

THE AIRPLANES INTELLIGENT VISUAL MONITORING SYSTEM

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Abstract:

The paper is devoted to the first stage of airplanes intelligent visual monitoring system development. The system will consist of 2 videocameras, video input, video output and video processing units (nowadays the model of the system with one camera is developed). Cameras are positioned on a two opposite sides of a landing strip in a way to provide for a visual measurement of distance from camera to a landing plane using stereoscopic method. Each videocamera inputs one frame that is digitized and transferred to the video processing unit. Airplanes are recognized and identified on each video frame during video processing. Depending on weather conditions the video processing unit can use one of a possible mixes of methods of an inputted frame digital filtering and one of two segmentation methods. When the weather conditions provide for a high contrast of an airplane on a scene it is enough to use only one of the segmentation methods to get a full airplane's silhouette. On the other hand, when there is a fog or rain and visibility is low we have to use also image filtration to make scene's contrast higher. We also get pixel coordinates of rectangular corners that contain an airplane's silhouette during segmentation. This gives us a possibility to use the stereoscopic method for a recognized and identified airplanes distance measurement.

The system can be used in airports for approaching airplanes additional automated visual control and landing when their altitude is too low for proper radar control or radar control in airport is absent at all.

Keywords: Digital image processing, Artificial intelligence, Intelligent measurement.

1. INTRODUCTION

One of the actual tasks of monitoring is airplanes recognition, identification and determination of their spatial coordinates in order to prevent emergency situations in the air and land areas of the airport because of the possibility of unauthorized access to runways. Among such unauthorized accesses are airplane landing to wrong runways, landing without keeping correct altitude and direction parameters etc. These problems are emphasized when visual monitoring of the nearby airport space is carried out in dusk or dawn, or complex weather conditions such as rain, fog, mist etc., which leads to low visibility.

Over the past decades a lot of systems were developed to improve the safety of aircraft movement in the nearby area of airports. Systems of the first generations relied on pilots and air traffic controllers. They used different identification sets, airplane's lights, light and noise signals, warning labels and more.

Systems of the latest generations use radio or GPS equipment such as: radars, active and passive identification technologies, secondary surveillance radars, Automatic Dependent Surveillance-Broadcast Systems (ADS-B);

Automatic Identification Systems (AIS); Flight Information Services (FIS); mode-s transponders etc. [1].

To the newest systems we may also include Cockpit Display of Traffic Information systems (CDTI), which only displays the information in the cockpit that is obtained from other systems and services. There are also hybrid systems that use information obtained from radar systems and information obtained by visual observation means, for example, Vocord AEROCON [2]. Vocord AEROCON system is based on a powerful computer datacenter, which processes all of the information incoming from the sensors through a computer network to collecting and processing nodes of a data center. Processed information is displayed on the air traffic controller's terminals.

The disadvantage of most of the known movement in the nearby airport's area safety improvement systems is the lack of a full visual control of the real situation, because known means provide only pseudo visual recognition of objects and pseudo visual monitoring. This disadvantage can be explained by the lack of effective methods and means of complex structured objects visual recognition on images.

Thus, the solution of airplanes visual identification and the airplanes spatial coordinates determination tasks becomes actual. As a result of these tasks solution it will be possible to design the cheap distributed computation nodes that are able to automatically detect landing airplanes and determine their coordinates. These nodes will be able to input process and transfer to the airport's personnel computers processed images of airport's nearby space scenes with marked airplanes on them with determined spatial position even in low visibility and outside the radar visibility at low altitude conditions. As a consequence, a safety of vehicles and people being in the airports nearby space will be increased.

2. VISUAL AIRPLANES RECOGNITION AND IDENTIFICATION METHODS

2.1 The digital filtration of images

The digital filtration (DF) is used to make airplanes silhouettes sharper on images that are taken in complex weather conditions such as fog, mist, etc. [3]. It is also optimized to help to acquire the entire airplanes silhouettes during further processing. DF consists of six sequential execution steps, each of which processes the image that is formed by the previous step. Execution starts from the high-frequency (HF) filtering of an inputted digitized grayscale raster image. After this, the histogram equalization of a filtered image is performed. Performance of high-frequency filtering and histogram equalization provides the scene's image sharpening. Further low-frequency (LF) filtering and image's histogram equalization reduces the variance

between object's pixels on an image, evenlier distributing the pixels with values of local maxima within the objects with a complex structure compared with known techniques, methods and operations. Repeated high-frequency filtering and histogram equalization of processed image allows us to get sharper images of the scene with the objects that are isolated by local maximum pixels values. Thus, the obtained image is characterized by low dispersion between the values of pixels within an image of each of the objects, such as airplanes, and high contrast between objects and background. The digital image filtering that is performed in such a way neutralizes the negative impact of environmental factors, increases the contrast between objects and background and increases the probability of correct entire objects with complex structure segmentation.

