DECODING M – QASK SIGNAL ADF III. GENERATION

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Air traffic has become in terms of the volume of flights more and more difficult to create safe movement of aircraft in the air and on the ground. Aircraft surface tracking after landing, before take – off on taxiway is paid a significant amount of attention. Also another aircraft and motor vehicle surface tracking system may be used presented local positioning system, that uses the principle of III. generation radio compasses. This article deals with III. generation radio compasses quadrature signal decoding used for determining the position of object on the airport. Such a system design uses triangulation method application with Google Maps. This principle allows real time displaying the position and movement of the object. It is expected, that object's tracking will be provided with relatively high accuracy. Taking into account the innovative idea, the accuracy issue would not be evaluated in this article.

K e y w o r d s: radio compass, Matlab, Simulink, local positioning system

1. INTRODUCTION

For aircraft surface tracking on airport area are used several systems. Using triangulation method and III. generation radio compasses integration is possible to create another method of aircraft and motor vehicle airport surface tracking. For determining the bearing information from radio compass output signal amplitude ratio is necessary to decode this quadrature signal. With knowledge of bearings from at least 3 radio compasses and using digital map, it is possible to create the tracking system. In the first chapter is described basic principle of III. generation radio compasses with created model in Simulink. Determining the bearing from radio compass quadrature signal decoding is described in second chapter. Mathematical model of object's position calculating is listed in third chapter. Final chapter describes design of local positioning system, which uses information from three radio compasses connected with Google Maps, supplemented by advantages of such a system for aircraft and vehicles airport surface tracking, but also for tracking in normal traffic.

2 BASIC PRINCIPLE OF III. GENERATION RADIO COMPASSES AND IT'S MODEL IN SIMULINK

Automatic III. generation radio compasses use antenna system consists of loop antenna and sense antenna. Bearing information is obtained by sinus – cosines loop antenna signal modulation followed by digital processing of summed loop and sense antenna signal. Determining the final bearing information is made by microprocessor based on signal amplitudes and phases.

The loop antenna consists of two crossed coils, where one is oriented in longitudinal and one in lateral aircraft axis. The longitudinal oriented antenna is called sine antenna and lateral oriented is called cosine antenna. For determining bearing information is sine antenna signal phase modulated by rectangular 32 Hz signal and cosine antenna signal is modulated by the same signal, but 90 ºshifted. Signal that modulates sine antenna signal is called sine modulating signal and signal that modulates cosine antenna is called cosine modulating signal.

By processing signals from loop antennas by creating the bearing information, signals are summing taking into account their phases and amplitudes. By this, there are created four different time sections – quadrants marked as I, II, III, IV. Next is the summed loop antenna signal counted with sense antenna signal, which is not modulated. Because the sense antenna signal amplitude is greater, the initial phase will be the same in all four quadrants and only amplitude will change (Figure 1).
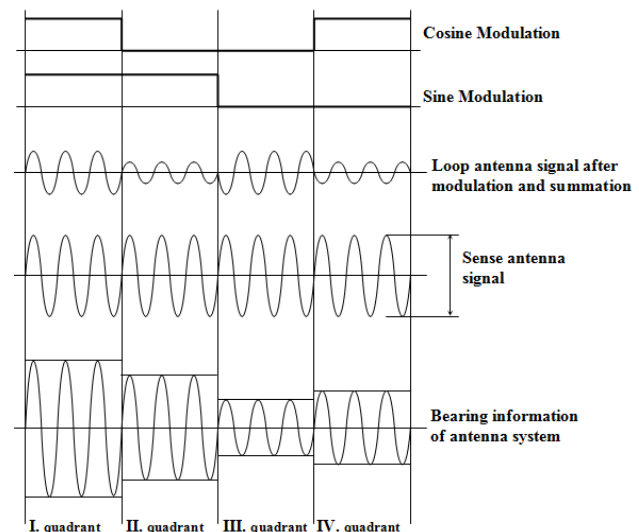

**Figure 1 Impact of sense antenna signal on bearing information.**

Bearing information is then represented by signal amplitude ratio in four quadrants of one modulating period.

