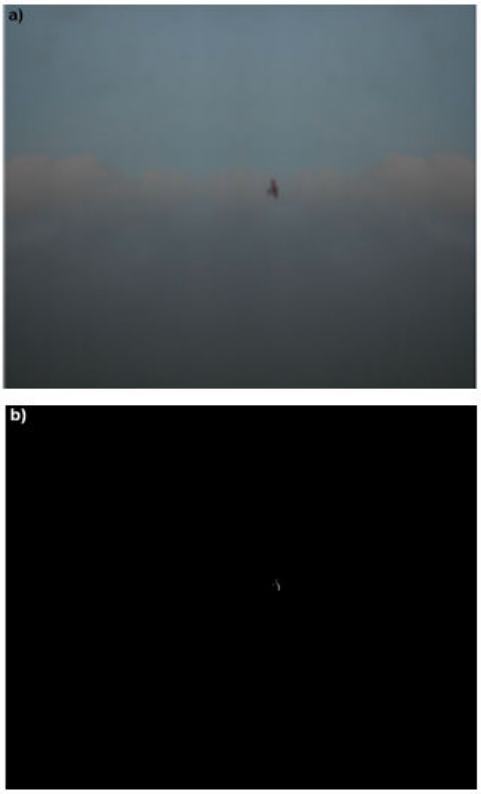

Fig. 4 Results of using Sobel's filter: a) image acquired from visonal system, b) image after filtering using Sobel's filter

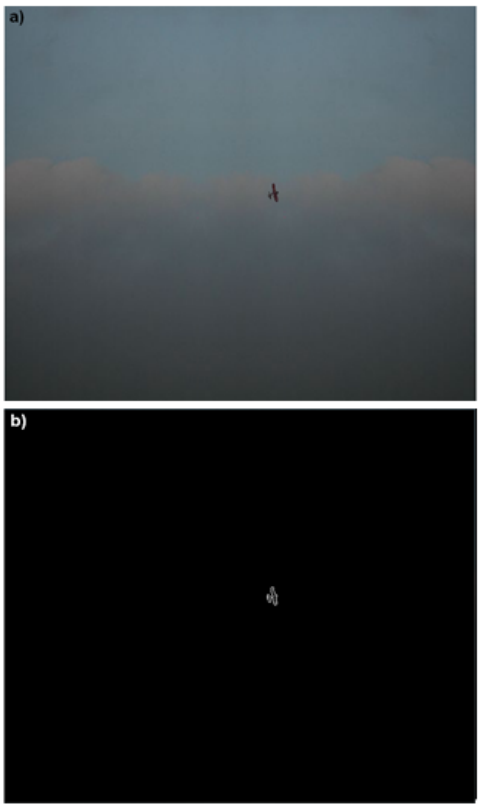

Fig. 5 Results of using Sobel's filter:
image acquired from visonal system after unplait operation, b) image after unplait operation and filtering using Sobel's filter

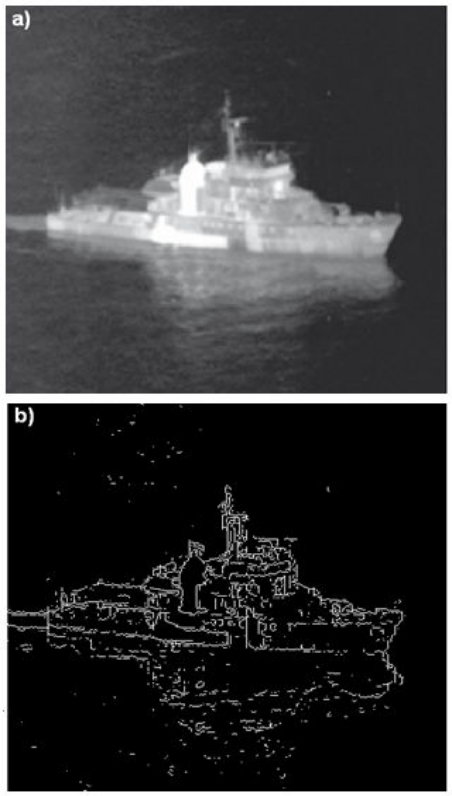

Fig. 6 Results of using Sobel's filter: a) image acquired from thermovision system and after unplait operation, b) image after unplait operations and filtering using Sobel's filter

