

Visual-Based Guiding Method for Unmanned Helicopter Approaching to Landmark

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Abstract—This paper proposes an image-guided method for estimating the position of an AUH (autonomous unmanned helicopter) from one captured landmark image. The proposed method is intended for application as auxiliary information for the guidance of an AUH during approach of a landmark based landing. The relation between the camera position and landmark image can be analyzed by projective geometry with the provision of sufficient landmark features. ANFIS is utilized for establishing the mapping relation and establishing a fuzzy model for efficient camera position estimation. The proposed method provides a highly accurate method of AUH guidance during landmark approach.

Keywords—camera position estimation; visual-based guiding; ANFIS; incomplete landmark image

I. INTRODUCTION

Unmanned aerial vehicles (UAVs) are very useful systems for aerial photography, gas pollution detection or military applications. UAVs could potentially replace human beings in the completion of many difficult tasks. Because of their ubiquitous uses, the theories and applications of UAV systems have become popular contemporary research topics. There are many types of UAVs with different functions. Generally UAVs can be divided into two major categories, fixed-wing type and rotary-wing type. The fixed-wing UAVs can carry out long-distance and high-altitude reconnaissance missions. However, flight control of fixed-wing UAVs is not easy in low-altitude conditions. Conversely, rotary-wing UAVs can hover in low-altitude while conducting surveys, photography or other investigations. Consequently in some applications, the rotary-wing type UAV is more useful than the fixed-wing UAV. One common type of rotary-wing type UAVs is the AUH (Autonomous Unmanned Helicopter). AUHs have characteristics that include of 6-DOF flight dynamics, VTOL (vertical taking-off and landing) and the ability to hover. These

attributes make them ideal for aerial photography or investigation in areas that limit maneuverability.

In recent years, there has been a lot of research interested in a more intelligent design of autonomous controllers for controlling the basic flight modes of unmanned helicopters [1] – [3]. The controller design for AUHs requires multiple sensor feedback signals for sensing states of motion. One of the basic flight mode controls of unmanned helicopters is landing. The most commonly used sensors are IMU (Inertial Measurement Unit) and GPS (Global Positioning System). The IMU provides three-axis angular velocity, and the GPS provides three-axis position information. For landing control, the height and pose of an unmanned helicopter are very important. There is a statement in [4] that the desired downward velocity is proportional to the square of the height. However, GPS error can range up to 6 meters [5]. This is much larger than the size of small unmanned helicopters and the landmark, both of which are usually measured in centimeters. Such large erroneous GPS measurements weaken the accurately landing ability of small unmanned helicopters. This paper will focus on the development of a position estimation method for that provides greater accuracy of position information for the guidance of unmanned helicopters during the approach to the landmark. The schematic diagram is shown in Fig. 1.

One of the guiding sensors is an image system which is usually collocated with IMU and GPS in the outdoor environment. The image system has been used on vehicles for navigation, obstacle avoidance or position estimation. In [6], the algorithm to extract the edge of the runway for computing the position of airplane was proposed. In [7] – [9], the image-guided methods with two or more images for guiding the RC unmanned helicopter approaching to the landmark are discussed. It is obvious that multiple-camera measurement system is an effective and mature method. However, the

payload of the small unmanned helicopters has to be considered. Hence the image system is the smaller the better. In [10] and [11], image sequences are used to estimate the position of an unmanned helicopter. We developed a method for estimating the camera position from only a single image. Based on the estimated information, the unmanned helicopter can be guided to land autonomously.

The parking apron of a helicopter is in the shape of circle with an 'H' inside it. There are some recognition algorithms designed for recognizing the 'H' of the landmark [12], [13]. For the purpose of landing small unmanned helicopters autonomously and safely, the relative position between the small unmanned helicopter and the landmark has to be considered. Consequently, we propose a method for estimating the camera position from a single image. Referring to Fig. 1, when the unmanned helicopter is approaching the landmark, the camera position can be described by R , θ and Q .

Obviously, the measurement of spatial information from one image is very difficult. However, the relation between the camera position and landmark image can be analyzed by projective geometry. The proposed method for estimating the camera position from one image is illustrated in Fig. 2. In this method, we select sufficient features of the landmark image

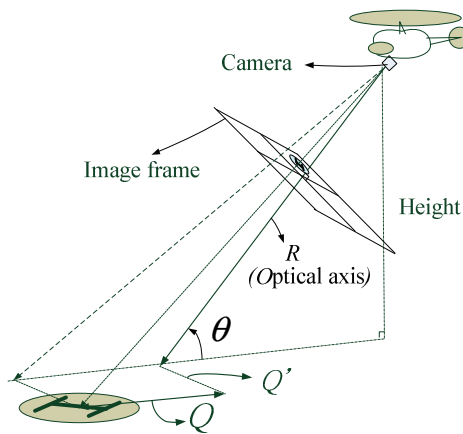


Fig. 1. The AUH approaching to landmark.