For calculating the bearing is needed to create a model of III. generation radio compass in Simulink. After simulation, we got output signal divided into 4 quadrants. Block diagram of III. generation radio compass in Simulink will be as described on Figure 2.
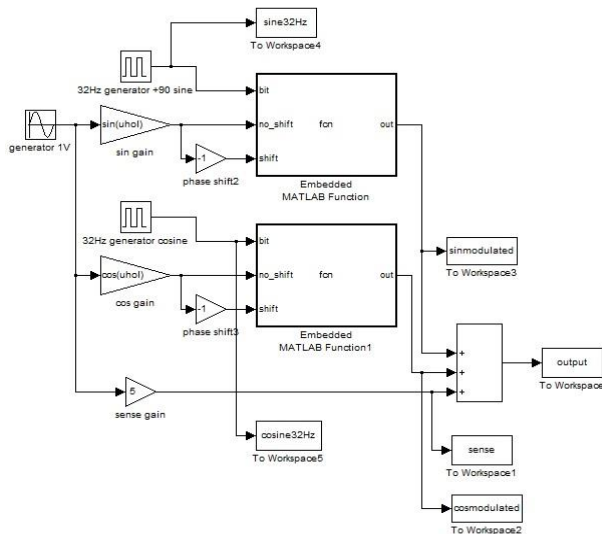
Figure 2 Block diagram of III. generation radio compass in Simulink.

The output signal after summation contains the bearing information, which has the form as described on Figure 3. Signal magnitudes in separate quadrants are different for various bearings. This fact can be used for calculating the specific bearing.
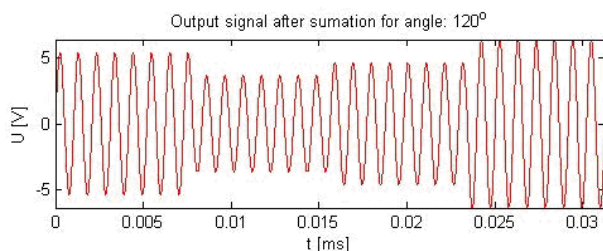

Figure 3 Radio compass output signal after summation.

3 QUADRATURE MADULATED SIGNAL DECODING IN MATLAB

By simulation in Simulink were gathered data of amplitudes size in separate quadrants for bearings in whole range 0° až 360°. This set of data is suitable for using neural network, where as inputs were used four of amplitudes for specific bearing and as output was used the concrete bearing. Because data were gathered with sampling 0.1°, it was possible thanks to neural networks and used Levenberg – Marquardt algorithm to approximate these curves in shape of sine with very high precision.

The relation between bearing and signal amplitude is not a function, because for one value of amplitude there exist just two values of bearing, what describes Figure 4.
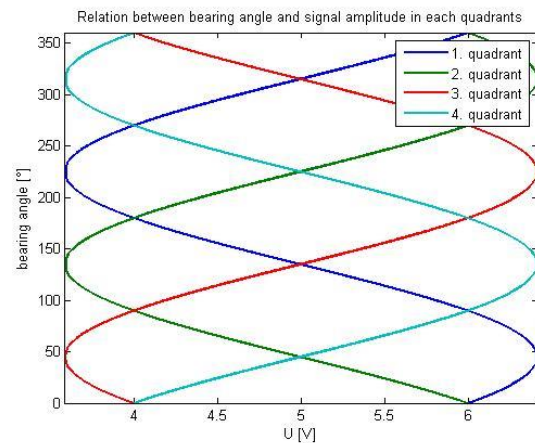
Figure 4 Relation between bearing and signal amplitude in separate quadrants.

Algorithm for counting the bearing is based on calculating amplitudes ratio in separate quadrants. In general, we could label this ratio as x. The relation between bearing and x (or separate amplitudes) is not a function, but for every value x exist 2 values of bearing from which one is the right bearing and the other one is just shifted considering to theoretical maximum or minimum of curve shaped like turned sine what results also from Figure 4.

In the firs step, it was necessary for every x to find these two values of bearing. In the next step I transformed these bearings to length of a circular arc., so that angles from 0° do 180° were different from angles 180° do 360° just by sign, to be able to calculate the right bearing. Lengths represented the right angle weren't much different, but lengths represented shifted angle were much more different, so by sorting these values by size, then by determining their respected differences and averaging of values which were very close to each other, was able to calculate value of bearing corresponding to the foursome of amplitudes in all four output signal quadrants. Mentioned procedure was in Matlab implemented as a function with three parameters.

```
[angle] = determineAngle(amp,Yt,psim);
```

Inaccuracy of determining the bearing from amplitudes in four quadrants was ranged from 0 to 0.015 with sampling 0.1°, what represents almost insignificant error and can be considered as relatively accurate calculation of bearing.

4 USING TRIANGULATION METHOD FOR TRACKING THE OBJECT'S MOVEMENT

For determining the position by triangulation method is necessary to receive the signal at least in two and more stations. The nature of triangulation method will be explained with application to solved problem in navigation based on using three radio compasses –

receivers, and one transmitter – aircraft. Determining the position of aircraft is done based on known azimuths (angle between line receiver – geographical north and line transmitter - receiver), according to which are made lines where the aircraft is located in their intersections. Measuring azimuths is performed in measuring outposts A, B, C. This type of using triangulation method is described in Figure 5.
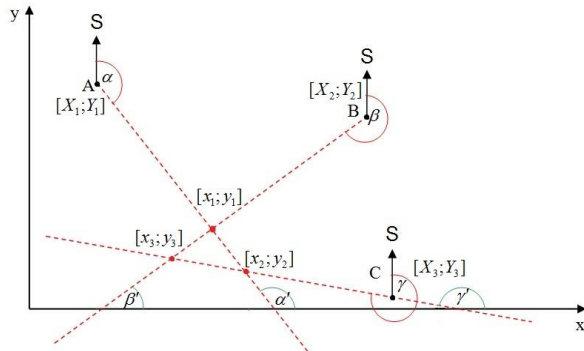

Figure 5 Principle of triangulation method.

