Low Distance Airplanes Detection and Tracking Visually using Spectral Residual and KLT Composition

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Abstract
This paper presents the method for detection and tracking airplanes which can be observed visually in low distances from sensors. They are used widely for some reasons such as military or unmanned aerial vehicle (UAV) because of their ability to hide from radar signals; however they can be detected and viewed by human eyes. Vision based methods are low cost and robust against jamming signals. Therefore, it is mandatory to have some visual approaches to detect airplanes. By this way, we propose spectral density for airplane detection and KLT algorithm for tracking. This approach is a hybrid of two distinct methods which have been presented by researchers and used widely in detection or tracking specific objects. To have accurate detection, image intensity would be adjusted adaptively. Correct detected airplanes would be achievable by eliminating some long optical flow trajectory in image frames. The proposed method would be analyzed and evaluated by comparison with state of the art approaches. The experimental results show the power of our approach in detection of multiple airplanes unless they become too small in presence of other objects and multiple airplanes. We make some test by implementing our approach on an useful database presented by some researchers.

Keywords: Airplane Detection; Spectral Density; KLT Method; Adaptive Image Adjusting.

1. Introduction

Nowadays visual aircraft detection is one of the interesting subjects in image processing projects because of the wide usage of low distance and low altitude airplanes. These kinds of airplanes are applied in military purposes, airplane industries and training. Unmanned Aerial Vehicle (UAV) is used for espy, mapping, taking picture, etc. and is utilized by many countries. Since keeping borders against unwanted imposition, study of constructed airplanes and monitoring their behaviors are necessary for industries and governments, many researchers spend their time on some subjects such as visual approach. The means of Visual approach are tracking and detection by some sensors which work as like as eyes, such as cameras. Images must be processed, analyzed and utilized by image processing and computer vision techniques. By this way, we can have some information about the object.

In this paper, spectral residual of image is applied to extract salient regions that indicate the most plausible regions of objects. Since the purpose of the paper is to track airplanes in sky we need to search for airplane features and track them. Blob analysis is common in tracking and is used for objects detection and clustering in video frames. Blobs are commonly extracted by morphological approaches that utilized in some researches such as [1]. In this research, blobs are extracted from salient regions extracted from spectral residual and analyzed by their aspect ratio. All of the probable regions for airplane existence are extracted and used for tracking by famous KLT (Kanade-Lucas-Tomasi) algorithm that has been discussed in [2]. All of the good features for tracking are extracted and tracked by KLT method and followed frame by frame in video sequence. The detection procedure, spectral density extraction and blob analysis, is repeated every 7 frame to find new airplanes and remove unwanted events because of noise, clouds, birds, etc. The diagram of the proposed approach was illustrated in Fig. 1.

We made a wide range of experiments and evaluated the method by comparing with state of the art method. For this reason, the aircraft database presented in [3] was used for experiments and comparisons.

The rest of the paper is summarized as follow. In the next subsection; related works, some methods are presented discussed before for detection and aircraft tracking. Section 2 is about proposed approach. Experimental Results are presented in section 3. The final section summarizes overall discussion.

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1.1 Related work

In literature, there are researches about tracking that state of the art survey has been reported in [4]. The common step for tracking is feature selection that has been received a lot of attention by researchers. Common features which are used for visual tracking are color, edges, optical flow, SIFT, HOG, and texture. In [5] edges were used for tracking. SIFT and HOG feature are described for object detection in [6,7] and were used by authors in [8,9] for tracking. Optical flow presented in [10] is very popular for tracking and has been proposed as the main feature for tracking in some literatures such as [11].

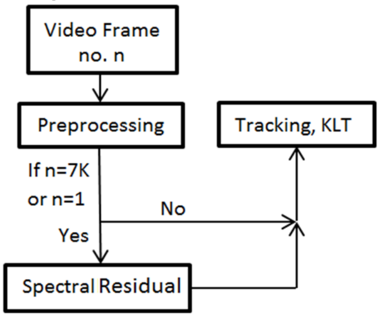

Fig. 1. Diagram of proposed approach.