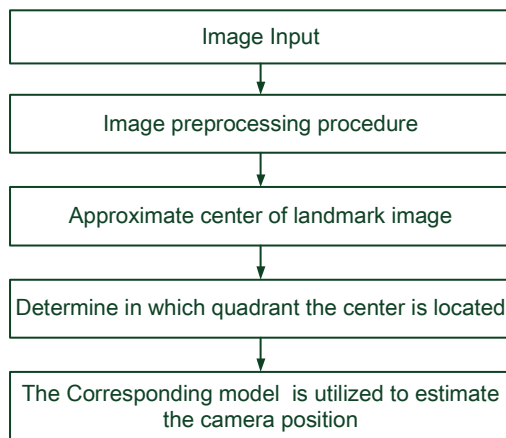


Fig. 2. The method of camera position estimation from landmark image.

which can be related to the camera position. The mapping relation established by projective geometry is very complicated and the amount of data is substantial. Therefore the database is divided into four parts so as to reduce the size of the database by considering which quadrant the “center” of the landmark image is located in. The ANFIS is utilized for learning the database and establishing a fuzzy model of the mapping relation.

In Fig. 2, the four major processes of the method are illustrated. The first step is “Image preprocessing procedure”. In this procedure, the captured landmark picture is preprocessed into a clear and intact shape, and the binary image is computed to decrease the computation time. The second step is “Computing the approximate center of the landmark image”. Since the landmark image is seriously deformed, the label ‘H’ on the landmark is employed for calculating the projection of the landmark center. The third step is “Determine in which quadrant the center is located”. In this step, the approximate center is used to represent the location of landmark image. The last step is “Estimate the camera position with corresponding model”. The camera position can be estimated quickly using the fuzzy model obtained by the ANFIS.

In the section of experimental results, different deformation cases of the landmark image are considered. Distortions that occur when the camera is at different shooting positions are simulated. The simulation is helpful for observing landmark image features. Moreover, the basic rectangle of the landmark image, corner detection, and the calculation of approximate center of landmark are demonstrated in the experimental results. The training results of ANFIS and camera position estimation results are demonstrated at the end of this paper.

II. ANALYSIS OF IMAGE FEATURES VIA PROJECTIVE GEOMETRY

In this research, we consider the case of an unmanned helicopter approaching a landmark during landing. Fig. 3 illustrates the projection of the landmark diameter and the relation between the camera and the landmark. The landmark can be projected onto the image frame through the camera center [14]. The most obvious feature of the landmark is the diameter. The projection of the landmark diameter can be divided into vertical and horizontal directions. The projection cases specific to vertical direction and horizontal direction will be discussed in the following subsections.

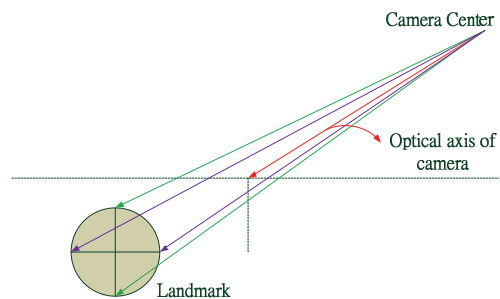


Fig. 3. The center projection of the landmark.

A. Landmark image features projection in the horizontal direction

We will first consider the projection case of the horizontal diameter. In Fig. 4, the plane π is perpendicular to the optical axis, and π is located somewhere on the optical axis. Here, π is equivalent to the image frame. In addition, from Fig. 4, the landmark diameter is projected onto π and the projection of the landmark radius r is $\hat{m}$ and $\hat{n}$ in the vertical and the horizontal directions, respectively. The geometric projection relation between landmark radius r and $\hat{m}$, $\hat{n}$ is shown as Fig. 4. The distance P and B are

$$P = \sqrt{R^2 + H^2}, \quad (1)$$

$$B = \sqrt{(Q+P)^2 + H^2}, \quad (2)$$

respectively. Where H is the altitude of camera and R is the distance from the camera center to the ground.

To analyze the projection relations in Fig. 4, three regions, named Ψ_1 , Ψ_2 and Ψ_3 , in the shape of triangle, are employed. They are shown as colored regions in Figs. 5, 6, and 7, respectively. Consider the case of Fig. 5, region Ψ_1 is a triangle with several angles in it. The angles could be computed with trigonometric functions. The derivation of the angles are (3) and (4).

$$\begin{cases} \alpha_1 = \tan^{-1}((Q'+r)/B) \\ \alpha_2 = \tan^{-1}(Q'/B) \\ \alpha_3 = \tan^{-1}((Q'-r)/B) \end{cases} \quad (3)$$

$$\begin{cases} \beta_2 = \alpha_1 - \alpha_2 \\ \beta_1 = \alpha_1 - \alpha_2 - \beta_2 \end{cases} \quad (4)$$

Next, the region Ψ_2 is shown in Fig. 6. There are three angles γ_1 , γ_2 and γ_3 in this region. The derivation of the angles is (5). Similarly, B' can be computed with trigonometric functions and γ_1 , γ_2 , γ_3 .

$$\begin{cases} \gamma_1 = \tan^{-1}((Q+P)/H) \\ \gamma_2 = 90 - \theta \\ \gamma_3 = \gamma_1 - \gamma_2 \end{cases} \quad (5)$$

