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Projection of Surveillance Camera Field of View onto Aircraft Moving Navigation Map

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Abstract

This paper describes the method of projection and display of surveillance camera field of view onto moving navigation map installed inside the aircraft, or, in case of unmanned craft, onto the map shown on control table on the ground, or in another aircraft. The surveillance camera is installed on stablilized platform with two controlable axes: pitch axis and yaw axis, thus providing five angular degrees of freedom relative to the ground (inertial) coordinate system, namely five independent angles. The camera does not contain any roll angle. This paper describes the method of projection of the camera axis, i.e. projection of the edges of camera angle of view, relative to flat surface of the ground, together with visualization of the surface corresponding to the field of view of the camera. Accuracy testing was performed with standard project software, as well as testing with moving map in real navigation system of the aircraft.

In broader sense, this method may be used as a part of the algorythm for fire control of the weapon inside the gun turret on the aircraft.

***Keywords**: Navigation, Moving Map, Stabilized Platform, Surveillance Camera, Projection of Field of View, Reference Direction*

Introduction

Modern aircraft navigation uses moving navigation map which contains all required data and illustrations. Surveillance camera is also used, mainly on helicopter. As a rule, the camera is installed on stabilized platform. Two axes (pitch and yaw) are used for platform (camera) control, and rigid platform connection to the aircraftis used for roll axis control. This provides for obtaining of the camera with five angular degrees of freedom out of which two angles represent the angles of the camera (platform), while another three angles represent the angles of the aircraft. The image from the camera is transferred both to a monitor and a recorder installed inside the cabin of the aircraft. Camera orientation may be followed via signalization of the angles, as well as by observing of the image on the monitor – by ground recognition. In latter case, moving navigation map is complemented with visual projection of camera angle of view, and therefore it may be used for the control of camera directioning. Moving navigation map shows the projection of the spatial field of view on the ground, which is flat in this case, but the projection may either be in the form of full circular field of view (shown as the ellipse on the map), or actual rectangular angle of view (shown as a quadrangle on the map), with indicated position of the aircraft (shown as ortogonal projection on the ground). The projection of the angular field of view may exceed the edges of the map currently shown on the screen. In that case, the quadrangle is either open or it vanishes from the map. This paper describes the method for projection of the field of view of surveillance camera onto the moving map. The method is based on the transformation of coordinate systems, and it has the exact mathematical character. The input data are the three angular positions from the aircraft navigation system: φ, θ and ψ , and the two angles from the stabilized platform: θ_1 and ψ_1, as well as relative altitude of the aircraft H, relative to the ground it is flying over. The obtained results are the two angles of camera axis relative to the ground: θ_k and ψ_k, the coordinates of penetration point of the camera axis through the surface of the ground, namely penetration of the edges of the field of view through the surface of the ground, relative to the reference point of the position of the aircraft (ortogonal projection).

The operational range relative to the angles is the following:

φ ±90°
θ ±90°
ψ ±180° or 0 - 360°
θ_1 ±90°
ψ_1 ±180° or 0 - 360°

Reference navigation direction is north, which also represents reference direction of the projection of the camera axis.

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Problem Statement

Stabilized platform with surveillance camera is installed on the aircraft. It contains two controlable axes: pitch axis and jaw axis, relative to the coordinate system of the aircraft. The coordinate system relative to the aircraft is determined by three angles: φ, θ and ψ relative to the ground coordinate system, or the coordinate system inside the aircraft center of gravity containing the axes parallel with the axes of the ground (inertial) coordinate system. The position of the aircraft is determined with three angles: φ, θ and ψ , as well as with altitude H relative to the ground. The position of the camera is determined by the position of the aircraft, as well as with two angles: θ_1 and ψ_1 relative to the connected coordinate system of the aircraft. The right-hand coordinate systems are used (for the aircraft, it is the following: Ox_1 – representing the direction of longitudinal axis, Oy_1 – representing the right-hand wing, and Oz_1 – representing the downward direction).

The problem which is solved here is reduced to the transformation of the angles of the camera (platform) from the aircraft coordinate system into ground coordinate system, namely the definition of relevant projections which are then downloaded into the projection of the moving navigation map.