Object detection is one of the basic concepts that can be introduced through tracking task. In this case the object is detected and localized in images. There are some researches in object detection that human detection and tracking is the main purpose of the authors [12]. In this case, HOG features were proposed with SVM classifier for human or pedestrian detection. In [13] color was proposed for face detection and tracking.

Airplane is favorite object that researchers pay attention on it. Radar signal cannot detect some low altitude flying objects but they can be observed by human eyes and tracked. Therefore, some visual approaches need to be investigated for tracking. In [9] optical flow discussed for image registration in stereo vision applications. Optical flow has a lot of application in tracking. In [2] a method has been described by authors, KLT, that optimizes the performance of optical flow. KLT uses good features for tracking extracted from corners. KLT method was used for tracking in [3]. Although optical flow and KLT method is good for tracking tasks, object tracking remains challenging when we face some unwanted events such as camera movements and illumination changes. Based on some efforts to overcome these failures, some techniques such as histogram equalization have been presented. Kalman Filter is a searching tool that has been presented to predict the interest object in video frame and has been used in [15]. However Kalman filter can detect and predict the object, it can be used for one target or object and will fail to track multiple objects. Mean Shift searching is a clustering algorithm which was proposed for tracking the interest object in [16]. The most problem in mean-shift algorithm is the time consuming process for clustering in each frame. Furthermore, the algorithm will be failed in presence of multiple objects near each other. Thus, blob analysis that is derived from background reduction and morphological processes is more common [1]. Occlusions are uninteresting events that make tracking tasks too challenging, because, two or more objects will be counted as just one object. To have an accurate tracking and detection some patch based approaches have been suggested in [12]. Patches establish a dictionary or codebook that contains object features. This bag of features is classified and used for feature matching and searching. In some works, researchers' aims are to detect targets from aerial vehicles. In this case they are looking for interest objects by template matching [12]. The model of the object which has been stored is used for matching.

When all is said and done, there are some challenging events in tracking such as image blurring coming from camera movements, occlusion, luminance changes, and changing colors in different frames that researchers present techniques to compensate these flaws. In this paper an approach is tried to be presented to have a robust airplane detection and tracking.

2. Proposed Approach Steps

The aim of this section is to provide the proposed algorithm to detect and track airplanes visually in some steps. During the detection process we need to compensate unwanted events such as noise, occlusion and false positives to have an accurate detection. This section is divided in 3 subsections to cover authors' concept.

2.1 Preprocessing

The first step in most image processing and computer vision tasks is preprocessing. It is concluded with image enhancement, color transformation, image adjusting, filtering, etc. that prepares the image for further processes. In this paper we present an adaptive image adjusting that separate image objects based on their intensities. To remove noise from image median filter is applied and the resulting image would be sent to next step.

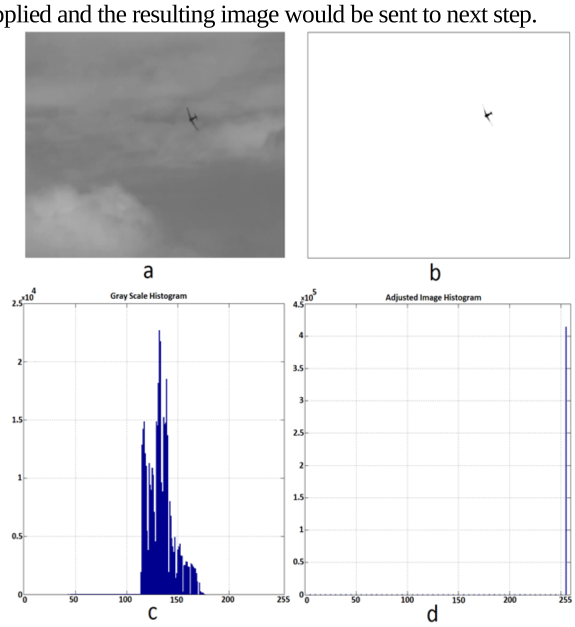

Fig. 2. Histograms of adjusted image. a) Gray scale original image, b) adjusted image, c) histogram of the gray scale original image, d) histogram of adjusted image

