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A Simulation Method of Generating Multi-view Image of Aircraft Targets

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Abstract. Aircraft target detection in airport remote sensing image by deep learning is a hot topic of current research, however, training deep network model needs a large amount of datasets, and there is no website or the specialized agencies to collect remote sensing images of airport. To solve the problem, a multi-view images generation method for aircraft targets is proposed in this paper. Firstly, the aircraft viewpoint transformation detection imaging model was established, and the coordinate transformation is deduced in detail; secondly, a multi-view image simulation algorithm structure was designed, and the realization of the algorithm is introduced in detail. Experimental results show that the method has good simulation effect on remote sensing images of airport and have high use value.

Introduction

Aircraft targets can be either an important goal included in the plan or an unexpected temporary targe t[1,2], typical aircraft targets are the following categories: One is the air attack targets, mainly a variety of aircrafts, which location will change at any time and striking time is fleeting; another are the ground or sea mobile facilities; the other is the fixed facilities, but will soon be able to play a military role, and are very sensitive to the striking time, such as the bridges where the enemies are about to pass, the missile positions where will be launching soon.

In the battlefield environment,it has important military significance that aircrafts can correctly detect and identify targets which is the basis for follow-up tasks such as targets tracking. Among them, the recognition of aircraft targets has an important role in promoting for the development of technology, the expansion of the application scope of weapon systems and enhancing the attacking efficiency.As the aircraft targets has maneuverability, targets attitudes information are unpredictable, which posing higher demand for recognition tasks. So in the process of studying the technology of recognition of aircraft targets, a large number of aircraft targets image data sets are needed, such as airport standby aircrafts, coastal ships. Because these targets belong to military secrets, it is difficult to obtain the image data sets ofdifferent types and different angles. Combining aircraft viewpoints transformation imaging model, the paper puts forward a multi-view images of aircraft targets simulation method based on geometric deformation, which can effectively improve the comprehensive of the aircraft targets image data sets and fully exploit the feature information of aircraft targets with limited image data sets. So far domestic research on the front and down looking infrared image processing and targets recognition are much more deeply. Such as the second chapter of monograph[3], by establishing and analysing of the real-time image geometric deformation model based on the flight attitude of aircrafts, the geometric correction of the real-time image is achieved, and improving the reliability and accuracy of the matching. So a multi-view images generation method for aircraft targets is proposed in this paper.

Establishment and Analysis of the Airborne Camera Detection Imaging Model

Research on the simulation of multi-view images of aircraft targets, the key to acquire the image data is to establish the airborne camera detection imaging model, the essence of establishing model is based on the attitude angles and flight altitudes, and the related reference coordinate systems, then finding the mathematical expression of coordinate transformation relation of image geometric transformation.

Definition of Related Coordinate System

Based on the coordinate system defined in the analysis of the flight guidance and control system [4], and the description of visual coordinate system in machine vision, the reference coordinate system $oxyz$, the camera coordinate system $o_c x_c y_c z_c$ and the image coordinate system $o_i x_i y_i$ is used in this study. Figure 1 gives the diagram of the coordinate system.

(1) Reference coordinate system $oxyz$. Taking the point of the aircraft that is vertical to the ground as the coordinate origin o , x is along the flight direction of the aircraft, forward is positive. y is vertical to the ground, upward is positive. z satisfies the right hand rule and is vertical to the xoy .

(2)Camera coordinate system $o_c x_c y_c z_c$ .Taking the optical center of the camera as the coordinate origin o_c , the optical axis of the camera is x_c , forward is positive. The y_c is vertical to the x_c in the vertical section, upward is positive. z_c satisfies the right hand rule. $x^{\bullet}$, $y^{\bullet}$, $z^{\bullet}$ are corresponding positions of camera coordinate system under ideal flight condition.

(3) Image coordinate system $o_i x_i y_i$. Image coordinate system $o_i x_i y_i$ is a two dimensional rectangular coordinate system based on real-time image. The intersection of the optical axis and virtual image plane is coordinate origin o_i, x_i is parallel to the z_c of the camera coordinate system, in theopposite direction. y_i is parallel to the y_c of the camera coordinate system, in the same direction.

