Light Source Target Detection Algorithm for Vision-based UAV Recovery

Dae-Yeon Won* and Min-Jea Tahk**
Division of Aerospace Engineering,
School of Mechanical, Aerospace and Systems Engineering
Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Korea 305-701

Eun-Jung Roh* and Sung-Sik Shin******
UAV Group, Korea Institute of Aerospace Technology, Korean Air,
Daejeon, Korea 305-811

Abstract

In the vision-based recovery phase, a terminal guidance for the blended-wing UAV requires visual information of high accuracy. This paper presents the light source target design and detection algorithm for vision-based UAV recovery. We propose a recovery target design with red and green LEDs. This frame provides the relative position between the target and the UAV. The target detection algorithm includes HSV-based segmentation, morphology, and blob processing. These techniques are employed to give efficient detection results in day and night net recovery operations. The performance of the proposed target design and detection algorithm are evaluated through ground-based experiments.

Key Word : Target detection, BWB UAV, Vision-based recovery

Introduction

There has been an increased emphasis on the use of UAVs (unmanned aerial vehicles) in various activities for both civilian and military applications. Such applications include surveillance, reconnaissance, target tracking, data acquisition, jamming, communications relay, decoy or harassment. Recent improvements in sensor technology, data processing, and actuator systems make possible the development of small UAVs under 30 kg. For small UAVs, a blended-wing-body (BWB) UAV is an innovative tactical UAV concept. BWB UAV has an alternative airframe design which incorporates design feature from both a traditional tube and wing configuration. The potential advantages of the BWB UAV are efficient high-lift wings and wide airfoil-shaped body.

With the rapid progress of UAV systems in recent years, the autonomous system of UAVs has reached a stable phase in the following areas: stability and control augmented system, way point navigation and guidance. However, autonomous flight control system design for the fixed-wing UAV landing is still one of the challenging problems. Since a number of conditions such as stall speed, wind speed, relations between kinetic and potential energies should be considered in the fixed-wing UAV landing phase, it still requires dependency on human operators.

* Ph. D. Student
** Professor
E-mail : mjtahk@fdcl.kaist.ac.kr Tel : +82-42-869-3718 Fax : +82-42-869-3710
*** Researcher
**** Senior Researcher

On the other hand, the review and analysis of UAV accident data [1] from the FAA Civil Aerospace Medical Institute indicated that the percentage involvement of human factors issues varied across UAVs from 21% to 68%. Also, 47% of the Hunter accidents and 68% of the Pioneer accidents involved an error by the human operator during landing. Thus, it is recognized that most UAV accidents during recovery is attributed to operator failure. This point shows that the importance of developing the safe UAV recovery system.

In this paper, vision-based net recovery concept by using light source targets is proposed. This operation is designed for small and narrow landing zone. The proposed light source target design is available in day and night. In addition, it gives more information needed to central guidance with single on board camera.

This paper is organized as follows: in the first section, the vision-based net recovery concept is presented. The second section proposed light source target design for net recovery phase. In the third section illustrates the light source target detection algorithm with experiment results. The final section summarizes the overall discussion.

Vision-based Net Recovery

This vision-based net recovery is performed when a manual runway recovery is not available because of open-field recovery environments. The vision-based net recovery mode can be activated under the assurance of 100m correction distance. After the activation of the vision-based recovery mode, the blended-wing body UAV will be guided to predetermined recovery point by autopilot systems. The vision camera mounted on the vehicle detects the recovery net and its light source targets for precision terminal guidance.

In the automatic landing of BWB UAV using the net recovery system, UAV could automatically fly into a net for recovery as shown Fig. 1. Recently, optical sensing payloads such as Day Light TV(DLTV), mini panoramic camera, Forward Looking Infra Red(FLIR), and Infra Red Line Scan(IRLS) are added to UAV systems to search an arbitrary target [2]. These optical sensors might be used to detect a net for recovery. In application of a net recovery system, it is a critical requirement that the lateral deviation error from the center of a net location and the lateral acceleration of the vehicle is perfectly eliminated to minimize the damage to the vehicle.

The operation mode of vision-based net recovery phase is designed by considering specifications of BWB UAV and its landing environments. Table 1 shows the vision-based net recovery phase overview.