Image adjusting is stretching the desired range of image intensity histogram to new area or rang to highlight interesting regions and objects. Adaptive adjusting is proposed to achieve a good result in video frames. For this reason histogram of image intensity is extracted in each frame. Since airplanes in sky occupy a small part of images, airplane intensities cover small fraction of image. By this way, the histogram of the image contains with large amount of sky intensities and small amount for airplanes. Image adjusting would be useful for further process to segment airplane from background. As we know, airplanes are observed in sky with different intensities or color from background. By adjusting the image, the intensities of airplane would be distributed during all of the intensity range, [0 255], and rest of them will be concatenated in 255 or 0. If background intensity be higher than desired range they move to 255 otherwise they move to 0. Fig. 2 shows the histograms of the images intensities. This figure illustrates the original image in gray scale (a), adjusted image (b), histogram of gray scale (c) and histogram of adjusted images (d). As we can see from the figure, airplane has been bolded in adjusted image and background has been removed.

In most of the images some unwanted objects would be extracted. Noise causes these events. Although image adjusting shifts noise intensity to undesired range, some of them have intensities in the range of airplane intensities and would be appeared in image. According to speckle or salt and pepper noises in video images, median filter has a good performance for noise reduction. Therefore, in this paper two dimensions median filter is implemented to remove noises.

2.2 Spectral residual

The aim of the object detection is to find interest object and extract it from background. There are researches in object detection which use particular feature of targets such as edges [17], local appearance [18], etc. Since extracting these kinds of features is time consuming in video processing and training stage is needed to train object's information, general purpose saliency detection is required. Saliency detection is presented in this paper based on the efforts of Hou et al [19]. In [19] log spectrum has been presented for saliency map extraction.

$$L(f) = \log(A(f)) \tag{1}$$

In above equation, *A(f)* is the amplitude of Fourier transform of image. According to the experiments in [19], average spectrum can be approximated by convoluting the input image:

$$Av(f) = h_n(f) * L(f) \tag{2}$$

Where $h_n(f)$ is an n×n matrix defined as below:

$$h_n(f) = \frac{1}{n^2}\begin{bmatrix} 1 & 1 & \dots & 1 \\ 1 & 1 & \dots & 1 \\ \vdots & \vdots & \ddots & \vdots \\ 1 & 1 & \dots & 1 \end{bmatrix} \tag{3}$$

Spectral residual *R(f)* could be achieved by:

$$R(f) = L(f) - Av(f) \tag{4}$$

Saliency map would be available in spatial domain of image by Inverse Fourier Transform. Saliency map contains with specified areas which can be used to interpret expected portions of the image. Saliency map is illustrated by Eq. (5).

$$S(x) = F^{-1}\left(\exp(R(f) + P(f))\right)^2 \tag{5}$$

Where *P* denotes to phase or angle of Fourier transform, and F^{-1} is inverse Fourier transform. As discussed in [19], a threshold is applied to segment image and detect proto-objects in saliency map.

$$O(x) = \begin{cases} 1 & ifS(x) > threshold \\ 0 & else \quad where \end{cases} \tag{6}$$

In our experiments, the threshold is set to 10×(average intensity).

Although saliency map and segmentation help us to remove background and extract most probable regions for object, some unwanted objects or false positives would be extracted because of clutters in natural images. To compensate this kind of faults we implemented aspect ratio of aircraft to extract them in image. Aspect ratio is defined as the ratio of length to width. The result of this operation would be an image containing the most probable regions of the object. Fig. 3 illustrates saliency map and segmented image after setting a threshold, and extracted the most probable regions by implementing aspect ratio. As the Fig. 3 shows, some undesirable regions are detected in segmented saliency map. This event is unavoidable because of the differences of intensities of objects with background.

2.3 Tracking

KLT (Kanade-Lucas-Tomasi) tracking algorithm is a common tracking algorithm that has been presented in [2] and is used widely in all of the tracking tasks. Optical flow which was discussed by Kanade-Lucas in [10] was optimized by Shi-Tomasi [2] by selecting good feature for tracking. The below equation is describing the motion between two consecutive frames in video.

$$I(x, y, t+\tau) = I(x-a, y-b, t) \tag{7}$$

In the equation, *I* represents the image intensity, *t* and τ are time and difference of time between two frames respectively, *a* and *b* are increments of dimensions in frame of time *t*. Images have some noises which they are imposed in frames and could be aggregated to Eq. (7).