The solution contains the angles of the camera relative to the ground coordinate system, i.e. the coordinate of the penetration point of the camera axis through the surface of the ground (Figure 1). In the case of rectangular field of view, these are the coordinates of the penetration of the edges of the field of view through the surface of the ground. Final result is visualized surface of the projection of camera angle of view on the moving navigation map.

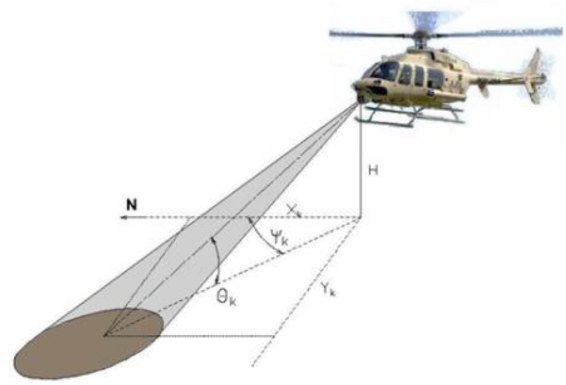

Figure 1: Helicopter with surveillance camera on a stabilized platform – projection of the total field of view on the ground

Problem Solution

The position of the camera is determined by the matrix of position angles in the connected coordinate system Ox_1, Oy_1, Oz_1:

$$\begin{vmatrix} \varphi \\ \theta \\ \psi \\ \theta_1 \\ \psi_1 \end{vmatrix}$$

The position of the aircraft is determined by the matrix of position angles in the ground coordinate system Ox_0, Oy_0, Oz_0: and altitude H above the ground.

The referent position on the map is orthogonal projection of the aircraft position relative to the ground.

The connection between the coordinate system of the camera (stabilized platform) Ox_k, Oy_k, Oz_k, and connected coordinate system of the aircraft Ox_1, Oy_1, Oz_1 is determined by the transformation matrix (Table 1):

Table 1 – Transformation matrix $Ox_1y_1z_1$ - $Ox_ky_kz_k$

	Ox_1	Oy_1	Oz_1
Ox_k	$\cos\theta_1 * \cos\psi_1$	$\sin\psi_1$	$-\sin\theta_1 * \cos\psi_1$
Oy_k	$-\cos\theta_1 * \sin\psi_1$	$\cos\psi_1$	$\sin\theta_1 * \sin\psi_1$
Oz_k	$\sin\theta_1$	0	$\cos\theta_1$

The axes Oy_k and Oz_k are not relevant in this case; therefore the same are omitted from the results of matrix multiplication. The relation between connected coordinate system of the aircraft Ox_1, Oy_1, Oz_1 and groung coordinate system Ox_0, Oy_0, Oz_0[1] (Figure 2) is determined by the transformation matrix[2], (Table 2):

Table 2 – Transformation matrix $Ox_0y_0z_0$ – $Ox_1y_1z_1$

	Ox_0	Oy_0	Oz_0
Ox_1	$\cos\theta * \cos\psi$	$\sin\psi$	$-\cos\psi * \sin\theta$
Oy_1	$-\cos\theta * \sin\psi * \cos\varphi + \sin\theta * \sin\varphi$	$\cos\psi * \cos\varphi$	$\cos\theta * \sin\varphi + \sin\theta * \sin\psi * \cos\varphi$
Oz_1	$\cos\theta * \sin\psi * \sin\varphi + \sin\theta * \cos\varphi$	$-\sin\varphi * \cos\theta$	$\cos\theta * \cos\varphi - \sin\theta * \sin\psi * \sin\varphi$

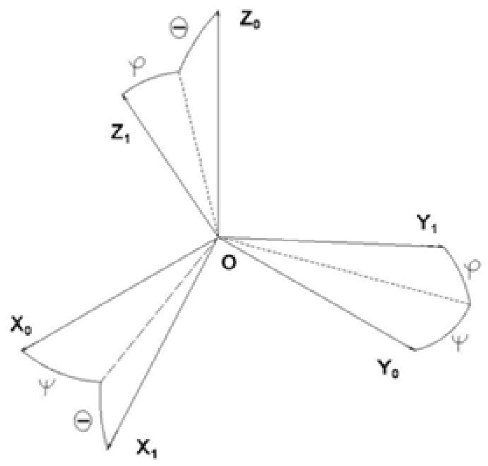

Figure 2: Connection of angles between coordinate systems $Ox_0y_0z_0$ and $Ox_1y_1z_1$