Table 1. Vision-based net recovery phase overview

Operation mode	Vision-based recovery
Recovery method	Net recovery
Altitude (m)	0-20
Velocity (m/s)	10
Operation time (sec)	10
Distance (m)	100

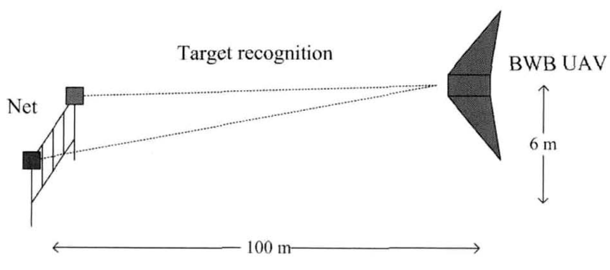


Fig. 1. Vision-based BWB net recovery concept

Table 2. Visual information requirements

Distance (m)	Altitude (m)	Visual information
100-60	20-10	Target Detection (center guide)
60-30	10-5	Target Detection (Euler angles, Distance, Center guide)
30-0	5	Center hold

The visual information listed in Table 2 indicates requirements of vision-based control system output for landing guidance in each stage.

Light Source Target Design

In this research, we use two light source targets composed of high-brightness LEDs, because LEDs have gained widespread use in lighting application and now can be found nearly everywhere. Also, much higher brightness LEDs have been established by special deposition techniques [3]. This opens up many new applications such as traffic light, backlighting displays and automotive lighting. Since LEDs maintain more stable state and reduced required power, we employ high-brightness LEDs for light source target design. They have good recognition properties in day and night. The proposed light source targets have green LEDs for the right target and red ones for the left target. Each target has 12 x 12 LEDs and 27 cm x 36 cm size. Its input voltage is 12 V and input current is from 20mA to 50mA. The red and green targets with red LEDs are shown in Fig. 2.

The light source targets are attached to the right and left ends of the top of net frame as shown in Fig. 3. Net frame is 6 m tall x 6 m wide and net is 3 m height and 6 m wide.

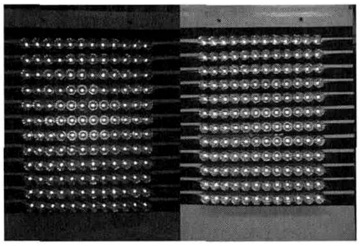


Fig. 2. Red and Green High brightness LED targets

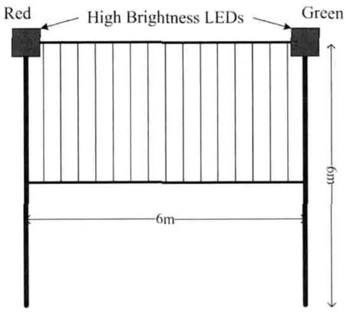


Fig. 3. Light source target frame

Target Detection Algorithm

Detection of the light source target means extraction of the red and green light sources in given images from a CCD camera. Since the light source target is distinguished from other features under its operation environments, we can extract the position of the light source in camera images. If we can find clear distinctions between the light source target and other features, we will decide the position of the target exactly. To extract the target clearly, we propose the target detection algorithm which includes threshold, morphology, and blob filtering process.

HSV based segmentation

The first step of the detection algorithm is the HSV-based image segmentation method.

HSV represents the hue, saturation and value. HSV color model is one of the alternate representations of RGB (red, green and blue). HSV improves the color cube representation of RGB by arranging colors of each hue in a radial slice, around a central axis of neutral colors which ranges from black at the bottom to white at the top [4].

HSV models paint mixture, with its saturation and value dimensions resembling mixtures of a brightly colored paint with, respectively, white and black. Since the HSI color model is close to human intuition, it is widely used in computer graphics, particularly as color pickers in image editing methods. The mathematical transformation from RGB to HSI can be computed in real time, and given by the following equations.