Therefore, Eq. (7) can be calculated to minimize the noise (n).

$$n = \iint_W \left[I(x-a, y-b, t) - I(x, y, t+\tau) \right]^2 w(x,y) dxdy \quad (8)$$

In the above equation, w(x,y) indicates to weighting function and W is the window of searching. According to reports in papers [2, 3], we set the weight to unity. Since displacement is small relative to searching window, this equation can be rewritten by Taylor series approximation as below. Furthermore, we don't inter time symbols to formulas because displacements are needed for this reason.

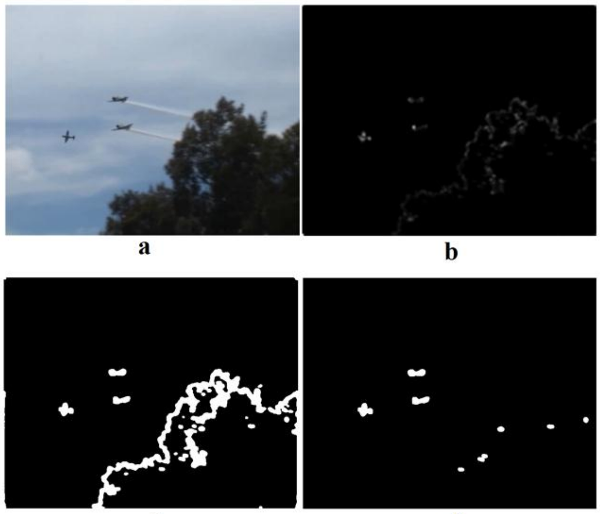

Fig. 3. Saliency map extraction using Spectral Residual. a) natural image, b) spectral residual, c) resulted image after threshold, d) resulted image using aspect ratio criteria.

$$I(x-a, y-b) \approx I(x,y) - a\frac{\partial I}{\partial x}(x,y) - b\frac{\partial I}{\partial y}(x,y), \quad (9)$$

$$g = \begin{bmatrix} \frac{\partial I}{\partial x} & \frac{\partial I}{\partial y} \end{bmatrix}^T \quad (10)$$

$$I(x-a, y-b) \approx I(x,y) - g.D, \quad D = (a,b) \quad (11)$$

By substituting these approximated series, Eq. (8) would be rewritten as below.

$$n = \iint_W \left[I(x,y,t) - g.D - I(x,y,t+\tau) \right]^2 dxdy \quad (12)$$

$$n = \iint_W \left[F - g.D \right]^2 dxdy$$
$$F = I(x,y,t) - I(x,y,t+\tau) \quad (13)$$

To find displacement, *D*, the Eq. (13) must be differentiated respect to *D* and set to zero.

$$\iint_W \left[F - g.D \right] g dxdy = 0 \quad (14)$$

$$\iint_W gg^T D dxdy = \iint_W F g dxdy$$
$$GD = H \quad (15)$$

$$G = \begin{bmatrix} \frac{\partial^2 I}{\partial x^2} & \frac{\partial^2 I}{\partial x \partial y} \\ \frac{\partial^2 I}{\partial x \partial y} & \frac{\partial^2 I}{\partial y^2} \end{bmatrix} \quad (16)$$

Fig. 4. Airplane Detection. Airplanes' contours and centers are shown by red color

Based on the Shi and Tomasi's definition in [2], if λ_1 and λ_2 are the eigenvalues of matrix G, the best features for tracking would satisfy the relation, min(λ_1 and λ_2)>λ_{th}, which threshold is obtained from uniform intensity regions. By this way, corners and highly textured of image is extracted.

In this paper we suggest to extract and track good features by KLT algorithm from regions that are obtained from spectral residual stage. It is time saving for us to track and extract specific points and regions. Furthermore, detection would be more accurate. The probable problem comes from segmented salient map which some unwanted regions or objects are extracted as Fig. 3. To remove such clutters we suggest two solutions. As we know moving camera and stable camera are two strategies which used for tracking. In stable camera clutters and false positives are from flying objects, although some small camera movements can cause this event. To overcome camera movement fault we remove all of the small optical flow lower than threshold. In airplane tracking using moving camera the goal is to maintain the airplane in middle of the scene, therefore all false positive events come from static objects and have bigger optical flow thus, they can be eliminate by setting a threshold.