Finally, the third region Ψ_3 is illustrated in Fig. 7. In this figure, the projections of the landmark radius r are $\hat{m}$ and $\hat{n}$ which can be obtained by (6) and (7).

$$\begin{cases} Q'_{proj} = B' \tan^{-1}(\alpha_2) \\ e = B' \tan^{-1}(\alpha_3) \\ f = B' \tan^{-1}(\alpha_1) \end{cases} \quad (6)$$

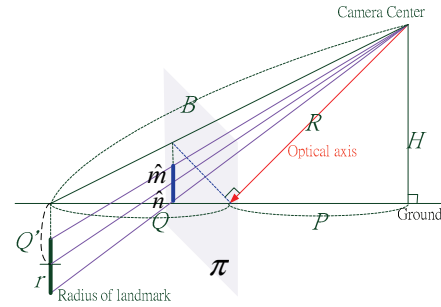


Fig. 4. The center projection of the landmark image features in horizontal direction.

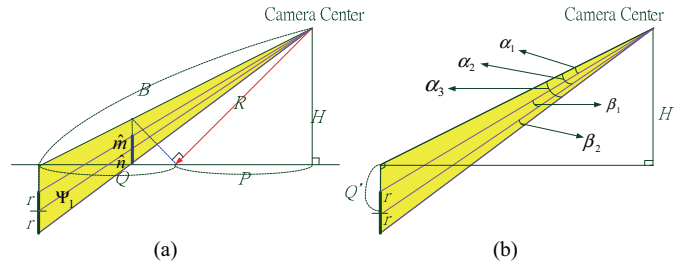


Fig. 5. Image features analysis in region Ψ_1 . (a) The region Ψ_1 referring to Fig. 4. (b) The important angles α_1 , α_2 , α_3 and β_1 , β_2 in region Ψ_1 .

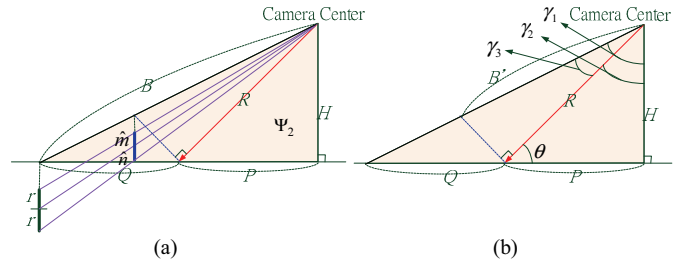


Fig. 6. Image features analysis in region Ψ_2 . (a) The region Ψ_2 referring to Fig. 4. (b) The important angles γ_1 , γ_2 and γ_3 in region Ψ_2 .

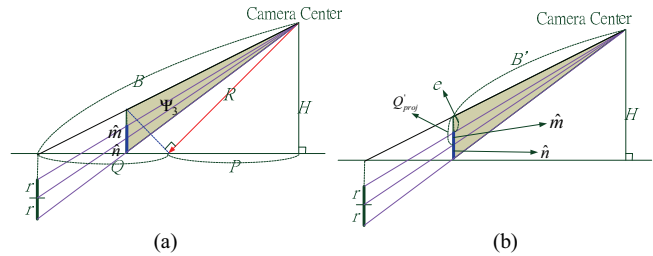


Fig. 7. Image features analysis in region Ψ_3 . (a) The region Ψ_3 referring to Fig. 4. (b) The landmark radius r , and its projections $\hat{m}$ and $\hat{n}$.

$$\begin{cases} \hat{m} = Q'_{proj} - e \\ \hat{n} = f - Q'_{proj} \end{cases} \quad (7)$$

B. Landmark image features projection in the vertical direction

In the case of landmark image features projections in the vertical direction, the geometric analyses will be more complicated than those of the horizontal case. However, the projection of the image features can be obtained by similar methods. In Fig. 8, the landmark radius is projected onto the plane π and form g_5, g_6 .

The projective geometry illustrated in Fig. 8 will be discussed in terms of five distinct regions. One of them is named Ω_1 , and as shown in Fig. 9, is a triangle. Three of them are triangles containing the vertical red lines individually, named Ω_2, Ω_3 , and Ω_4 , as shown in Fig. 10. And the last is a ladder-shaped region, named Ω_5 , as shown in Fig. 11.

Consider the colored region Ω_1 shown in Fig. 9(a). Many useful quantities including angles and line segments can be computed from the region Ω_1 . From Fig. 9(b), the angles obtained by (8) can be used to compute the line segments in Figs. 9(c) and 9(d) by equations (9)-(11).