$$H = \cos^{-1}\left\{ \frac{0.5\left[(R-G)+(R-B)\right]}{\left[(R-G)^2+(R-B)(G-B)^{1/2}\right]} \right\} \tag{1}$$

$$S = 1 - \frac{3}{(R+G+B)}\left[\min(R,G,B)\right] \tag{2}$$

$$V = \frac{1}{3}(R+G+b) \tag{3}$$

The purpose of segmentation is to categorize each HSV pixel in a given image as having a color in the specified range or not. In order to achieve this classification, it is necessary to have a measure of similarity [4]. In this method, the Mahalanobis distance is employed for the measure of specified range. The Mahalanobis distance is based on correlations between variables by which different patterns can be identified and analyzed [5]. It is used to determine similarity of unknown pixel set to a known one. It differs from Euclidean distance in that it takes into account the correlations of the sample image set and is scale-invariant. The Mahalanobis distance between vectors **z** and **m** is given by

$$D(\mathbf{z},\mathbf{m}) = \left[(\mathbf{z}-\mathbf{m})^T C^{-1}(\mathbf{z}-\mathbf{m})\right]^{1/2} \tag{4}$$

m is the average color denoted by the HSI vector. It is obtained by estimating target sample images. **z** denotes an arbitrary point in HSI space. C is the covariance matrix of the target sample images we wish to segment. The loci of points satisfying Eq. (5) describe a solid 3-D elliptical body with the important property that its principal axes are oriented in the direction of the maximum data spread as illustrated in Fig. 4. The resulting image by light source segmentation is the binary image.

$$D(\mathbf{z},\mathbf{m}) \le T \tag{5}$$

where T is threshold.

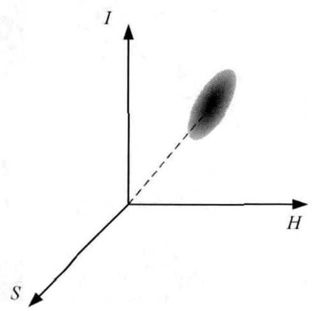


Fig. 4. Mahalanobis distance approach for enclosing data region for HSI vector

In this approach, computation of the average **m** and covariance matrix **C** is done using day and night sample images of target. Because **m** and **C** values represent the properties of the target, these values play an important role in the overall performance of the detection algorithm.

Morphology

The second step is the morphological operations called erosion and dilation. These operations are fundamental to morphological processing. The erosion operator erodes away the boundaries of regions of foreground pixels, while the dilation enlarge the boundaries of regions of foreground pixels. This step is used to eliminate irrelevant details on the binary image. Undesirable remaining segments in previous image processing are eliminated in this step.

Blob processing

The final step of the target detection algorithm is the blob filtering. Blobs obtained on the resulting binary image from the segmentation step represent possible features of the light source target. Blobs are countered by the connect component labeling with 4-neighbors or 8-neighbors. Then we discard the blobs with less than minimum-area threshold and more than maximum-area threshold. The minimum and maximum areas are user-defined parameters and can be decided from the camera focal length and target size. If there are more than two blobs after blob filtering, the detection algorithm chooses the largest blob for the target.

Fig. 5 shows the image processing results on the red light source target image taken by vision camera. It can be seen that light source target is detected precisely by proposed algorithm.

Experimental Results

The proposed target design and detection algorithm are validated by performing ground-based experiments. Sample images of the light source target are taken by X420 CCD color camera in day and night. The properties of X420 CCD color camera are as follows:

- Resolution: 640px x 480px
- 1/4-inch CCD
- 34X optical zoom lens
- Auto focus
- Shutter speed control

The mean and covariance of HSV color properties for the red and green LEDs are measured from more than 9 sample images in three different distances. The mean and covariance matrix in day and night are given in Table 3. These values are normalized so they are lie between 0 and 255.

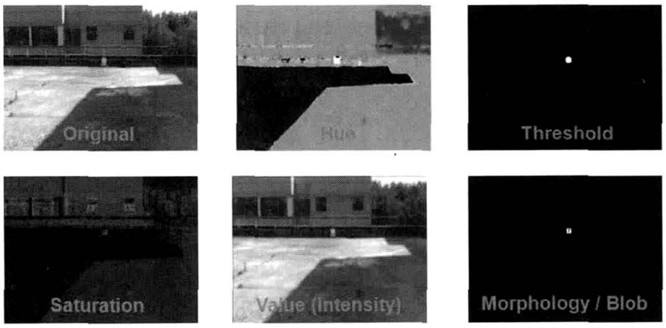


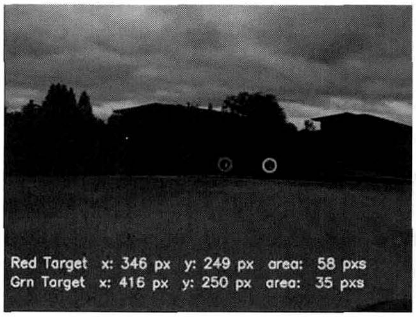
Fig. 5. Image processing results on the red light source targe image

Table 3. HSV color properties of Light source target.

