New Radio Navigation System for Aircraft Blind Landing

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Abstract— A new radio navigation system for aircraft blind landing is proposed. This system is based on measuring the phase shifts of signals received from four ground transmitters (antennas), placed on corners of the runway strip. The received signals phase shifts provide distance measurements accuracy in millimetres. The reception of these signals is made on the onboard antenna located on the aircraft. Three ground antennas out of the four will be sufficient for determining the location of the aircraft.
As a result of the analysis, the coordinates of the onboard antenna, the coordinates of the centre of mass of the aircraft, and axis coordinate of the aircraft determined with respect to the runway coordinate system.

Keywords*- Radio navigation; blind landing; phase shift; ILS; MLS; GNSS*

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I. INTRODUCTION

The main task of civil aviation is to maintain a regularity of high intensity flights and landing of aircrafts with the given safety on all sizes of airports, temporary and emergency runways, even in case of difficult geographical places and bad climate conditions. The special difficulties caused when the decision of landing to be done in short period on non-equipped runways as landing for emergency evacuation and provide of medical aids etc. Instrument Landing System (ILS), Microwave Landing System (MLS), and Global Navigation Satellite System (GNSS) are the most popular blind landing systems now days. The modern landing systems like ILS and MLS costs from 1.5 to 5 millions [1]. High interest now days on using GNSS system for landing and navigation of aircrafts, the cost of GNSS system depends on the cost of ground system part plus the expenses of the satellite constellation, which is necessary to renew through every 5 years [2]. The ILS and MLS systems can be used in international airports, but it is not possible using them in remote airports, emergency runways and in cases of rescue, and aid operations, because of complexity of their installation and adjustment. In case of GNSS system, at least four GPS satellites needed in the horizon to determine the location of the aircraft, which is may be not possible in some geographical places [3]. The need for reliable, accurate, flexible and cheap blind aircraft landing system for non-equipped runways and squares remains unfulfilled. The blind aircraft landing system suggested should overcome problems and limitations of above mentioned landing systems, and met the requirements of International Civil Aviation Organization ICAO [4]. In this paper, a new radio navigation system for aircraft blind landing is proposed, which is based on measuring the phases of signals received from four ground transmitters (antennas), placed on corners of a runway strip. The reception of signals is made on one antenna located on the aircraft.

In this paper, we describe the following

- Runway coordinate of proposed landing system.
- Coordinates of four ground antennas with respect to runway coordinate system.
- Distance equations between the onboard and ground antennas.
- Calculating the onboard antenna coordinates with respect to runway coordinate system.

Calculating the aircraft centre mass coordinates with respect to the runway coordinate system.

II. RUNWAY COORDINATE SYSTEM

Fig.(1) shows the system coordinates of the airport runway, and coordinates of the four ground transmitters, in the standard Cartesian coordinate system, where the positive x-coordinate pointing to the landing direction, positive y-coordinate pointing up, positive z-coordinate pointing to the right of the landing direction.

Therefore, the ground antennas coordinates are

$$\begin{aligned} &A_1(x_{A1}, y_{A1}, z_{A1}) = A_1(0,0,w/2)\\ &A_2(x_{A2}, y_{A2}, z_{A2}) = A_2(0,0,-w/2)\\ &A_3(x_{A3}, y_{A3}, z_{A3}) = A_3(L,0,w/2)\\ &A_4(x_{A4}, y_{A4}, z_{A4}) = A_4(L,0,-w/2) \end{aligned} \quad (1)$$

Where; w is the width of the runway, l is the length of the runway.

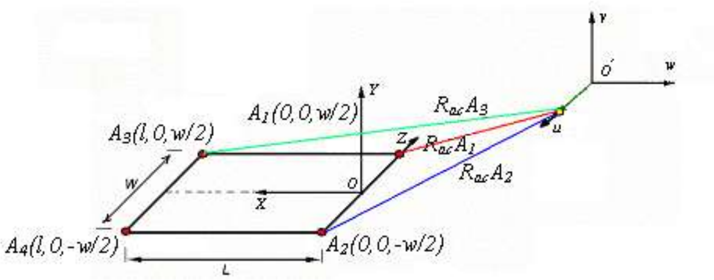

Fig. 1. Runway system coordinates and onboard antenna system coordinates

- **Distance Equations**

Let, the coordinates of the onboard antenna as, x_1, y_1, and z_1, then, we can write down the distance equations between the ground antennas and the onboard antenna as follows:

$$R_{acA1} = \sqrt{x_1^2 + y_1^2 + z_1^2 - z_1 W + (W/2)^2} \;;$$

$$R_{acA2} = \sqrt{x_1^2 + y_1^2 + z_1^2 + z_1 W + (W/2)^2}\ ; \qquad (2)$$

$$R_{acA3} = \sqrt{x_1^2 - x_1 L + (L/2)^2 + y_1^2 + z_1^2 - z_1 W + (W/2)^2}$$

III. CALCULATING THE ONBOARD ANTENNA COORDINATES

By solving the equations of distances, which relate the coordinates of ground and onboard antennas, we can calculate coordinates of the onboard antenna with respect to the runway coordinate system. The onboard antenna (a_c) coordinates can be written as

$$x_1 = \frac{(L^2 - 4N)}{4L};$$

$$z_1 = \frac{M}{2W};$$

$$y_1 = \frac{1}{4}\sqrt{16(Ra_c A_1)^2 - \frac{(L^2-4N)^2}{L^2} - 16\left(\frac{M}{2W} - \frac{W}{2}\right)^2} \qquad (3)$$

Where

$$N = (Ra_c A_3)^2 - (Ra_c A_1)^2;\ M = (Ra_c A_2)^2 - (Ra_c A_1)^2$$

Ra_1A_1 – measured distance between onboard antenna (a_1), and ground antenna (A_1).