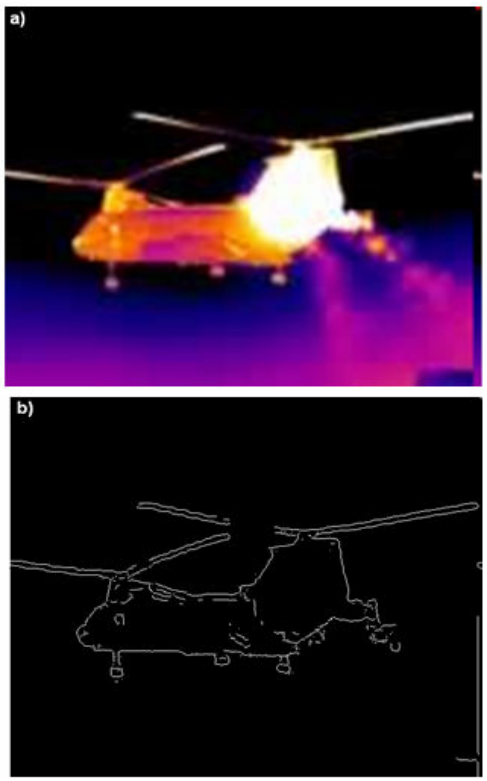

Fig. 7 Results of using Sobel's filter: a) image acquired from thermovision system, b) image after filtering using Sobel's filter

Applying the finding edges function allow in a way to eliminate the noises origin from the changed conditions of vision system which influence on quality of image processing. Figure 4 shows results of filtering images acquired from visional system using Sobel's filter. Figure 5 shows results of using Sobel's filter on the same images but previously on images the unpalit operation was executed. In turn on figure 6 and 7 the results of using Sobel's filter on images acquired from thermovisional system where presented.

V. The Module of Recognition and Identification Visional and Thermal Images

There are many methods of images recognition [1], [5]. As an identification method of chosen elements on images acquired from camera can be used the Hough's transform.
The set of collinear points (x, y) can be described as follow [7][8][9]:

$$\lambda_0 = \{(x, y) \in R^2 : y - \hat{a}x - \hat{b} = 0\} \tag{8}$$

where: $\hat{a}$ and $\hat{b}$ are the constant parameters which described the straight line.

The solution of equation $y - \hat{a}x - \hat{b} = 0$ for constant $(\hat{a}, \hat{b})$ is the set of points on surface. The feature of such calculated map $(\hat{a}, \hat{b}) \rightarrow \lambda_0$ is that, for one point in parameters space we receive the set of collinear point on picture. In order to calculate the values of parameters (a, b) of straight line which go through the given point $(\hat{x}, \hat{y})$ it should be solved the equation $\hat{y} - a\hat{x} - b = 0$ relative to (a, b). It is the same as calculation the bunch of straight lines which go through the given point $(\hat{x}, \hat{y})$. As the results of identification are taken the straight lines (a, b), which collect from the all active pixels of image the biggest numbers of vote. The expansion of this method to the detection of curved lines parametrically defined is enough simple. Points of picture (x, y) which are laying on curved line which is described by n-th parameters $(a_1, ..., a_n)$ can be presented in form as:

$$\lambda_0 = \{(x, y) \in R^2 : g((\hat{a}_1, ..., \hat{a}_n), (x, y)) = 0\} \tag{9}$$

where: $g((\hat{a}_1, ..., \hat{a}_n), (x, y)) = 0$ is the equation described the curved line.

To calculate which curved line $(a_1, ..., a_n)$ is taking the biggest vote from the active points of picture *B* the Hough transform $H(a_1, ..., a_n)$ is defined as follow:

$$H(a_1, ..., a_n) = \sum_{(x_i, y_i) \in B} h(\hat{x}_i, \hat{y}_i, a_1, ..., a_n) \tag{10}$$

where:

$$h(\hat{x}_i, \hat{y}_i, a_1, ..., a_n) = \begin{cases} 1 \; if \; g((\hat{x}_i, \hat{y}_i), (a_1, ..., a_n)) = 0 \\ 0 \; otherwise \end{cases} \tag{11}$$