$$\begin{cases} \omega_1 = \tan^{-1}((P+Q+r)/H) \\ \omega_2 = \omega_1 - \gamma_2 \\ \omega_6 = \tan^{-1}((P+Q-r)/H) \\ \omega_3 = \omega_1 - \omega_6 \\ \omega_7 = \tan^{-1}((P+Q)/H) \\ \omega_4 = \omega_1 - \omega_7 \\ \omega_5 = \omega_1 - \omega_6 - \omega_4 \\ \omega_8 = \omega_6 - \gamma_2 \end{cases} \quad (8)$$

$$\begin{cases} e_3 = R * \tan(\omega_2) \\ e_4 = R * \tan(\omega_8) \\ e_5 = R * \tan(\omega_8 + \omega_5) \\ e_1 = e_5 - e_4 \\ e_2 = e_3 - e_5 \end{cases} \quad (9)$$

$$\begin{cases} k_1 = \sqrt{(P+Q+r)^2 + H^2} \\ k_2 = \sqrt{(P+Q)^2 + H^2} \\ k_3 = \sqrt{(P+Q-r)^2 + H^2} \end{cases} \quad (10)$$

$$\begin{cases} u_1 = \sqrt{R^2 + e_3^2} \\ u_2 = \sqrt{R^2 + e_5^2} \\ u_3 = \sqrt{R^2 + e_4^2} \end{cases} \quad (11)$$

From the triangles $\Omega_2, \Omega_3, \Omega_4$ in Fig. 10 and the results obtained from equations (9)-(11), one can obtain q_1, q_2 and q_3 by (12).

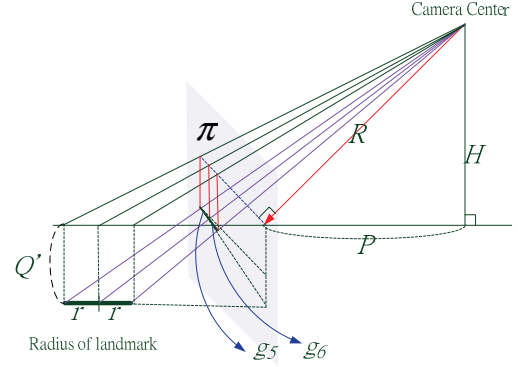


Fig. 8. The center projection of the landmark image features in vertical direction.

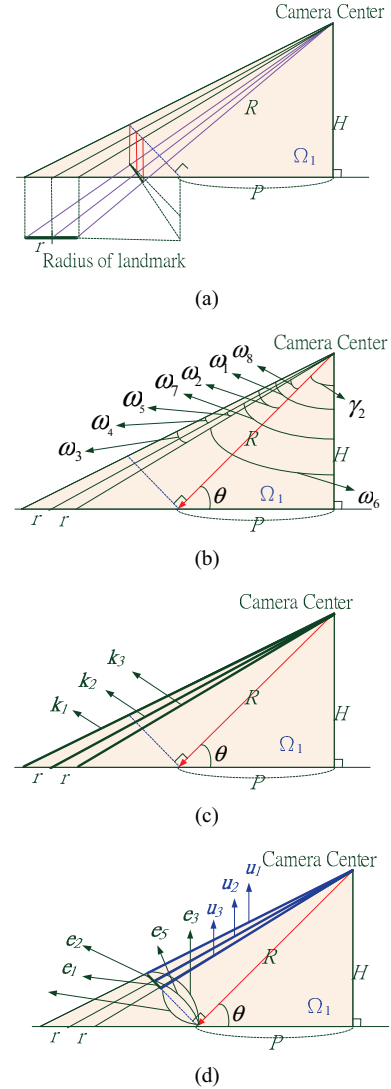


Fig. 9. Image features analysis in region Ω_1 . (a) The region Ω_1 referring to Fig. 8. (b) The important angles ω_1 - ω_8 in region Ω_1 . (c) The important lines k_1 - k_3 in region Ω_1 . (d) Other important features.

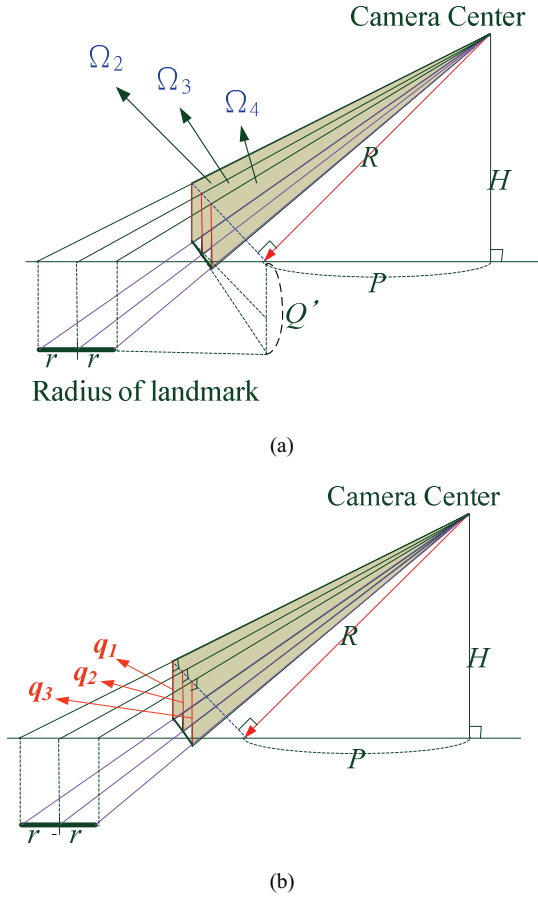


Fig. 10. Image features analysis in regions Ω_2 , Ω_3 , Ω_4 . (a) The regions Ω_2 , Ω_3 , Ω_4 referring to Fig. 8. (b) The important line segments q_1 - q_3 in regions Ω_2 , Ω_3 , Ω_4 .