It can be seen from the Fig. 1 images are moved to tracking block after passing through preprocessing stage and spectral residual. In some conditions which two or more airplanes occlude each other, or new airplanes come to the scene, it is needed to have a detection stage to find and localize airplanes. Therefore, spectral residual is implemented to every 7 frame. We choose every 7 frame arbitrarily which based on our observation and experiments in the database, it is a significant choice to find coming airplane to the scene. Thus, based on the application or database, it can be changed. Other frames don't need any detection or spectral residual extraction process and airplanes would be tracked by KLT algorithm and their features are obtained from previous regions from segmented saliency map. By this way a fast, accurate, and reliable tracking process would be obtained.

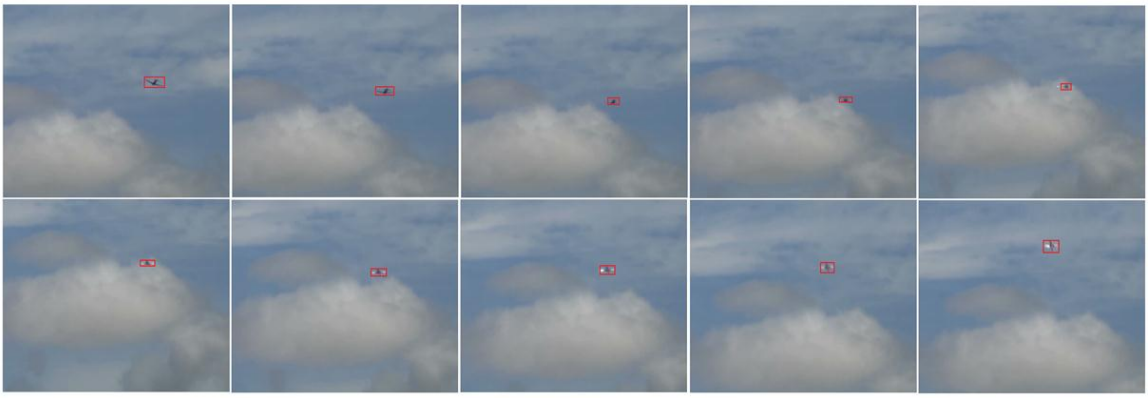

Fig. 5. Consecutive s step frames of an aerobatic airplane

3. Experimental Results

We examine our proposed approach by making some experiments on common database presented in [3], and compare it with state of the art methods and results show the acceptable performance of our approach in detection and tracking. Fig. 4 shows some example of the database. It can be seen from Fig. 4 that the database contains with variety scenes of airplanes such as occlusion, and multiple in various sizes.

The database has been collected in AVI format. All of them are at the rate of 25 frames per second and frame size of 720×576 pixels. 27 videos less than 1 minute and 4 sequences in low resolution 640×480 exist in the database. As mentioned before, several types of airplanes, jet, aerobatic, fighter, transport, and propeller with occlusion, pose variations, and multiple planes. All of them include the camera movements and optical zoom.

In this paper we specify the detected objects by their contours at every 7 frame. It is achievable because we use spectral residual for detection. Fig. 4 illustrates detected airplanes in various scenes. The centers of the detected objects are shown by a red plus sign. Good features are extracted from these regions and tracked by KLT algorithm. The tracked objects are shown by a rectangle such as Fig. 5.

We implemented our method by MATLAB using a Pentium dual core 32 bit PC with 2.60 GHz CPU and evaluated by experiments on all of the sequences in the database and compare with [3] that authors use KLT with Haar features, state of the art methods such as Kalman Filter using appearance model which was discussed in [13], Mean Shift clustering as presented in [16] and GMM model as like as [1]. These methods are used widely for tracking tasks. Table 1 shows the tracking results and process time and compares our method with them.

We used tracking accuracy to evaluate tracking performance. It means the number of correctly tracked airplanes per total number of airplanes in frames or sequences. Furthermore, frame would be considered as unsuccessful tracking process if some false positives be detected and tracked or airplanes are not detected. Therefore, tracking accuracy would count the total tracked airplane properly without any false positives. To achieve the best criteria for comparison, we compare our method with others with their optimum parameters and their best accuracies.