2.2 The binary segmentation

The digital image binary segmentation method (BS) is designed to provide an entire airplane's silhouette segmentation [3].

The BS implementation starts with the inputted grayscale image of the scene $I(x,y)$ transformation into binary image $I_b(x,y)$. Processing a binary image of the scene makes it possible to minimize the segmentation computational complexity in the computer system compared to the other color systems. In the second step, the binary image is processed by morphological opening. As a result we obtain an image $I_m(x,y)$. Morphological processing allows us to increase the probability of connected region creation from certain elements of the single object which have different levels of intensity and also decreases noise. On the third step, the binary image of the scene $I_m(x,y)$ is divided into connected regions by one of the labeling connected components methods. As a result a segmented image $I_s(x,y)$ with separated from the background and from each other labeled objects is created. During this operation all pixels of each area are assigned a unique identifier that identifies this area. On the next step we calculate an area for each of the created regions that is equal to the number of pixels with the same ID value:

$$S_c = (\sum_{x=1}^M \sum_{y=1}^N I_s(x,y)) / c, I_s(x,y) = c, \quad (1)$$

where S_c – area of labeled image's $I_s(x,y)$ region, that is defined by a set of IDs with value c , M – width of the image in pixels, N – height of the image in pixels. On the next step the regions which area is too small for further airplane recognition and identification are deleted. Connected components labeling with further regions with too small area for proper airplane recognition and identification deletion allows to leave on image only those objects which area is enough for further proper recognition and identification. On the other hand, further processing of the scene on the computational nodes is also accelerated. If there are connected regions on acquired image after deletion, then using each area's IDs coordinates circumscribing quadrilateral's upper left and bottom right point's pixel coordinates for each object are defined. Coordinates definition allows applying the method in object tracking systems, security systems and more. On the next step objects' silhouettes are segmented on the scene's image using these coordinates. Each segmented objects' silhouette

is scaled to the size of the pre-trained artificial neural network's (ANN) input creating so the image $I_o(f,g)$, where $f = \overline{1, W}$, $g = \overline{1, H}$, where

$$w = \left\lceil \max(\max(\frac{Wp_i}{Hp_i}, \max(\frac{Lp_i}{Hp_i})) + 0.5) * H \right\rceil, \quad (2)$$

where $i = \overline{1, N}$, N – total amount of airplanes models that are identified; W – width of airplane's image in pixels; H – height of airplane's image in pixels; Wp_i , Lp_i , Hp_i – linear dimensions of width, length and height of i -th airplane model in meters accordingly. Value H is chosen experimentally during ANN designing in a way to provide acceptable ratio between airplane recognition and airplane identification error to the time of recognition and identification processes execution on a target computer means.

2.3 The grayscale-binary segmentation

The digital image grayscale-binary segmentation method (GBS) is designed to provide more precise entire aircraft's silhouette segmentation than the binary segmentation method.

The GBS execution starts with a grayscale inputted image $I(x,y)$ morphological opening. As a result an image $I_q(x,y)$ is obtained. Further the grayscale morphological reconstruction of the image $I_q(x,y)$ using the image $I(x,y)$ is performed. As a result an image $I_r(x,y)$ is obtained. These two steps increase the contrast of airplanes' silhouettes with a background and reduce heterogeneity inside the silhouettes. This increases the probability of obtaining the airplane's solid silhouette comparing to the BS during segmentation of less contrast images. Binarizing the resulting image we obtain an image $I_b(x,y)$. The binarized image is processed using morphological closing creating an image $I_m(x,y)$. Further operations are performed as described for BS starting from the step 3.

GBS in the joint application with DF up to 10% reduces airplanes false omissions (see Table 1) compared to other combinations of methods. However, unlike the BS it has a much higher time complexity due to the use of morphological image reconstruction.

2.4 The recognition and identification methods

Each of the 4 developed methods of airplanes recognition and identification performs recognition and identification in two stages (see Table 1, 2). On the first stage airplanes recognition among multiple airplanes silhouettes separated from the background and other objects by means of an ANN is performed. Identification is performed only after successful airplane recognition. Identification by means of ANN is performed using grayscale silhouette of an airplane obtained after an inputted image digital filtration or obtained from an unprocessed inputted image (if filtration was not performed). Only a region with detected airplane is analyzed. This minimizes the impact of background noise and noise objects on the identification process.

