

# AIRPORT POSITIONING SYSTEM

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The article deals with III. generation radio compasses quadrature signal decoding, which could be used for determining the object's position on the airport surface. In terms of the volume of flights, for air traffic it has become 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 are paid significant amount of attention. Also another aircraft and motor vehicle surface tracking system may be used as the presented local positioning system, which is based on the principle of III. generation radio compasses. Such a system design uses triangulation method application with Google Maps. The principle allows real time displaying the position and movement of the object. It is expected, that object's airport surface 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

Aircraft surface tracking on airport area makes use of several systems. Applying the triangulation method and integration of III. generation radio compasses enables development of another method of airport surface tracking of aircraft and motor vehicles. 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. The 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 ADF III. GENERATION MODEL IN SIMULINK

Mathematical model is based on block scheme of III. generation radio compass, which antenna system consists from sense antenna and loop antenna (sine and cosine antenna). As a replacement for the antenna system, a harmonic signal generator block with frequency  $1920\pi = 960 \text{ Hz}$  was used. The amplitude of the generator is set to 1 V. Amplitude for sensed antenna signal is set to 5V. For needs of phase modulation square signal generator with frequency 32 Hz were used, where the generated signals for sine antenna modulation were shifted  $90^\circ$  against for cosine antenna signal modulation. Phase modulation of signal is represented by rotating the phase of modulated signal when modulating signal is on 0.

Bearing information is then represented by the output signal amplitude ratio in four quadrants of one modulating period. Block scheme of III. generation radio compass in Simulink is described in

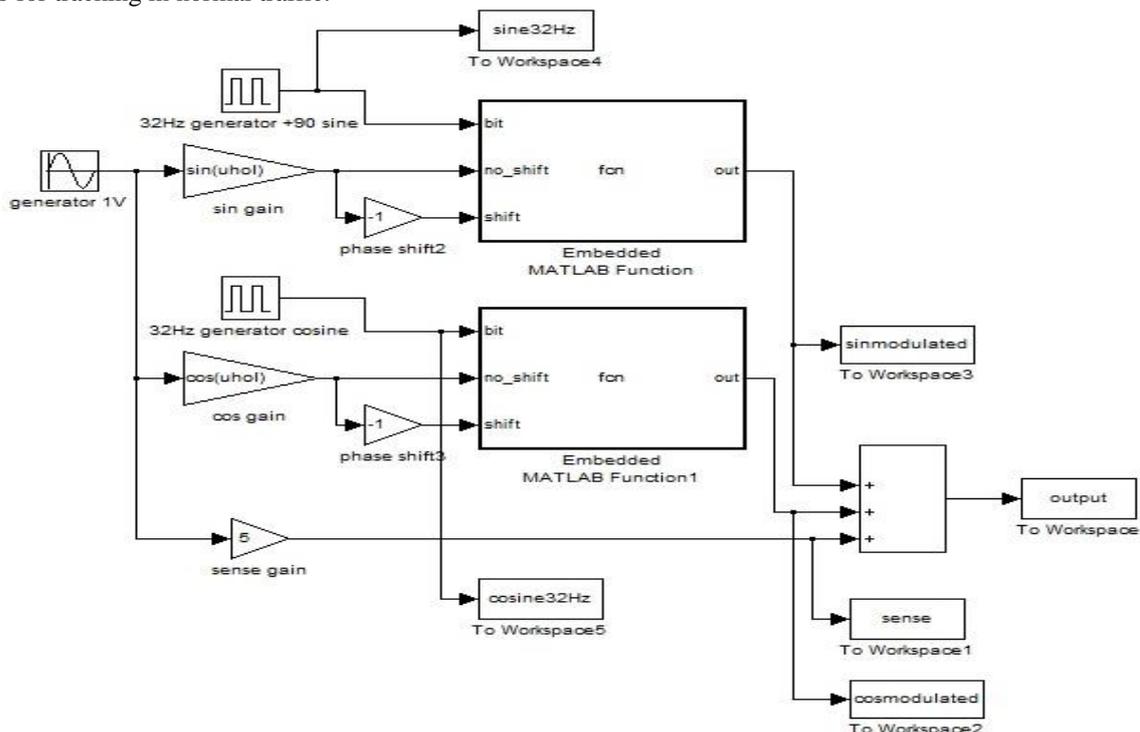


Figure 1 Block scheme of signal creating in III. generation radio compass in Simulink

The III. generation radio compass output signal, which contains bearing information, is shown in Figure 2. Size of amplitudes in separate quadrants of output signal is different for each bearing angle. This fact can be used for calculating the bearing angle.

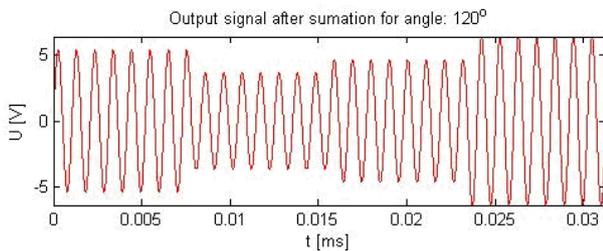


Figure 2 Radio compass output signal after summation

### 3 DECODING OF M – QASK SIGNAL

Simulation in Simulink help gather data of amplitudes size in separate quadrants for bearings in whole range 0° up to 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 3.