3.1 Comparisons

In many researches GMM is used and modeled based on the RGB space and extracts foreground from background. As it can be observed from table 1, Tracking Accuracy using GMM is not better than our proposed method and False Positive is relatively high. The high false positive is inevitable because GMM uses blob analysis mainly that is very sensitive to unwanted objects such as clouds, birds, and buildings in airplane database.

Kalman Filter is one of the famous approaches for tracking and estimating the most probable region of presence of the object such as approach in [13]. Kalman Filter is based on the Gaussian distribution and can support the single peak but it is modified by GMM to find more peaks and objects. As it can be seen from Table 1, it has an accuracy 79% . As aforementioned, it is obvious that Gaussian distribution and blob analysis is responsible for occurring false positives and making worse process.

Mean Shift clustering is used widely in tracking process [16]. It is working properly in some tasks that camera is stable and false positives can be removed by background subtraction. To achieve the reasonable accuracy some additional processes are needed to decrease the false positives. Then, the complexity and the process time would be increased. Table 1 shows that the process time of our method is reasonable.

In [3] the author is presenting an approach to track and detect airplane. In this paper Haar feature is used to detect object that is a famous feature in face detection tasks. KLT algorithm is used for tracking. Since the Haar feature use intensity of the object it makes mistake by extracting regions such as clouds or birds in some frames and causes false positives.

In our proposed approach, we use spectral residual and aspect ratio for object detection. Since moving camera tries to locate airplanes at middle of the screen, false positives are removed by eliminating high optical flows. Furthermore, detection is repeated every 7 frame as we mentioned in section 2-3, and all of the airplanes are detected and tracked. Process time and tracking accuracy of our approach are reasonable and better than other state of the art methods.

As Fig. 4 shows, top right airplane, our method has better accuracy than presented approach in [3] which uses this sequence as the challenging video. The paintings on the airplane caused some problems in detection and tracking in [3], although the airplane is detected and tracked accurately by our proposed method in most of the frames. Fig. 5 shows some consecutive frames of tracked airplane in one of the sequences. The airplane in this sequence has various positions and the cloud exists in sky. The airplane has different intensities in sequences which would be challenging for detection but image adjusting makes all of the parts and intensities belonging to the airplane more available and spectral residual make a reliable saliency map for detection.

3.2 Faults and limitations

We encounter some detection problems in the database. These faults come from very small or far airplanes, noises, occlusions or camera movements.

One of the limitations in our work is the camera movements. Camera movements are not very critical problem but in some cases it would have disruptive effects on. Since the data base contains with videos from moving camera we eliminate large optical flows during tracking process. Therefore, in some cases which the camera cannot follow the object some good points would be removed. As Fig. 6 illustrates, an airplane are divided in 3 parts and every part may be detected as an airplane. Another limitation is about the size of the object. Fig. 6 illustrates that our algorithm would not track successfully if the flying object is too far from the camera. This fault comes from the Spectral Residual and aspect ratio parameters for noise elimination.

Fig. 6. Two samples of fails of our proposed approach.

4. Conclusion

In this paper we proposed a method with several stages to track airplanes. They are image adjusting, spectral residual or saliency map extraction, and tracking using state of the art method KLT algorithm. Our method has the ability to detect multiple objects in several scales, accurate, with reasonable speed. We evaluated our method by making experiments by aircraft tracking dataset. In this research we faced problems which they affected the tracking and detection processes. They come from camera movements which cause multiple detection of an airplane, very far away airplanes that they are observed very small, and occlusions.

For future, we have a plan to overcome the discussed problems and have a more reliable technique for tracking. Some training approach such as SVM would be useful to have an accurate tracking in presence of occlusion and other unwanted events. Furthermore, some features such as HOG would be significance for object recognition. Furthermore, some matching approach can be utilized. Detecting and tracking small flying objects are other problem that would be in our next research proceedings.

Table 1. Comparing tracking Results

	Tracking Accuracy	Process Time Per Frame
Our Method	86%	0.09
[3]	82%	0.09
GMM	80%	0.1
Kalman Filter + Appearance	79%	0.09
Mean Shift Clustering	80%	0.12

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