2.5 The coordinate measuring method

For stereoscopic object's spatial coordinates determination method realization two cameras which are in different points and register the same scene are needed. The pair of images which are obtained are named stereopair. Single cameras are located in the way that their optical axes are parallel, and a line which passes through optical centers is perpendicular to optical axes. Let length of base is even b . The coordinates system's start O is located on a datum line in the middle between the optical centers of cameras, the OZ axe is parallel to optical axes, and the OX axe is directed along a datum line (figure. 1). Then the coordinates start point in the planes of cameras images coincide with the main points of $u_0 = v_0 = 0$, and coordinates measurements units in the global system and in the videocamera's image planes are identical $w = h = 1$.

Object's point M has global coordinates (X, Y, Z) . Coordinates of this projection in the image plane of the first (left) camera will mark as (x', y') , second (right) camera – through (x'', y'') (The projections of the same point M in the different cameras' images planes are named conjugating points).

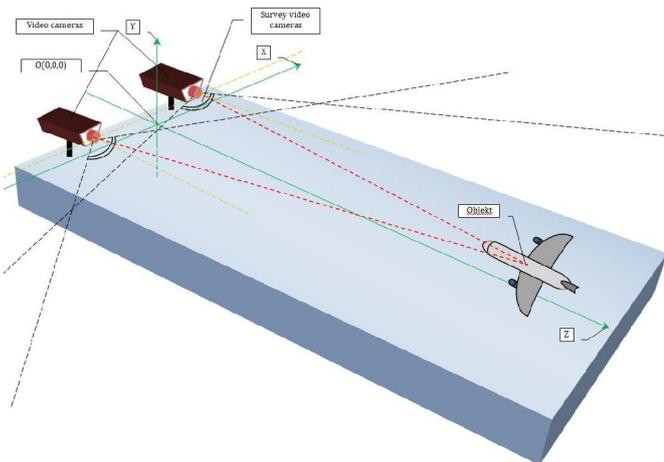


Fig. 1. Representation of airplane is in space using the stereoscopic method.

$$x' = f \left(X + \frac{b}{2} \right) / Z, \quad x'' = f \left(X - \frac{b}{2} \right) / Z, \quad y' = y'' = fY / Z \quad (3)$$

The coordinates of conjugating points (y – coordinate) are congruent. It matters very much when the automated search of the stereopair's coherent points is performed. This allows substantially shorten the sizes of search area. It goes out from the first two correlations (3), that:

$$Z = fb / (x' - x'') \quad (4)$$

It means that, knowing geometry of survey and executing measuring of projections' coordinates the same point in the cameras image planes, it is possible to calculate the depth (Z coordinate) of this point. Moreover, the obtained correlations allow calculating the three-dimensional coordinates of the point fully:

$$X = b \frac{(x' + x'')}{2(x' - x'')}, \quad Y = b \frac{(y' + y'')}{2(x' - x'')} \quad (5)$$

3. THE MODEL OF THE AIRPLANES VISUAL RECOGNITION AND IDENTIFICATION SYSTEM

On the Figure 2 the visual airplanes identification system's hardware-software model with one camera connected is shown. The implemented model is based on standard modules MC56F8367EVM and ADSP-BF533 EZ-KIT Lite. It consists of:

- the PAL CCD videocamera, which inputs video sequence of a scene on which it is necessary to recognize and identify airplanes;
- the input video sequence node that performs analog-to-digital conversion of inputted analogue video sequence from videocamera;
- the module MC56F8367EVM on which basis the input/output node of the system's model is implemented;
- the processed scene output node which performs airplane labeling inside informative part of analog video signal;
- the module ADSP-BF533 EZ-KIT Lite on which basis the scene processing node is implemented.

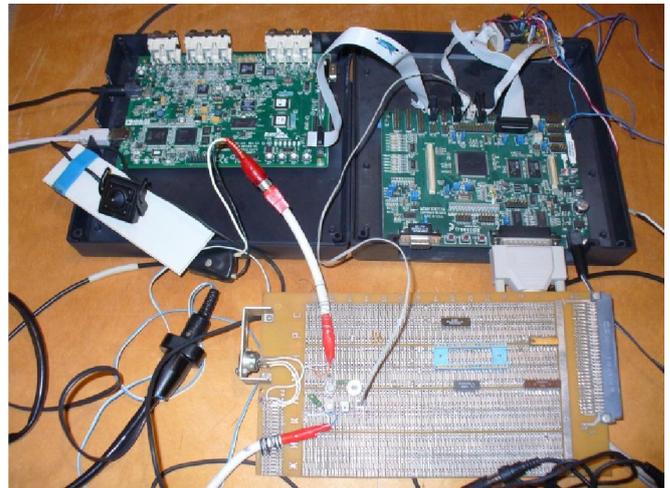


Fig. 2. The visual airplanes identification system's hardware-software model with one camera connected.