As the result of such calculation the matrix is received in which every element is described by values of parameters $(a_1, ..., a_n)$. The cello f the matrix is increased by one if the curved line described by cell coordinate $(a_1, ..., a_n)$ is going through the point $(\hat{x}, \hat{y})$ of object on picture *B*. It can be accepted that Hough transform consist in to mapping the picture *B* onto matrix *A* which is called accumulator.
Presented above method can be generalized on to irregular patterns [12]. Lets make an assumption that pattern *W* can be rotated about angle α and shifted about vector $[x_T, y_T]$. In such way the given point of pattern (x_i, y_i) is transformed onto point (x_i', y_i'). So in such case the Hough transform $H(x_T, y_T, \alpha)$ for picture $B(x,y)$ can be defined as follow:

$$H(x_T, y_T, \alpha) = \sum_{(x_i, y_i) \in M_w} h(x_i, y_i, x_T, y_T, \alpha) \tag{12}$$

where:

$$h(x_i, y_i, x_T, y_T, \alpha) = \begin{cases} 1 \; if \; (x_i', y_i') \in b(B) \\ 0 \; otherwise \end{cases} \tag{13}$$

Generalized this method it can be written as:

$$h(x_i, y_i, x_T, y_T, \alpha) = 255 - |B(x_i', y_i') - W(x_i, y_i)| \tag{14}$$

Often to avoid the loss of some information about picture during its conversion onto monochromatic the Hough transform can be generalized on pictures with TrueColor type palette of colors [13]. It is made by calculating the distance between colors. The problems can be solved by calculating the distance between two points (r_B, b_B, g_B) and (r_W, b_W, g_W) which are placed in RGB cube. This distance can be defined as follow:

$$|B(x_i', y_i') - W(x_i, y_i)| = \sqrt{(r_B - r_W)^2 + (g_B - g_W)^2 + (b_B - b_W)^2} \tag{15}$$

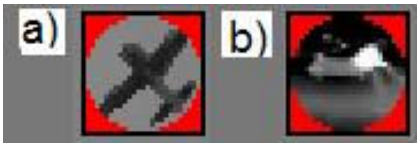

Fig.8 The patterns of objects which will be searched on images: a) optical, b) thermal

On optical and thermal images we carry out the researches using described above methods. On acquired images we were searching the patterns of objects, presented on figure 8. This

patterns were made from parts of analyzed images and saved in pattern's data base.
Researches were made on original images as well as on images after unplait operations and after using Sobel's filter. The results were presented on figures below. Also the images from thermal camera were used in this researches.

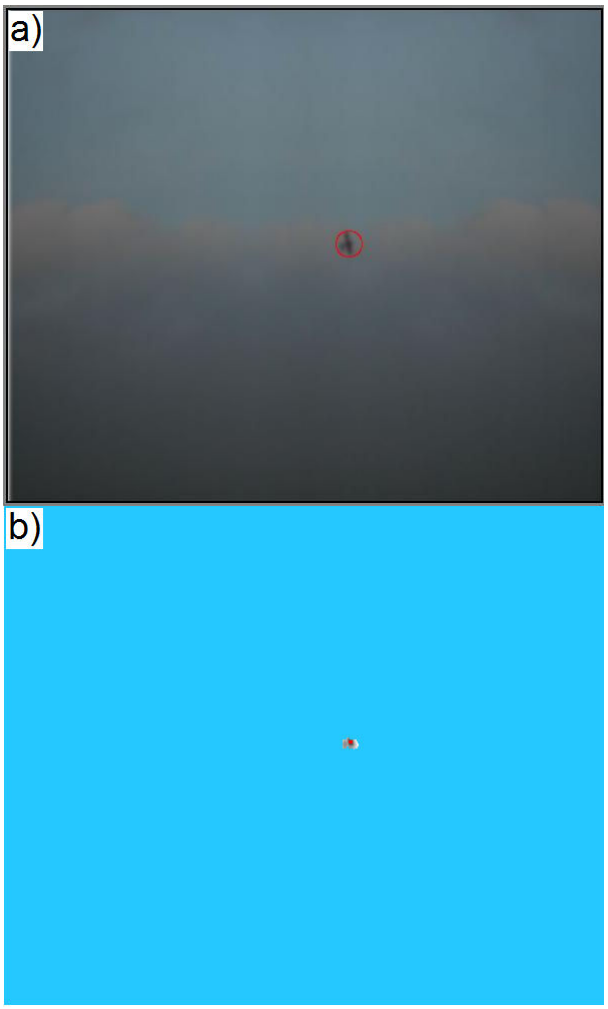

Fig. 9. Results of identification of searched object on original image a) image with pointed position of object, b) Hough Transform accumulator matrix.