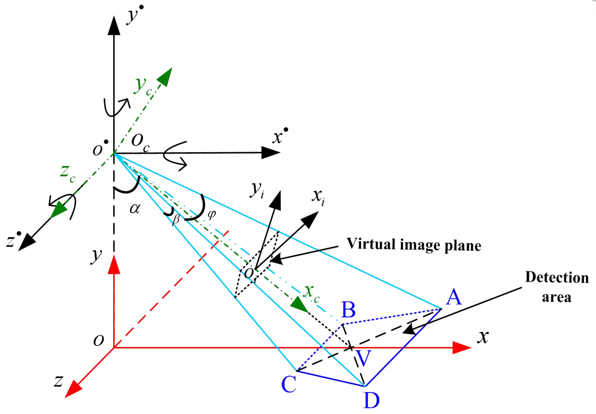


Fig1. Coordinate system

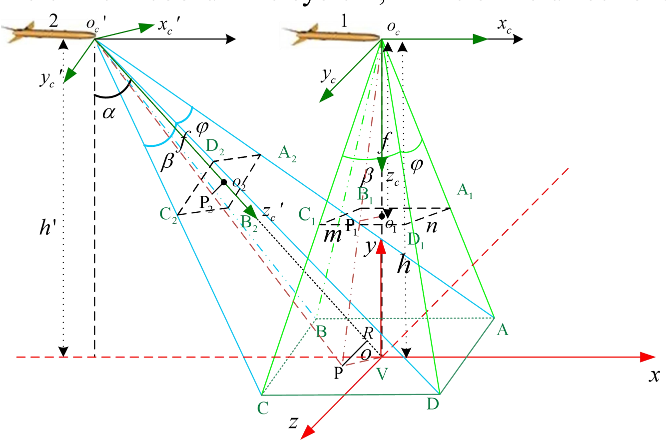


Fig2.Aircraft viewpoints transformation imaging

Establishment of Mathematical Model

Aircrafts shoot thesame target V by transforming positions and attitude angles can get images from different viewpoints, taking P arbitrarily on the imaging area, deriving the correspondence between P and P_1 in the $A_1B_1C_1D_1$ and P_2 in the $A_2B_2C_2D_2$ by establishing the mathematical model, then transformation relation from $A_1B_1C_1D_1$ to $A_2B_2C_2D_2$ can bededuced.

Supposing the imageis $A_1B_1C_1D_1$ in time T_1 , after the aircraft transforms the viewpoints, the imageis $A_2B_2C_2D_2$ in time T_2 , camera detection area is $ABCD$, central point is V , focal length is f and the height is h . The angle between the optical axis of the camera and y -axisis α after transforming the viewpoints. Figure 2 shows the diagram of the aircraft viewpoints transformationimaging.

(1) Transformation of the image coordinate system to thecamera coordinate system in time T_1 .

Firstly establish the camera imaging model, as is shown infigure 3.The distance of P and optical center is l , P_1 isthe position of P in image coordinate system. O_c istheoptical center and the origin of the camera coordinatesystem, f is the focal lengthof the camera, that is thedistance between optical center and the center of the virtualimage plane.

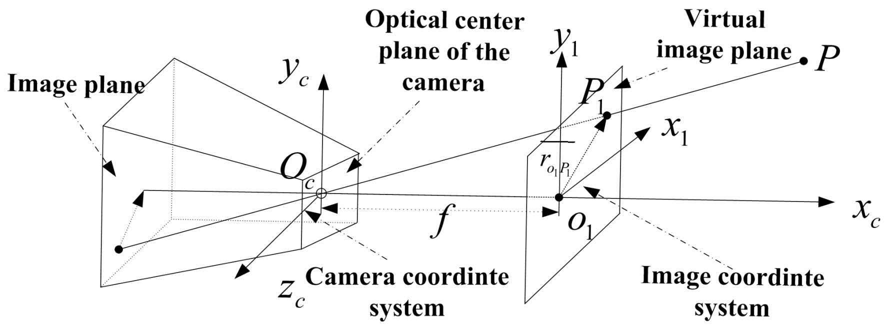


Fig3. Camera imaging model

Assuming the coordinate of P_1 in image coordinate systemis (x_{i1}, y_{i1}) , the coordinate of P in camera coordinatesystem is (x_{c1}, y_{c1}, z_{c1}) , according to the geometrictransformation of the triangle similarity, it can be deduced that thetransformation of P_1 from the image coordinate system tothe camera coordinate system:

$$\begin{cases} x_{c1} = x_{i1}h/f \\ y_{c1} = y_{i1}h/f \\ z_{c1} = h \end{cases} \tag{1}$$

(2)Transformation of the camera coordinate system to the reference coordinate system in time T_1.