As described in Figure 5, these three lines don't intersect in one point. But they made three intersects, which create triangle and the object is located near by these intersects. Fact that there is not only a single intersect is based on inaccuracy of radio compasses as it self. More accurate position of object we can determine by calculating the center of mentioned triangle. Calculating the equations of lines, their intersections and center of triangle, in fact the calculating the object's coordinates will be more detailed described in next part.

Lines equation computation

Assume that source of the signal with coordinates $[X_t; Y_t]$, (Figure 6), is aimed from three outposts A, B, C. Object is then located near intersects of three lines crossing points A, B, C. Equation of the line from outpost A would look like:

$$y = k.x + q \Rightarrow q = Y_1 - k.X_1 = Y_1 - tg(\alpha').X_1 \quad (1)$$

$$y = k.x + [Y_1 - tg(\alpha').X_1] \quad (2)$$

$$y = tg(\alpha').x + [Y_1 - tg(\alpha').X_1] \quad (3)$$

Principle of determining of line equation is described in Figure 6.
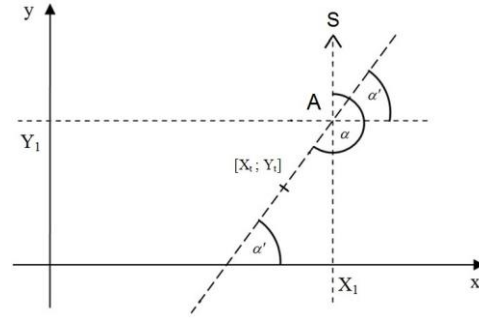

Figure 6 Line equation computation.

Where $[X_t; Y_t]$ are coordinates of object – source of signal. And where $[X_1; Y_1]$ are coordinates of outpost A, and α is angle between geographical north and transmitter of radio signal, which we can determine from radio compass placed in outpost A. Angle α' we calculate as following:

$$\alpha = 0° \Rightarrow \alpha' = 0° \quad (4)$$

$$\alpha \in \left(0°;180°\right\rangle \Rightarrow \alpha' = 90° - \alpha \quad (5)$$

$$\alpha \in \left(180°;360°\right) \Rightarrow \alpha' = 270° - \alpha \quad (6)$$

$$\alpha = 360° \Rightarrow \alpha' = 0° \quad (7)$$

Similarly I derive also line equations from outposts B, C and then also the conditions for calculating angles β' and γ', which are the same with conditions for calculating α'. From outpost B:

$$y = tg(\beta').x + [Y_2 - tg(\beta').X_2] \quad (8)$$

From outpost C:

$$y = tg(\gamma').x + [Y_3 - tg(\gamma').X_3] \quad (9)$$

Equations provided higher are representing equations of three lines, which should intersect in one point. However, because of III. generation radio compasses inaccuracy, which maximum error is approximately ±3°, these three lines create 3 intersects. These intersects represents three approximately coordinates of object.

Line intersects computation

Line Intersects are possible to compute by successive combination of line equations, which results in system of two equations with two variables. In computation of first intersect can be used equations mentioned earlier (3) and (8).

$$y = tg(\alpha').x + [Y_1 - tg(\alpha').X_1]$$

$$y = tg(\beta').x + [Y_2 - tg(\beta').X_2]$$

For computation of line intersects and so coordinates [x; y] were used method, which allows to find

solutions of system of linear equations – Cramer rule. This method for calculating was also usable for programming in C++. Using Cramer rule we can create equations showed below, which determine value of intersects:

$$x = \frac{(c_1.b_2) - (c_2.b_1)}{(a_1.b_2) - (a_2.b_1)} \quad y = \frac{(a_1.c_2) - (a_2.c_1)}{(a_1.b_2) - (a_2.b_1)} \tag{10}$$

Where:

$$a_1 = \tan(\alpha') \qquad a_2 = \tan(\beta')$$
$$b_1 = -1 \qquad\qquad b_2 = -1$$
$$c_1 = \tan(\alpha').X_1 - Y_1 \quad c_2 = \tan(\beta').X_2 - Y_2 \tag{11}$$

Form of stated equations is the same as is used with programming solution.