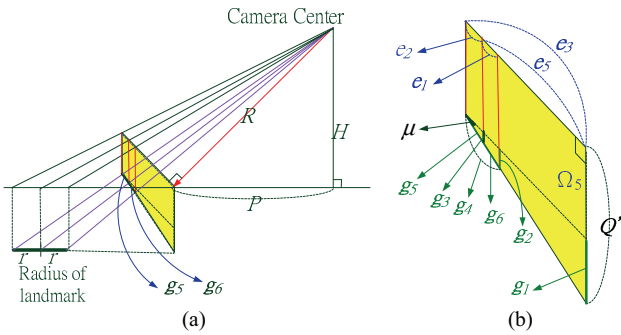


Fig. 11. Image features analysis in plane Ω_5 . (a) The region Ω_5 referring to Fig. 8. (b) Features g_5 , g_6 in region Ω_5 .

$$\begin{cases} q_1 = u_1(Q'/k_1) \\ q_2 = u_2(Q'/k_2) \\ q_3 = u_3(Q'/k_3) \end{cases} \quad (12)$$

Then we discuss the third part, as in Fig. 11, the projection of the landmark radius g_5 and g_6 are included in Ω_5 . The derivation of g_5 and g_6 is shown in (13).

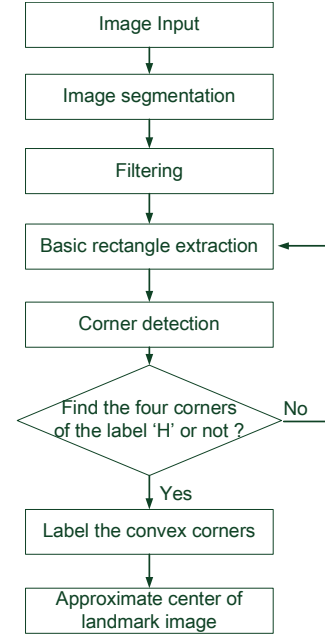


Fig. 12. The Image feature extraction procedure.

$$\begin{cases} g_1 = Q' - q_1 \\ g_2 = q_3 - q_1 \\ g_3 = q_2 - q_1 \\ g_4 = \sqrt{(e_1 + e_2)^2 + g_2^2} \\ g_5 = \sqrt{e_2^2 + g_3^2} \\ g_6 = g_4 - g_5 \end{cases} \quad (13)$$

III. IMAGE FEATURES EXTRACTION

The procedure of image feature extraction is illustrated in Fig. 12. There are three major parts in this procedure. They are “Image preprocessing procedure”, “Corner detection and approximate center computing” and “Landmark image feature extraction”. Details about the three parts are discussed below.

A. Image preprocessing procedure

The landmark image features can be obtained by image preprocessing [15]. There are three major parts in this algorithm. The first part is image segmentation, including thresholding and filtering for segmenting the approximate landmark image in the frame. Thresholding is a fundamental tool for segmentation of an image when objects and background pixels can be distinguished by their grey level values. When an image is segmented into a binary image, analysis and computing become far easier. The second technique used for image pre-processing is morphological image processing, which is utilized to obtain more complete and clear edges of the target image. Erosion and dilation are the commonly used operations of morphological image processing [16]. The third part is landmark image extraction, including “Recursive connected labeling algorithm”, “Basic rectangle computing” and “Major axis and minor axis computing”. A connected labeling algorithm is usually used for multiple

objects labeling in image. But this process is not necessary in this paper since only a signal landmark image is considered.

B. Corner detection and approximate center computing

A corner detection algorithm is utilized for detecting the four corners of the label 'H' of the landmark. There are many different corner detection algorithms developed for locating feature points. One of the common corner detection algorithms is Harris corner detector [17]. The main principle of Harris corner detector is to use the Gaussian filter to detect the corners response of each pixel in the image. Gaussian filter can not only enhance the significant corners, but also remove the undesirable corners. Moreover, it can reduce the probability of misjudgment. Although the Harris corner detector is a very useful tool, it requires a lot of computing time. Therefore the corner detection operations are applied only for the basic rectangle to reduce computation time.

Further, the procedure is developed to locate the approximate center of the landmark image. The procedure is described as follows.

- STEP 1 Detect the corners of the image in the basic rectangle.
- STEP 2 Detect the convex corners of the label 'H'.
- STEP 3 Label the convex corners and extracted the four corners of the label 'H'.
- STEP 4 Find the intersection of the diagonals, and designate these coordinates as the approximate center of the landmark image.

C. Landmark image feature extraction

From section II, we know that the deformation of a landmark image is unavoidable. Even so, the projection relation can be analyzed via the proposed method. The projections of the landmark radius in vertical and horizontal directions are g_5 , g_6 , $\hat{m}$, and $\hat{n}$, respectively. Fig. 13(a) is an example of the image of the landmark. The white part is obviously a deformed circle. Fig. 13(b) is a sketch map showing the features of the landmark image.