The visual airplanes identification and coordinates determination system's hardware-software model with two video cameras connected is the next stage of the airplanes intelligent visual monitoring system development.

4. RESEARCH OF THE DEVELOPED METHODS

3.1 The research of the airplanes recognition and identification methods

The results of designed recognition and identification methods modeling is shown in tables 1 and 2.

Table 1.

| The probability of airplane recognition | | | | |
|---|--------------------|-----|-----------------|-----|
| | Without filtration | | With filtration | |
| | BS | GBS | BS | GBS |
| Landing (cloudy) | 97% | 46% | 93% | 97% |
| Manoeuvring (fog) | 0% | 0% | 85% | 95% |
| Takeoff (clearly) | 97% | 50% | 95% | 97% |

Table 2.
The probability of airplane identification after its recognition

| | Without filtration | | With filtration | |
|-------------------|--------------------|-----|-----------------|-----|
| | BS | GBS | BS | GBS |
| Landing (cloudy) | 82% | 39% | 79% | 82% |
| Manoeuvring(fog) | 0% | 0% | 75% | 77% |
| Takeoff (clearly) | 82% | 41% | 80% | 81% |

The research of the developed methods was carried out using MatLab IDE and developed hardware-software model of the visual airplanes identification system on the test video sequences with landing (328 frames), maneuvering (820 frames) and takeoff (360 frames) of Antonov Company's airplanes obtained in different weather conditions.

The research showed that all of the developed methods are sensitive to their operations' parameters such as filters characteristics, structural elements for morphological operations, binarization threshold, the determined value of airplane's silhouette size enoughness for its correct recognition and identification, parameters of artificial neural networks and others.

In particular, the use of DF is appropriate in bad weather conditions or when airplane's silhouette has textural heterogeneity that does not allow performing a complete airplane's silhouette segmentation without additional inside-silhouette smoothing. However, this often leads to an increase of false recognition due to extracting the artificially created scene's elements that are similar to the binary silhouettes of the airplanes.

The methods that are using the BS are focused on rapid recognition and identification of airplanes on a simple background, for example, the image of an approaching airplane on the sky background. In this case, the background is simple and the fastest system reaction is required due to the high speed of the airplane. The method that uses the DF and the GBS is focused on the recognition and identification of airplanes on a complex background in conditions of poor visibility and contrast. It increases the probability of recognition and identification due to reaction rate of computer vision system reduction. Using the DF without the GBS is unappropriated because of the small value of probability of airplane recognition and identification and higher computational complexity than the BS has.

3.1 The research of the coordinate determination method

The coordinates determination method modeling was carried out using images obtained from 640×480 pixels resolution videocameras and MatLab IDE. For simplicity of calculations we will accept, that video cameras acquire one object only.

For the object's spatial coordinates determination it is necessary to choose desired coordinates from the frame buffer. Coordinates system of images in this buffer we'll consider as the base global coordinates system.

On the entrance of the program there is an image that has been obtained in a result of the object obtaining from the frame buffer. The frame, that is shown on the figure 3 a), is

obtained from the first videocamera in which the selected object is as one pixel painted out in a black, and it is placed in such frame buffer's coordinates: $x=50$, $y=70$. On the figure 3 b) – result from the second videocamera, here an object is located in coordinates $x=-180$; $y=70$.

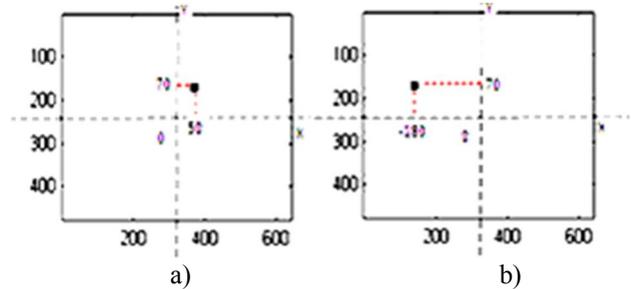


Fig. 3. The results of the coordinates determination method modeling.

The point $M(X, Y, Z)$ will be the result of a spatial coordinates determination process. Its spatial coordinates values vector in current case is equal to $(-50, 70, 50)$.

As we see, this algorithm does not require special mathematical calculations (if video cameras do not have the distorted lenses) and for its storage it is enough 1.77 Kb of the system's program memory.

4. CONCLUSIONS

The first stage of the airplanes intelligent visual monitoring system is implemented. At this stage, the airplanes recognition and identification methods, airplanes' spatial coordinates determination method and the visual airplanes identification system's hardware-software model with one camera connected are developed. The next step is to develop a model of visual airplanes identification and positioning system with two videocameras.

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