Center of triangle computation

Center from physics point of view is sort of center of mass of the body, which may lie beyond the material, from which the body is composed. In our case, however, it is not a body, but triangle. For coordinates of center of n points are valid equations:

$$x_t = \frac{\sum_{i=1}^{n} m_i.x_i}{\sum_{i=1}^{n} m_i} \qquad y_t = \frac{\sum_{i=1}^{n} m_i.y_i}{\sum_{i=1}^{n} m_i}, \tag{12}$$

In our case we can consider the mass as a infinitely small and equal for all intersects (triangle points), so the equations for calculating the center of triangle are:

$$x_t = \frac{x_1 + x_2 + x_3}{3} \qquad y_t = \frac{y_1 + y_2 + y_3}{3} \tag{13}$$

From stated results that canter of created triangle is possible to count as an arithmetic average from intersects. Computed coordinates of triangle center we can consider as coordinates of object – aircraft.

Accuracy of determining source of the signal with triangulation method depends mainly from the width of the characteristics of independent antenna systems. Size of uncertainty and hence the positioning errors increases with enlarging the distance between transmitter and receiver. Adding further measuring outpost can reduce the error.

5 DESIGN OF TRACKING SYSTEM

On Figure 7 is described principle of determining the position by three positioning outpost, measuring the bearing to transmitter – object. By using triangulation

method and digital map is possible to determine the accurate position of the object on this map.

Figure 7 Local positioning system.

Consider the local positioning system, which consist of three positioning outposts – III. generation radio compasses, which measure bearing to the transmitter. On Figure 8 is described block scheme of mentioned system.
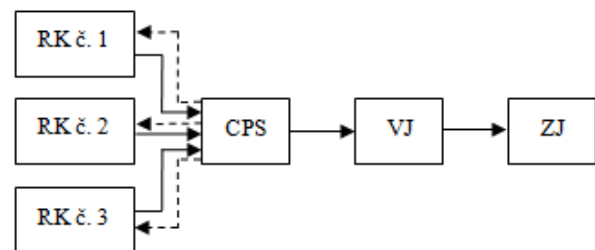

Figure 8 Block scheme of local positioning system design.

Where RK – represents III. generation radio compass, which measures bearing to transmitter. Measured data are transmitted to CPS – central positioning system and then to VJ – computational unit, where is based on received data computed the position of object, which is then displayed on ZJ – display unit. Displaying the position of object is possible automatically in specific time interval between measuring data, in real time, or as a request of operator by simple command.

Created software application as the local positioning system communicates with hardware device, which replaces the real positioning outposts. On Figure 9 is described such a device, which shows on display fictive bearings from positioning outposts. It contains three potentiometers for setting the bearing angle and their transmission to computer for displaying the position of object on map.

Figure 9 Hardware device – imitation of positioning outposts.

Software application for object tracking using triangulation method – local positioning system

Software application as a local positioning system was created in Qt, which showed as suitable for working with graphical interface. User interface is shown and described on Figure 10.

Figure 10 Basic parts of application for object position calculating.

Description of Figure 10:
1) GPS coordinates of radio compasses (positioning outposts).
2) Bearing angles to transmitter (object) respected to their positioning outposts.
3) Computed GPS coordinates of object.
4) Digital map.
5) Position of object on map.

The advantage of using Google Maps Api is, that it provides all map advantages Google, including zooming and panning without restriction and so on. Also it is possible to choose between types of maps, road map or satellite map. In case of absence of internet connection Google maps is not available any more, but this situation can be solved by changing to offline mode.

The advantage of this system is that it is an independent system, so it doesn't require additional device or sensors. It is sufficient to determine the GPS position of positioning outpost once, and then works independently.

Mentioned system is possible to place on various spots theoretically without any limits. And because it should work in middle waves range, there won't be so strong interference. It is a centralized system, so all information are transmitted to one central positioning station, where these data are processed, so there is possible to track and control the situation from one place and without high cost with realizing such a system. System is capable to work with more positioning outpost, what could increase the accuracy of tracking the object.

5 CONCLUSION

Using created mathematical model of triangulation method and calculated bearing angle after

decoding output quadrature signal from at least three II. Generation radio compasses, was possible to calculate the position of transmitter. This fact was used to help create software application, which based on positioning outpost coordinates and their respected bearing angles, display the position of object on map. Application is using Google Maps, what provides great advantages for working with map. Also there is solved the problem of internet unavailability by changing to offline mode. Application communicates through serial port with hardware device, which replaces the real positioning outposts and is capable of real time tracking. With it's advantages and mentioned facts, it is obvious that it is possible to create local positioning system for aircraft and motor vehicle surface tracking on airports but also in normal operation outside the airport area using III. generation radio compasses.

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