According to the above definition and analysis of thecoordinate system, assuming the coordinate of the airbornecamera in the reference coordinate system $oxyz$ is (x_0, y_0, z_0) , in the coordinate system $o^\bullet x^\bullet y^\bullet z^\bullet$, fourpyramids rotate about the $y^\bullet$ when the camera is in the yawangle ψ ; rotating about the $z^\bullet$ when the camera is in the pitch angle ϑ ; rotating about the $x^\bullet$ when the camera is inthe roll angle γ .

if the coordinate of the P in the referencecoordinate system is (x, y, z) , then it can deduced that P from the camera coordinate system to the referencecoordinate system:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} x^\bullet \\ y^\bullet \\ z^\bullet \end{bmatrix} + \begin{bmatrix} x_0 \\ y_0 \\ z_0 \end{bmatrix} = G \begin{bmatrix} x_{c1} \\ y_{c1} \\ z_{c1} \end{bmatrix} + \begin{bmatrix} x_0 \\ y_0 \\ z_0 \end{bmatrix} \tag{2}$$

The transformation matrix G [8] is:

$$G = \begin{bmatrix} \cos\vartheta\cos\psi & -\sin\vartheta\cos\psi\cos\gamma + \sin\psi\sin\gamma & \sin\vartheta\cos\psi\sin\gamma + \sin\psi\cos\gamma \\ \sin\vartheta & \cos\vartheta\cos\gamma & -\cos\vartheta\sin\gamma \\ -\sin\psi\cos\vartheta & \sin\vartheta\sin\psi\cos\gamma + \cos\psi\sin\gamma & -\sin\vartheta\sin\psi\sin\gamma + \cos\psi\cos\gamma \end{bmatrix} \tag{3}$$

Here the reference coordinate system can be regarded as thecamera coordinate system 1 gets a roll of $\gamma = 90^\circ$, substitutinginto the formula (3), the transformation matrix can be obtained as:

$$G' = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & -1 \\ 0 & 1 & 0 \end{bmatrix} \tag{4}$$

Transformation relationship of P from the coordinate (x_{c1}, y_{c1}, z_{c1}) in the camera coordinate system to thecoordinate (x, y, z) in the reference coordinate system is:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & -1 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x_{c1} \\ y_{c1} \\ z_{c1} \end{bmatrix} + \begin{bmatrix} 0 \\ h \\ 0 \end{bmatrix} = \begin{bmatrix} x_{c1} \\ -z_{c1} + h \\ y_{c1} \end{bmatrix} \tag{5}$$

(3)Transformation of the reference coordinate system to thecamera coordinate system in time T_2.

Assuming the coordinate of the camera after transformingviewpoints in the reference coordinate systemis (x_0', y_0', z_0') , transformation from the camera coordinatesystem to the reference coordinate system is:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = G \begin{bmatrix} x_{c2} \\ y_{c2} \\ z_{c2} \end{bmatrix} + \begin{bmatrix} x_0' \\ y_0' \\ z_0' \end{bmatrix} \tag{6}$$

Transformation from the reference coordinate system to the camera coordinate system is:

$$\begin{bmatrix} x_{c2} \\ y_{c2} \\ z_{c2} \end{bmatrix} = G^{-1} \left\{ \begin{bmatrix} x \\ y \\ z \end{bmatrix} - \begin{bmatrix} x_0' \\ y_0' \\ z_0' \end{bmatrix} \right\} = G^{-1} \begin{bmatrix} x - x_0' \\ y - y_0' \\ z - z_0' \end{bmatrix} \tag{7}$$

Here the transformation matrix G^{-1} is:

$$G^{-1} = \begin{bmatrix} \cos\vartheta\cos\psi & \sin\vartheta & -\sin\psi\cos\vartheta \\ -\sin\vartheta\cos\psi\cos\gamma + \sin\psi\sin\gamma & \cos\vartheta\cos\gamma & \sin\vartheta\sin\psi\cos\gamma + \cos\psi\sin\gamma \\ \sin\vartheta\cos\psi\sin\gamma + \sin\psi\cos\gamma & -\cos\vartheta\sin\gamma & -\sin\vartheta\sin\psi\sin\gamma + \cos\psi\cos\gamma \end{bmatrix} \tag{8}$$

(4) Transformation of the camera coordinate system to theimage coordinate system in time T_2.