The multiplication of matrixes (Table 1- only Ox_k axis, and Table 2) results in obtaining of the projection of the angles of camera axis relative to the ground cordinate system, namley axis x_k:

$A = \cos\psi_1 * \cos\theta_1 * \cos\theta * \cos\psi + \sin\psi_1 * (-\cos\theta * \sin\psi * \cos\varphi + \sin\theta * \sin\varphi)-$

*Corresponding Author: Zdravko Banjac

$- \sin\theta_1 * \cos\psi_1 * (\cos\theta * \cos\varphi - \sin\theta * \sin\psi * \sin\varphi)$ (1)

$B = \cos\psi_1 * \cos\theta_1 * \sin\psi + \sin\psi_1 * \cos\psi * \cos\varphi + \sin\theta_1 * \cos\psi_1 * \sin\varphi * \cos\theta$ (2)

$C = - \cos\psi_1 * \cos\theta_1 * \cos\psi * \sin\theta + \sin\psi_1 * (\cos\theta * \sin\varphi + \sin\theta * \sin\psi * \cos\varphi)$ -

$- \sin\theta_1 * \cos\psi_1 * (\cos\theta * \cos\varphi - \sin\theta * \sin\psi * \sin\varphi)$ (3)

$D = (A^2 + B^2)^{0.5}$ (4)

$\Theta_k = \mathrm{atan}\ (C/D)$ (5)

$\Psi_k = \mathrm{atan}\ (B/A)$ (6)

Finally, these two angles and altitude are used to determine coordinates of penetration point of the camera axis through the surface of the ground:

$X_k = - (H/\tan\Theta_k) * \cos\Psi_k$ (7)

$Y_k = (H/\tan\Theta_k) * \sin\Psi_k$ (8)

In case of projection of rectangular field of view instead of circular one, the procedure is repeated for all four edges of the field of view (Figure 3), where angles of the edges of the field of view 1 – 4 (Table 3) are taken instead of the angles of pitch and yaw of camera axis.

Table 3 – Angles of the edges of the rectangular field of view

$\Theta_1^1 = \Theta_1 + \delta_v$ $\Psi_1^1 = \Psi_1 - \delta_h$	$\Theta_1^2 = \Theta_1 + \delta_v$ $\Psi_1^2 = \Psi_1 + \delta_h$	$\Theta_1^3 = \Theta_1 - \delta_v$ $\Psi_1^3 = \Psi_1 + \delta_h$	$\Theta_1^4 = \Theta_1 - \delta_v$ $\Psi_1^4 = \Psi_1 - \delta_h$

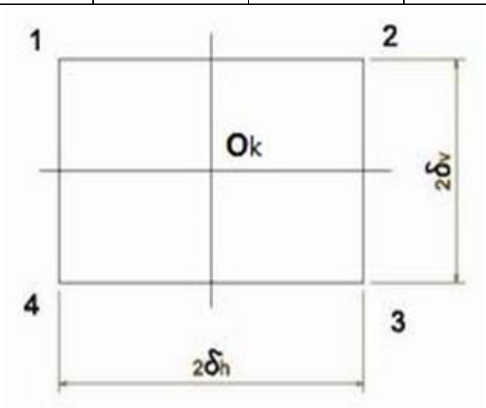

Figure 3: Rectangular field of view

Results of AccuracyTesting

Standard CATIA project software was used for the testing of accuracy of this method. A system has been modelled with the ground representing reference part with fixed coordinate system, the zero point of which is positioned within the projection of the aircraft on the surface of the ground. The aircraft is represented by a platform (frame) with its connected coordinate system (Figure 4), and it has three angular degrees of freedom (angles φ, Θ and Ψ). The camera is installed inside the platform, and it has two angular degrees of freedom (angles Θ_1 and Ψ_1). Typical angular combinations were tested in all operative quadrants of each angle, thirty two (32) combinations in total. An example with the aircraft directed to the left, with positive roll angle, and the camera directed to the left and downward, is given herein. The comparison is given taking in consideration the fact that orientation of the axes in CATIA software is different relative to the airctarft (right-hand) coordinate system.