Target Property	Day (1/3000 sec shutter speed)	
	Red	Green
Mean	$[122.4 \quad 188.4 \quad 113.0]^T$	$[67.6 \quad 141.0 \quad 42.7]^T$
Covariance	$\begin{bmatrix} 0.0653 & -0.0002 & -0.0008 \\ -0.0002 & 0.0004 & 0.0000 \\ -0.0008 & 0.0000 & 0.0004 \end{bmatrix}$	$\begin{bmatrix} 0.0145 & -0.0006 & -0.0020 \\ -0.0006 & 0.0003 & 0.0008 \\ -0.0020 & 0.0008 & 0.0034 \end{bmatrix}$
Target Property	Night (1/800 sec shutter speed)	
	Red	Green
Mean	$[141.5 \quad 197.4 \quad 123.9]^T$	$[69.7 \quad 166.4 \quad 70.3]^T$
Covariance	$\begin{bmatrix} 0.0087 & 0.0002 & 0.0004 \\ 0.0002 & 0.0004 & 0.0000 \\ 0.0004 & 0.0000 & 0.0003 \end{bmatrix}$	$\begin{bmatrix} 0.0157 & 0.0000 & -0.0003 \\ 0.0000 & 0.0002 & 0.0001 \\ -0.0003 & 0.0001 & 0.0004 \end{bmatrix}$

Table 4. Ground-based experimental results.

Target Detection	Day		Nigh	
	Red	Green	Red	Green
Success (frame)	141	71	144	156
Fault (frame)	4	67	13	1
Fail (frame)	9	16	3	3
Total (frame)	154	154	160	160



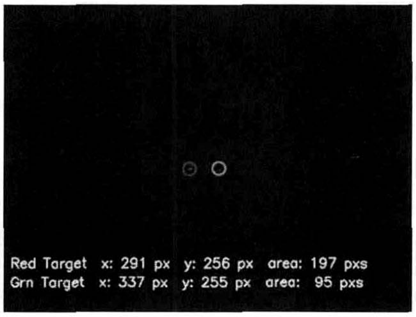


Fig. 6. The light source target detection results in day(left) and night(right)

The proposed detection algorithm is implemented by Microsoft Visual Studio 6.0 with OpenCV library. OpenCV library provides many popular image processing and computer vision algorithms in C/C++ languages[6]. In the ground-based experiments, the camera is attached to the car moving at 15m/s while it approaches the target. The detection algorithm is activated at more than 100m distance from the target. Fig. 6 shows the results of the target detection algorithm during approach.

Table 4 presents the results of ground-based experiments. Because the light source is distinguishable in dark environments, the algorithm shows better performance in night experiments than day experiments. Since the nature of light properties is different during between day and night, the camera shutter speed and input voltage to the target should be adjusted according to the operation time to make the target detected well. In day operation, high shutter speed and input voltage are required. On the other hand, low shutter speed and input voltage are required during night operation to avoid light-intensity saturation.

Also, it is seen from the Table 4 that fault/fail detection rate of the green LED target is much higher than the red LED target in day operations. This results is caused by trees behind the target. Since the hue property of the green LED target and trees is at a close range, the detection algorithm cannot classify the target and trees clearly in day operations. On the other hand, street lamps are obstacles of the red LED detection in night operations.

Thus, to improve the performance capability of the proposed detection algorithm, the user-defined parameters of the image processing algorithm including Mahalanobis distance, minimum and maximum blob areas should be chosen appropriately, depending on the operation environments.

Conclusions

This paper is concerned with the light source target design and detection algorithm for vision-based blended wing body UAV. We present the target design that can be applied to a net recovery operation in open field environments. This target is composed of red and green high-brightness LEDs available during day and night operation. The proposed detection algorithm includes color segmentation based on Mahalanobis distance with HSV color model, morphology operators, and blob filtering. Experimental results of the proposed method demonstrate the effectiveness and performance with its image processing algorithm. The findings from the proposed method suggest developing an efficient recognition net recovery target design by using light sources. The idea of light source target design can be extended to other vision-based control applications. Further work being undertaken includes flight experiments.

Acknowledgement

The authors gratefully acknowledge for financial support by Korea Ministry of Knowledge Economy.

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