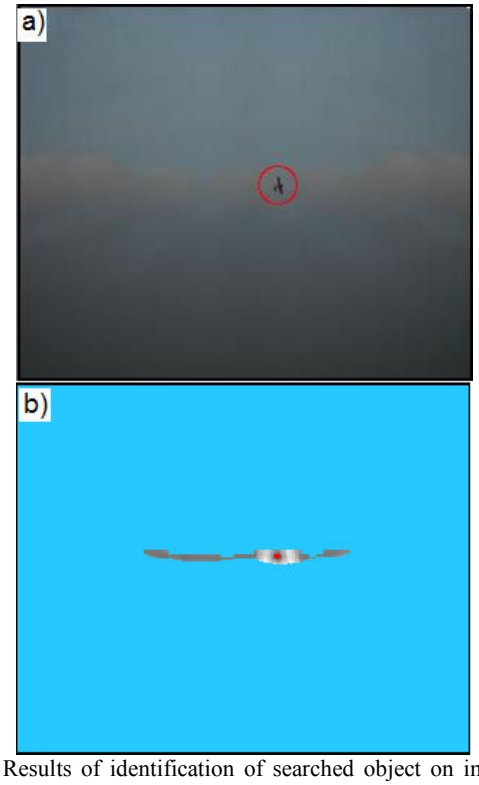

Fig. 10. Results of identification of searched object on image after unplait operation a) image with pointed position of object, b) Hough Transform accumulator matrix.

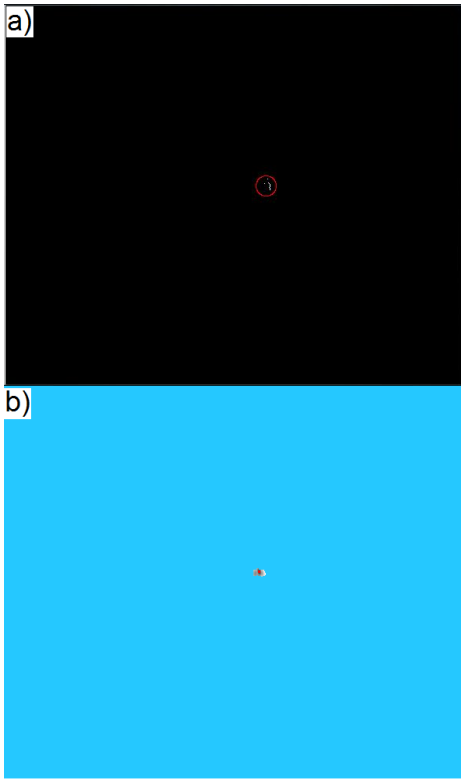

Fig. 11. Results of identification of searched object on image after using Sobel's filter a) image with pointed position of object, b) Hough Transform accumulator matrix.

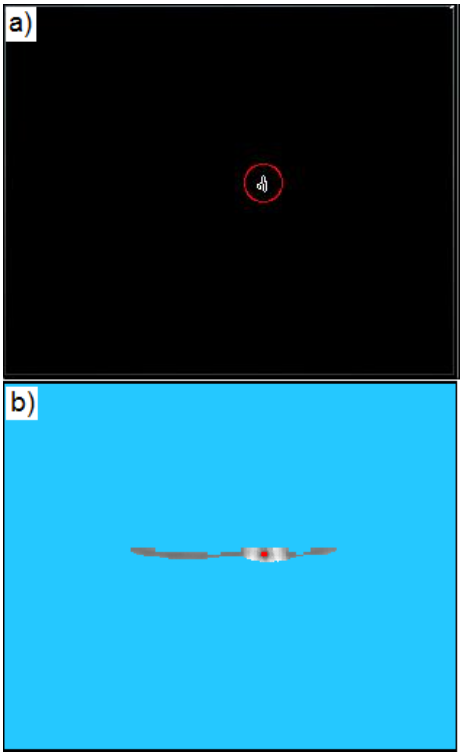

Fig. 12. Results of identification of searched object on image after unplait operation and using Sobel's filter a) image with pointed position of object, b) Hough Transform accumulator matrix.