Numerical results are shown for the following input values:
$\Psi = - 9.91^o$
$\Theta = - 3.312^o$
$\varphi = 12.96^o$
$\Psi_1 = 19.841^o$
$\Theta_1 = - 9.693^o$

The following values are obtained for camera angles, namely:
Calculated (equasions 1 – 6):
$\Psi_k = 11.655^o$
$\Theta_k = - 8.192^o$
CATIA:
$\Psi_k = 11.655^o$
$\Theta_k = - 8.19^o$

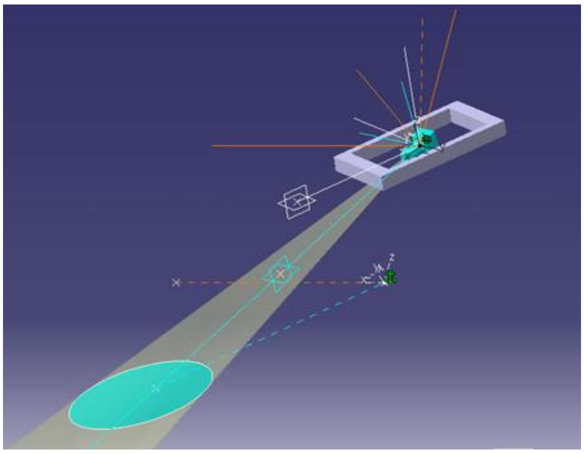

Figure 4: CATIA parallel test model of the aircraft with surveillance camera

Implementation on Aircarft Navigation System

The explained solution has been implemented in realized navigation system of Mi-17 helicopter, which contains the moving navigation map. The system is completed with the required software for transfer, processing and display of the data on the moving map.Testing was performed with real parameters of the navigation system and stabilized platform. The below Figure 5 shows an example of the projection of the field of view of the camera, with parameters corresponding to the previous example and camera rectangular angle of view of 12^o x 8^o, at aircraft relative altitude of 100 m.

The resulting projection can also be displayed on a map on the ground control panel of the unmanned aerial vehicle or on the control panel in another aircraft.

*Corresponding Author: Zdravko Banjac

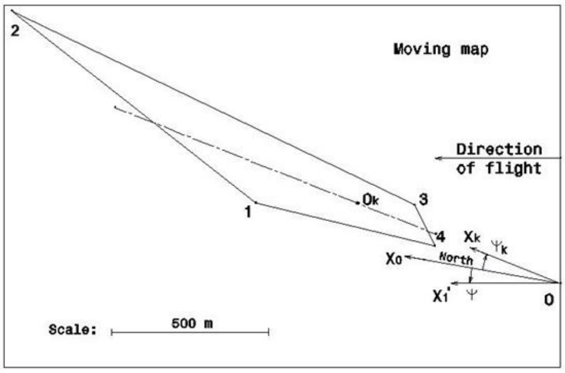

Figure 5: Projection of the camera field of view onto the moving map

Conclusion

The described method of modeling of the system with surveillance camera installed on the aircraft, gives the method for adding of the moving navigation map with visualized surface of the ground which is covered up by the field of view of the camera. This facilitates the pilot (operator) to define current direction of the camera axis, as well as the function of searching for the object on assumed or unknown location. The method is based on the use of input values (altitude and three angles from the navigation system, and two agnles from stabilized platform), and recalculation of the same in ground coordinate system, as well as the input of calculated coordinates into the moving map. The method has exact mathematical character. It has been tested on accuracy, and it has been implemented in realized navigation system of the aircraft, where it was checked in practice.

This method may be used as a part of the algorithm for fire control of the weapon installed inside the turret of the aircraft.

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Nomenclature

H	Relative altitude
O	Begining of coordinate system
X	x - axis
Y	y - axis
Z	z - axis
φ	Roll angle
Θ	Pitch angle
Ψ	Yaw angle
δ	Field of view semi angle

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