IV. DATABASE CONSTRUCTION AND ANFIS STRUCTURE

ANFIS (Adaptive Neuro-Fuzzy Inference Systems) is a very high efficiency learning algorithm. Its learning effect is equivalent to that of NNs (neural network), but the requisite learning time is substantially lower. Consequently, ANFIS is employed in this paper for learning the mapping relation between the landmark and camera position.

The input of the ANFIS are g_5 , g_6 , e_5 , $\hat{m}$, $\hat{n}$, q_2 , and d . The output of ANFIS are θ , R and Q . The amount of the training data is very large. Since the center of the landmark image will only appear in one of the quadrants, the database is then split into four parts depending on the quadrant location of the estimated center so to reduce the quantities of training data required. They are “the landmark image located at the first quadrant”, “the landmark image located at the second

quadrant”, “the landmark image located at the third quadrant” and “the landmark image located at the fourth quadrant”.

Four ANFIS named “ $ANFIS_{First_Quadrant}$ ”, “ $ANFIS_{Second_Quadrant}$ ”, “ $ANFIS_{Third_Quadrant}$ ” and “ $ANFIS_{Fourth_Quadrant}$ ” are established by the corresponding database. The ANFIS for all databases is called “ $ANFIS_{cam_estimation}$ ” and its structure is illustrated in Fig. 14. The structure of any one of these ANFIS's is illustrated in Fig. 15.

V. EXPERIMENTAL RESULTS

The experimental results of the proposed method for camera position estimation are discussed in this section. The features are not easily extracted from a deformed landmark image. Fig. 16 shows some simulation results of the projection of the landmark under different conditions. The intersection of optical axis of the camera system and ground is set to be at (0,

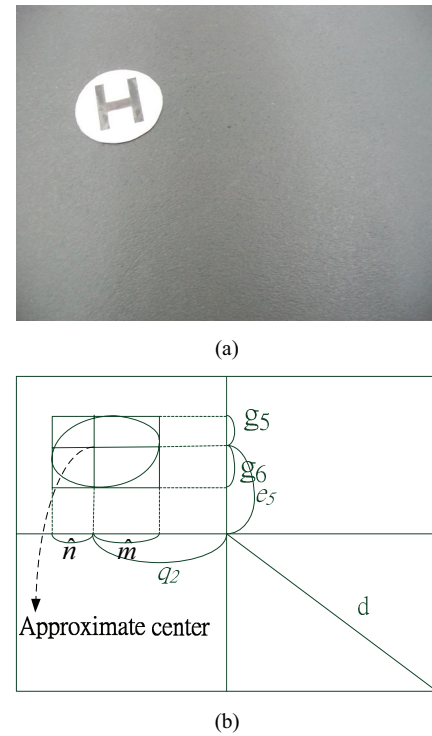


Fig. 13. The features of landmark image. (a) The captured landmark image. (b) The selected features of landmark image and the approximate center.

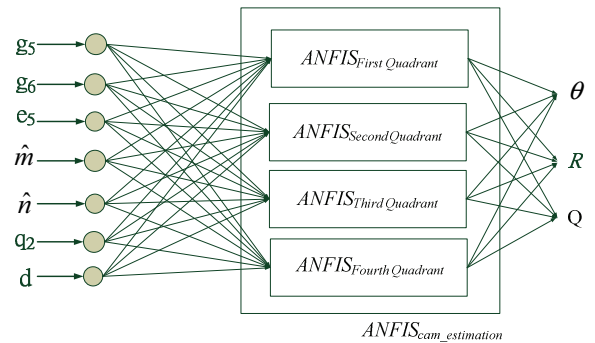


Fig. 14. The structure of the $ANFIS_{cam_estimation}$.

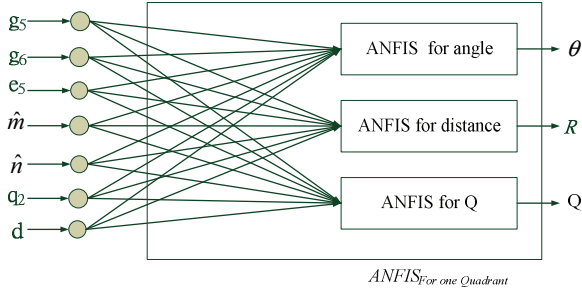


Fig. 15. The structure of one ANFIS in “ $ANFIS_{cam_estimation}$ ”