In the camera imaging model established above, the coordinate of the P_2 which is projected into the image coordinate system is (x_{i2}, y_{i2}) , the coordinate of the P inthe camera coordinate system is (x_{c2}, y_{c2}, z_{c2}) , it canbe concluded that the transformation of arbitrary objects in space from camera coordinate system to image coordinate system is:

$$\begin{cases} x_{i2} = \dfrac{x_{c2} z_{c2}}{f} \\ y_{i2} = \dfrac{y_{c2} z_{c2}}{f} \end{cases} \tag{9}$$

Multi-view Image Simulation Method

By using the coordinate transformation relation above, according tothe image coordinates of the original real-time image, thecoordinates of the new real-time image can be found out.Then assigning the grayscale values of the correspondingpoint from the original real-time image to the new real-time image, it can be obtained that the real-time image afterviewpoints transformation. Here are the detailed steps：

(1) Taking any point (x_{i1}, y_{i1}) in the original real-time image(image coordinate system), transforming it to thecorresponding point in the original camera coordinatesystem (x_{c1}, y_{c1}, z_{c1}) ,

$$\begin{bmatrix} x_{c1} \\ y_{c1} \\ z_{c1} \end{bmatrix} = \begin{bmatrix} \dfrac{h}{f} & 0 & 0 \\ 0 & \dfrac{h}{f} & 0 \\ 0 & 0 & h \end{bmatrix} \begin{bmatrix} x_{i1} \\ y_{i1} \\ 1 \end{bmatrix} \tag{10}$$

(2)Obtaining the coordinate of the corresponding point inthe reference coordinate system by coordinate transformation:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = G \begin{bmatrix} x_{c1} \\ y_{c1} \\ z_{c1} \end{bmatrix} + \begin{bmatrix} x_0 \\ y_0 \\ z_0 \end{bmatrix} = \begin{bmatrix} x_{c1} \\ z_{c1} + h \\ -y_{c1} \end{bmatrix} \tag{11}$$

(3)Transforming P from the reference coordinate system to the camera coordinate system in time T_2 :

$$\begin{bmatrix} x_{c2} \\ y_{c2} \\ z_{c2} \end{bmatrix} = G^{-1} \begin{bmatrix} x - x_0 ' \\ y - y_0 ' \\ z - z_0 ' \end{bmatrix} \tag{12}$$

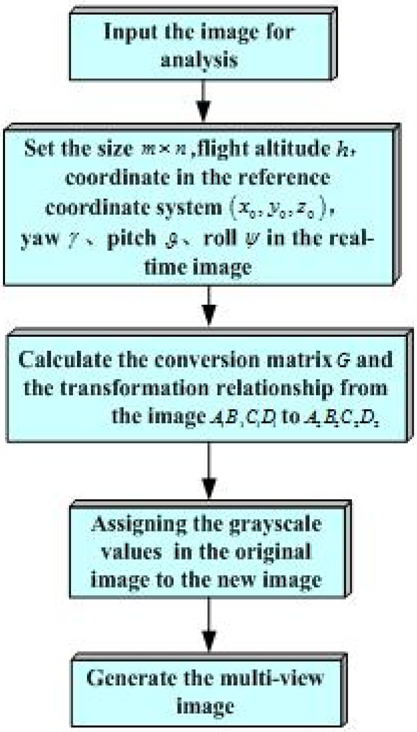
(x_0', y_0', z_0') is the coordinate of the airborne camera in thereference coordinate system after transforming theviewpoint.

(4)The coordinates in the transformation to the newreal-time image is $\left(\frac{x_{c2}z_{c2}}{f}, \frac{y_{c2}z_{c2}}{f}\right)$.

(5)Assigning the grayscale values of the point in the originalreal-time image to the corresponding point in the newreal-time image by bilinear interpolation.

(6)According to the size of the new real-time image, loopover all of its pixels, repeat step (1) to (5).

Following the above steps, it can be generated by simulationof the multi-view images of aircraft targets based onthe geometric deformation.The method flow chart is shown in Figure 4.