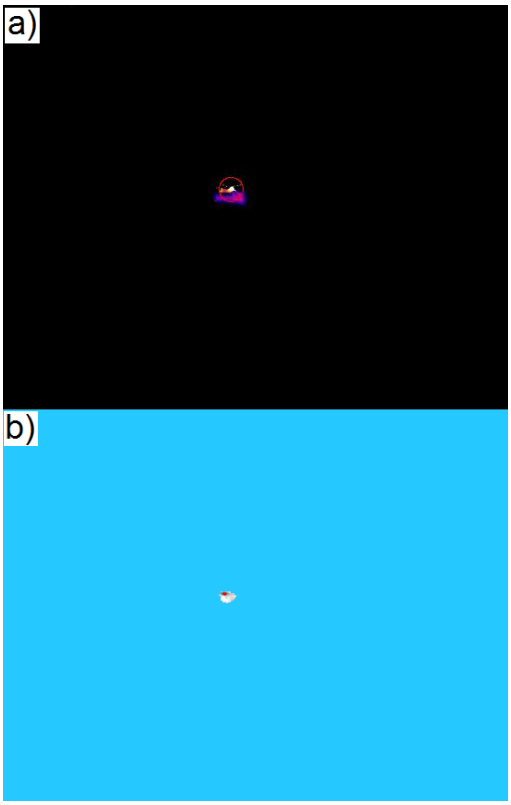

Fig. 13. Results of identification of searched object on original thermal image a) image with pointed position of object, b) Hough Transform accumulator matrix.

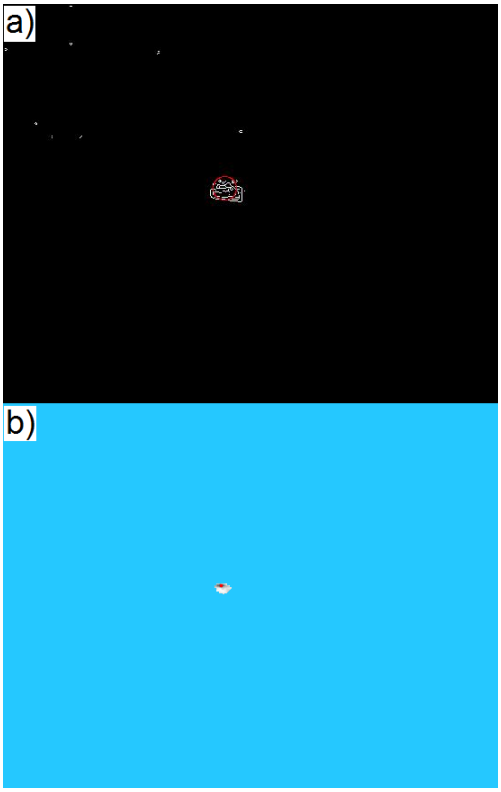

Fig. 14. Results of identification of searched object on thermal image after using Sobel's filter a) image with pointed position of object, b) Hough Transform accumulator matrix.

VI. CONCLUSION

The worked out conception of thermo-optical set is presently in project level. After end of algorithmic works, in laboratory conditions as well as in the simulated operating conditions which will be approximate to real, the verifying investigations of received methods of objects' recognition in supervised zone will be conducted. Moreover the worked out thermo-optical system allows for conducting research concentrated on thermal and optical images' filtrating, stereoscopy observation of chosen zone as well as classification, recognition and identification of object on thermal and optical images in real time. Besides this set will create possibility to investigation of thermal profiles of marine and low flying objects in laboratory imitating conditions which with large faithfulness will approximate the real conditions and also in operating conditions

Good effects of improving images quality gives preliminary processing of images using in sequence filters: high-pass, carving and gradient as well as unplait operation. It allows to emboss information about searched objects, which are important according to its identification and tracking in given space. At suitable selection of filters sequence in preliminary processing of images it is possible in analyzed image to keep classification features of searched object and the same to eliminated information which is irrelevant from the reconnaissance point of view. Such approach case the shorten of time required for analysis.

According to the results of research, it was shown that using edges filters for images acquired by optical and thermal visional systems, allows to shorten the time of object searching and image analysis at once allows for correct identification and the same tracking of chosen objects. For optical images of observed area good effects gives using Sobel's filter, because at present of 10% noise it is possible to correct identification of objects in searched space. The same results can be achieved using thermal images of observed zone.

Taking into account results of research In module of filtration and processing of optical and thermal visional information of observed zone, the algorithms which assure preliminary processing should be implemented. Especially important is to assure of realizing the unplait operation which cause improvement of acquired images quality according to noise influence. These noises are cause by lo light level especially during sundown and night as well as possibility of raining, snowing or fog occurrence. Environmental noises influence both on the quality of optical visional system and thermal imaging of observed zone. Therefore this operation should be processed for optical and thermal images.

Carried out researches confirm that Hough transform is very usability for identification of low-flying objects. Despite of changes the conditions of coastal-zone observation this method allow to skillfully identify the searched objects.

In current implementation this method allows to work on stationary images which were recorded using thermo-optical set. It is because the algorithms takes a long time to calculate images. Actually we are working on changing algorithms and its adaptation to work in real or semi-real time [5], [6].

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