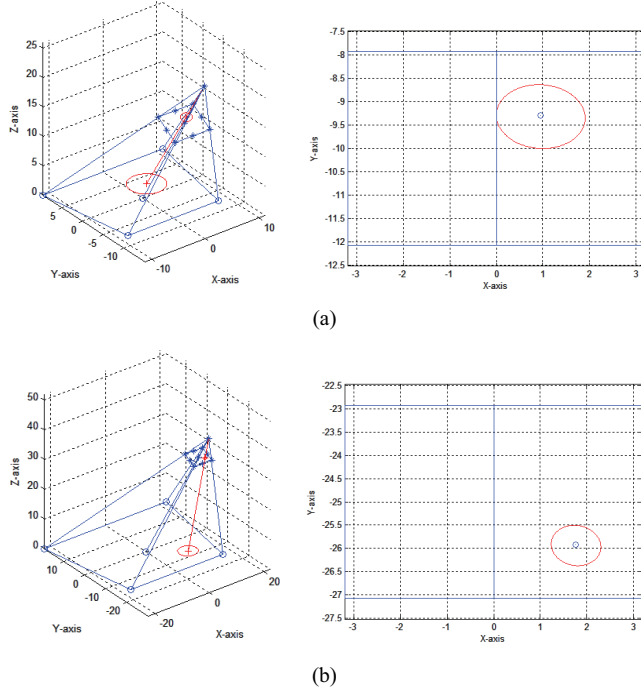


Fig. 16. The simulations of the projection of the landmark. (a) The camera system at $R=30$, $\theta=30^\circ$ and the landmark position at (3,3). (b) The camera system at $R=60$, $\theta=30^\circ$ and the center of landmark at (10,-7)

0). For example, Fig. 16(a) shows the relations of a randomly set camera system and the landmark, and the corresponding projection of the landmark and the center is shown in Fig. 16(b). Similarly, Fig.16(c) and (d) show the camera position at $R=60$, $\theta=30^\circ$ and the center of landmark at (10, -7). The deformation of the landmark image is obvious.

A. Image processing and feature extraction results

Consider the image shown in Fig. 17, in our simulations, the landmark diameter is 3cm and the size of the image is 320 by 240 pixels. For example, Fig. 17(a) is an obtained real image, and Fig. 17(b) is the binary image and the basic rectangle of landmark. The order statistics filter [18] is utilized for obtaining the clear landmark image. The computed major and minor axis of basic rectangle are 71.70 and 58.47, respectively. Fig. 17(c) shows the corner detection result and approximate center.

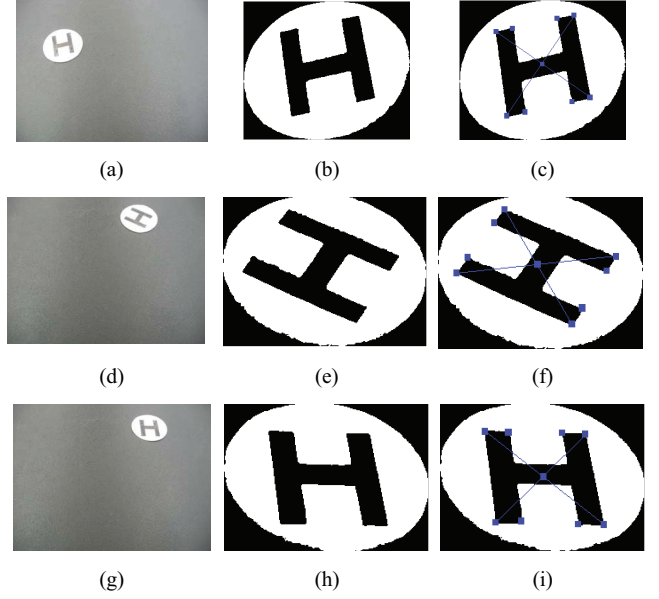


Fig. 17. The simulations of the image processing and feature extraction results. (a) The test image 1. (b) The binary image and the basic rectangle of test image 1. (c) the corner detection and approximate center of test image 1. (d) The test image 2. (e) The binary image and the basic rectangle of test image 2. (f) the corner detection and approximate center of test image 2. (g) The test image 3. (h) The binary image and the basic rectangle of test image 3. (i) the corner detection and approximate center of test image 3.

TABLE I. IMAGE FEATURES THAT EXTRACTED FROM FIG. 16

Image No.	Image Features					
	g_5	g_6	e_5	$\hat{m}$	$\hat{n}$	q_2
Test image1	32.55	22.70	37.33	28.41	37.83	77.29
Test image2	22.27	22.23	82.36	29.44	30.31	53.68
Test image3	20.64	21.11	80.48	28.50	29.00	60.38

Similarly, the other features in Fig. 17 are collated in TABLE I. By reviewing this data we can see that the simulation results demonstrate that the proposed image process method can extract landmark image features. Furthermore the corner detection algorithm will not be affected by the rotation or deformation of a landmark image. The landmark image is clear therefore the features are easily extracted.

B. Camera position estimating results

The ANFIS training data is generated by geometric computation and then classified into four parts to reduce the training time and the structure of ANFIS. This paper considers the practical application of an AUH approaching a landmark. The research does not examine extreme situations. Therefore the training range of R is from 20cm to 300cm. The training range of θ is from 55° to 90° . The training RMSE (root mean squared error) of R , θ and Q in $ANFIS_{First_Quadrant}$ are 0.1325, 0.1433 and 0.1654, respectively. The training RMSE of R , θ