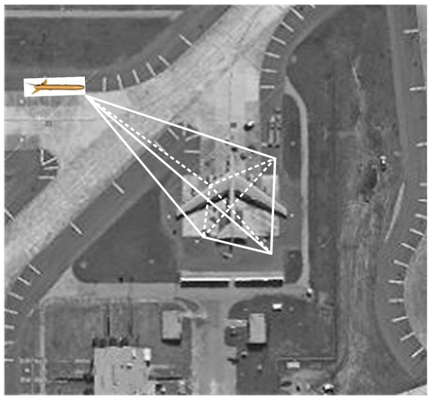


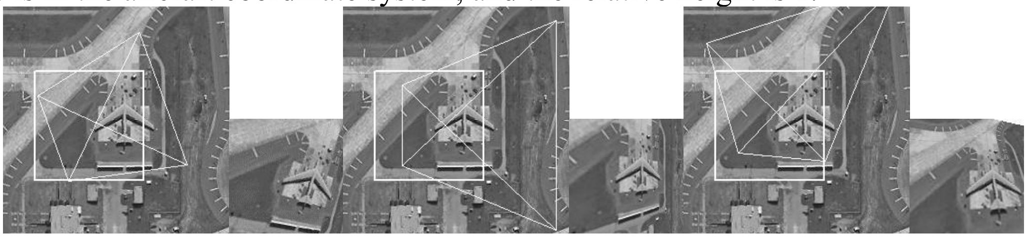
Fig 4. Flow chart of multi-view images simulation method Fig 5.Detection of aircraft over an airport

Experimental Results and Analysis

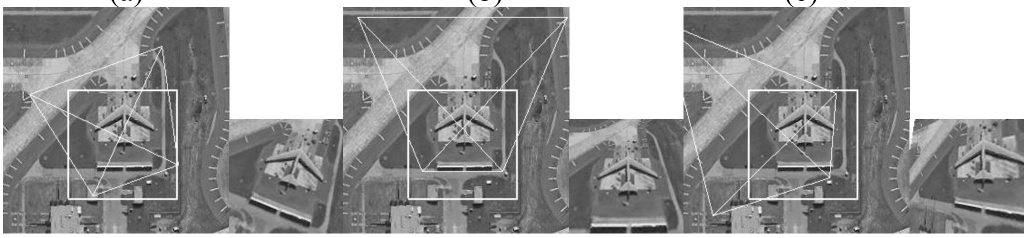
As mentioned above, this paper established the camera detection imaging model andanalyzed the coordinate transformation, to validatethe validity of the model, this section designs aaircraft targetsmulti-view images simulation experimentbased on the viewpointstransformation imaging model ofaircrafts, the simulation of the real-time images in differentviewpoints and attitude anglesare given. Figure 5 is the viewpoints transformation anddetection of aircraft in an airport.

Based on the establishment of the viewpoints transformation imaging model of the aircrafts, the C++ Builder 6 software platform is used to realize the determination of the imaging area and the simulation of the multi-view images in different viewpoints and different attitude angles. The simulation experiment used a reference image with the size of 256×256 , and the size of the simulated real-time images are 64×64 . Figure 6 shows the simulation results.

Figure (a), (b), (c) is the simulation imaging of the aircraftunder the same viewpoint and a certain attitude condition,figure (d), (e), (f) is the simulation imaging in anotherviewpoint and a certain attitude condition. It can be seenthat the imaging of different viewpoints and attitudesareconsistent with the model established in this paper, verifyingthe correctness of the viewpoints transformation imagingmodel established above. The simulation parametersare shown in table 1, the aircraft coordinate is in the aircraft coordinate system, and the relative height is 1.



(a) (b) (c)



(d) (e) (f)

Fig 6.Simulation of Different viewpoints and attitude angles

Table 1. Simulation parameters

Aircraft Coordinate	Image	Yaw(γ)	Pitch(ϑ)	Roll(ψ)
(95,131)	a	20°	10°	0°
	b	0°	20°	0°
	c	0°	10°	20°
(132,149)	d	20°	10°	0°
	e	0°	20°	0°
	f	0°	10°	20°

Conclusion

This paper carried on the problem of preparing aircraft target datasets, putting forward a simulation method of multi-view image of aircraft targets. Firstly the correlative coordinate system is defined,on this basis,the transformation relationship between the new and the old images is deduced by establishing the imaging model of aircraft viewpoints transformation, finding the influence on the image of variation of the viewpoints and attitude angles of the aircrafts, and the multi-view images under this condition is simulated, the experimental results verified the correctness of the imaging model established in this paper, providing a new idea and basis for the preparation of aircraft target data sets.

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