Ra_1A_2 – measured distance between onboard antenna (a_1), and ground antenna (A_2).

Ra_1A_3 – measured distance between onboard antenna (a_1), and ground antenna (A_3).

IV. CALCULATING THE AIRCRAFT CENTRE MASS COORDINATES WITH RESPECT TO THE RUNWAY COORDINATE SYSTEM

Using the calculated coordinates of the onboard antenna, and the transformation matrix RPY (Roll-Pitch-Yaw), the coordinates of the aircraft centre mass, and it is attitude can be calculated with respect to the runway coordinate system. Homogeneous transformation matrix between two coordinate systems can be written as

$$\begin{bmatrix} a_{xyz} \\ 1 \end{bmatrix} = \begin{bmatrix} R_{3x3} & P_{3x1} \\ 0 & 1 \end{bmatrix} \begin{bmatrix} a_{uvw} \\ 1 \end{bmatrix} \qquad (4)$$

In our case

R_{3x3} - is the rotation matrix, i.e. rotation of aircraft coordinate system with respect to the runway coordinate system.

P_{3x1} - Translation of the origin of aircraft coordinate system with respect to origin of the runway coordinate system

a_{uvw} - The coordinates of the onboard antenna in the aircraft coordinate system.

a_{xyz} - The coordinates of the onboard antenna in the runway coordinate system.

There is different rotation matrices used in transformation between coordinate systems. In this work the rotation matrix RPY (Roll Pitch Yaw) is used [3].

The RPY rotation matrix can be written as [3].

$$R_{3x3} = RPY = rot(x,\xi)rot(z,\vartheta)rot(y,\varphi)$$

$$R_{3x3} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\xi & -\sin\xi \\ 0 & \sin\xi & \cos\xi \end{bmatrix} \begin{bmatrix} \cos\vartheta & -\sin\vartheta & 0 \\ \sin\vartheta & \cos\vartheta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos\varphi & 0 & \sin\varphi \\ 0 & 1 & 0 \\ -\sin\varphi & 0 & \cos\varphi \end{bmatrix}$$

$$R_{3x3} = \begin{bmatrix} \cos\vartheta\cos\varphi & -\sin\vartheta & \cos\vartheta\cos\varphi \\ \cos\xi\sin\vartheta\cos\varphi + \sin\xi\sin\varphi & \cos\xi\cos\vartheta & \cos\xi\sin\vartheta\sin\varphi - \sin\xi\cos\varphi \\ \sin\xi\sin\vartheta\cos\varphi - \cos\xi\sin\varphi & \sin\xi\cos\vartheta & \sin\xi\sin\vartheta + \cos\xi\cos\varphi \end{bmatrix} \qquad (5)$$

So, the transformation matrix can be written in the following form;

$$\begin{bmatrix} a_x \\ a_y \\ a_z \\ 1 \end{bmatrix} = \begin{bmatrix} R_1 & R_2 & R_3 & O'_x \\ R_4 & R_5 & R_6 & O'_y \\ R_7 & R_8 & R_9 & O'_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} a_u \\ a_v \\ a_w \\ 1 \end{bmatrix} \qquad (6)$$

Where

$R_1 = \cos\vartheta\cos\varphi$

$R_4 = \cos\xi\sin\vartheta\cos\varphi + \sin\xi\sin\varphi$

$R_7 = \sin\xi\sin\vartheta\cos\varphi - \cos\xi\sin\varphi$

(O'_x, O'_y, O'_z)– centre mass coordinates of the aircraft in the runway coordinate system, refer to fig. 1.

Since the coordinates of the onboard antenna in the aircraft coordinate system are known

$a_c(u_{ac}, v_{ac}, w_{ac}) = a_c(l,0,0)$

l – Is the distance between onboard antenna and the origin of the aircraft coordinate system.

Then equation(6), can be written as

$$\begin{bmatrix} a_x \\ a_y \\ a_z \\ 1 \end{bmatrix} = \begin{bmatrix} R_1 & R_2 & R_3 & O'_x \\ R_4 & R_5 & R_6 & O'_y \\ R_7 & R_8 & R_9 & O'_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} l \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

Then,

$$a_x = R_1 l + O'_x;\ a_y = R_4 l + O'_y;\ a_z = R_7 l + O'_z \qquad (7)$$

Then

$$O'_x = a_x - R_1 l;\ O'_y = a_y - R_4 l;\ O'_z = a_z - R_7 l;$$

Similarly, the aircraft coordinate axes $O'\ u\ v\ w$ can be fully defined in the runway coordinate system. This allows knowing the aircraft attitude with respect to the runway and the gliding slope.

Distances R_{acA_1}, R_{acA_2}, and R_{acA_3} (refer to equation (2)) between onboard and ground antennas are calculated using the measured shifts in phase of the received signals.

ISSN: 2321-8169
626 - 628

V. CONCLUSION

New radio navigation system for aircraft blind landing for non-equipped runways and squares was proposed. The onboard navigation algorithm will determine the location of the airplane with respect to the touch point on the runway using the received signals phase shifts, which provide distance measurements accuracy in millimeters [5]. The coordinates of the aircraft centre of mass, system coordinates of the airplane, and it is attitude calculated with respect to the runway coordinate system. This information allows the autopilot to perform full automatic landing operation, plus the display equipment offers the crew full information of the aircraft position with respect to the runway. For a future publications, the following subjects regarding the above proposed blind landing system will be discussed;

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