TABLE II. THE ESTIMATION RESULTS OF CAMERA POSITION

Data No.	Camera Position			Estimating Error		
	R (cm)	θ	Q (cm)	R (cm)	θ	Q (cm)
1	33	65	10	0.124	-0.145	0.216
2	45	78	19	0.217	0.204	0.145
3	59	57	21	-0.194	0.174	-0.164
4	65	81	45	-0.154	-0.134	0.201
5	106	84	50	0.198	0.165	0.169
6	124	59	54	-0.119	0.214	0.176
7	154	81	14	0.132	-0.175	0.203
8	169	71	35	0.211	0.132	-0.164
9	201	84	44	-0.209	-0.198	-0.170
10	284	65	95	-0.174	0.181	0.198

and Q in $ANFIS_{Second_Quadrant}$ are 0.1026, 0.2053 and 0.1461, respectively. The training RMSE of R , θ and Q in $ANFIS_{Third_Quadrant}$ are 0.1271, 0.0971 and 0.0745, respectively. The training RMSE of R , θ and Q in $ANFIS_{Fourth_Quadrant}$ are 0.0925, 0.1033 and 0.0754, respectively. Some of the estimation results of camera position are illustrated in TABLE II. In TABLE II, 10 data sets are employed to verify the fuzzy model. The average absolute error of R is 0.1732cm, the average absolute error of θ is 0.1722°, and the average absolute error of Q is 0.1806cm.

VI. CONCLUSIONS

For the guidance of an AUH during its landmark approach, we proposed a visual-based guidance method for camera position estimation. This method can estimate the camera position via select landmark features. The designed method can reduce the image process procedure. More importantly, the image features can be extracted from a deformed landmark image. The simulation results show that the basic rectangle and the label 'H' are very helpful for computing the image features.

In addition, the size of established database is very large. To reduce the quantities of training data and thereby speed up the ANFIS training the database is split into four parts. The ANFIS established an approximate fuzzy model to replace the complex projective relationship between the camera and landmark. In practical applications, this method can provide the position information required by an AUH for accurate guidance during approach to a landmark.

REFERENCES

- [1] Z. Fang, J. Wu, and P. Li, "Control System Design and Flight Testing for a Miniature Unmanned Helicopter," Proceedings of the 7th World Congress on Intelligent Control and Automation, Chongqing, pp. 2315–2319, June 2008.
- [2] X. Guo, W. Sun, Z. Li and L. Ren, "The Flight Control Design of Mini Unmanned Helicopter on Sliding Mode Control," Chinese Control and Decision Conference, China, pp. 3245–3248, May 2010.
- [3] P. Song, G. Qi and K. Li, "The Flight Control System Based On Multivariable PID Neural Network For Small-Scale Unmanned Helicopter," International Conference on Information Technology and Computer Science, Kiev, vol. 1, pp. 538–541, July 2009.
- [4] T. J. Ross, Fuzzy Logic with Engineering Applications, Wiley, 2010.
- [5] GPS 18 Technical Specifications, Revision D, Garmin International, USA, June 2005.
- [6] H.-U. Doehler and B. Korn, "Robust position estimation using images from an uncalibrated camera," Digital Avionics Systems Conference, USA, vol. 2, pp. 9.D.2–1–9.D.2–7, October 2003.
- [7] C. Xu, L. Qiu, M. Liu, B. Kong and Y. Ge, "Stereo Vision Based Relative Pose and Motion Estimation for Unmanned Helicopter Landing," IEEE International Conference on Information Acquisition, China, pp. 31–36, August 2006.
- [8] W. Bagen, J. Hu and Y. Xu, "A Vision-Based Unmanned Helicopter Ship Board Landing System," International Congress on Image and Signal Processing, Tianjin, China, pp. 1–5, October 2009.
- [9] A. Johnson, J. Montgomery and L. Matthies, "Vision Guided Landing of an Autonomous Helicopter in Hazardous Terrain," IEEE International Conference on Robotics and Automation, Barcelona, Spain, pp. 3966–3971, April 2005.
- [10] A. Cesetti, E. Frontoni, A. Mancini, P. Zingaretti and S. Longhi, "A Single-Camera Feature-Based Vision System for Helicopter Autonomous Landing," International Conference on Advanced Robotics, Munich, Germany, pp. 1–6, June 2009.
- [11] B. Yuan and Y. Hao, "A Method of Vision-Based State Estimation of an Unmanned Helicopter," International Conference on Wireless Communications Networking and Mobile Computing, Chengdu, pp. 1–4, September 2010.
- [12] G. F. Nsogo, K. Kith, B. J. van Wyk and M. A. van Wyk, "Robust Helipad Detection Algorithm," IEEE Africon Conference, pp.1–6, Namibia, September 2007.
- [13] Y. Fan, S. Haiqing and W. Hong, "A Vision-Based Algorithm for Landing Unmanned Aerial Vehicles," International Conference on Computer Science and Software Engineering, vol. 1, pp.993–996, China, December 2008.
- [14] R. Hartley and A. Zisserman, Multiple View Geometry in computer vision, Cambridge University Press, 2003.
- [15] D. A. Forsyth and J. Ponce, Computer Vision: A Modern Approach, Prentice Hall, 2002.
- [16] L. G. Shapiro and G. C. Stockman, Computer Vision, Prentice Hill. 2001.
- [17] M. Nixon and A. Aguado, Feature Extraction & Image Processing, Amsterdam Academic, Boston, 2008.
- [18] S. Peltonen, M. Gabbouj and J. Astola, "Nonlinear Order Statistic Filter Design: Methodologies," International Symposium on Image and Signal Processing and Analysis, pp. 102–107, Croatia, June 2001.