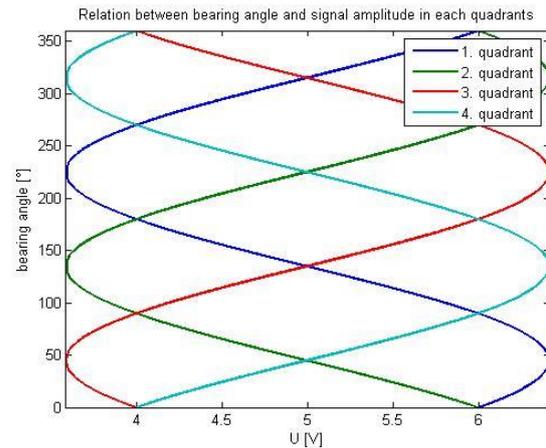


Figure 3 Relation between bearing and signal amplitude in separate quadrants.

The 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 3.

In the first 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 ranged from 0 to 0.015 with sampling 0.1°, what represents almost insignificant error and can be considered as relatively accurate calculation of the bearing angle.

### 4 TRIANGULATION METHOD IN PRAXIS

To determine the position by triangulation method it 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 4.

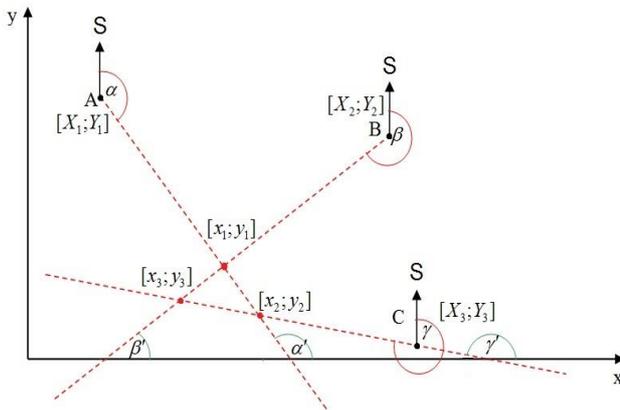


Figure 4 Principle of triangulation method

As described in Figure 4, the three lines don't intersect in one point. But they made three intersects, which create triangle and the object is located near by these intersections. The fact that there is not only a single intersect is based on inaccuracy of radio compasses as themselves. More accurate position of object can be determined by calculating the center of mentioned triangle.

**Lines equation computation**

Assume that source of the signal with coordinates  $[X_i; Y_i]$ , (Figure 5), 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:

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

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

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

Principle of determining of line equation is described in Figure 5.

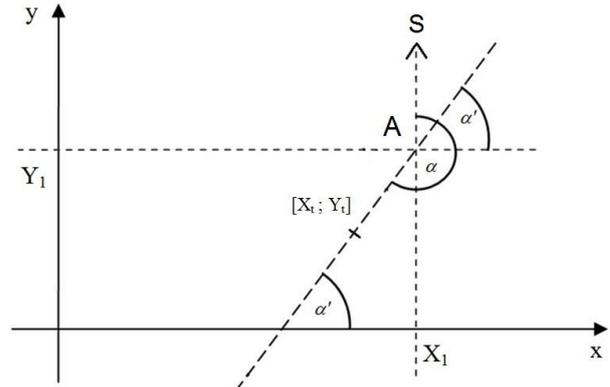


Figure 5 Line equation computation.

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

$$\alpha = 0^\circ \Rightarrow \alpha' = 0^\circ \quad (4)$$

$$\alpha \in (0^\circ; 180^\circ) \Rightarrow \alpha' = 90^\circ - \alpha \quad (5)$$

$$\alpha \in (180^\circ; 360^\circ) \Rightarrow \alpha' = 270^\circ - \alpha \quad (6)$$

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

Similarly I derive also line equations from outposts B, C and then also the conditions for calculating angles  $\beta'$  and  $\gamma'$ , which are the same with conditions for calculating  $\alpha'$ . From outpost B:

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

From outpost C:

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

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  $\pm 3^\circ$ , these three lines create 3 intersects. These intersects represents three approximately coordinates of object.

**Computing the line intersections**

Line intersections can be computed 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).

$$y = \text{tg}(\alpha') \cdot x + [Y_1 - \text{tg}(\alpha') \cdot X_1]$$

$$y = \text{tg}(\beta') \cdot x + [Y_2 - \text{tg}(\beta') \cdot X_2]$$

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:

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

Where:

$$a_1 = \tan(\alpha') \quad a_2 = \tan(\beta')$$

$$b_1 = -1 \quad b_2 = -1$$

$$c_1 = \tan(\alpha') \cdot X_1 - Y_1 \quad c_2 = \tan(\beta') \cdot X_2 - Y_2 \quad (11)$$

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:

$$x_t = \frac{\sum_{i=1}^n m_i \cdot x_i}{\sum_{i=1}^n m_i} \quad y_t = \frac{\sum_{i=1}^n m_i \cdot y_i}{\sum_{i=1}^n m_i} \quad (12)$$

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:

$$x_t = \frac{x_1 + x_2 + x_3}{3} \quad y_t = \frac{y_1 + y_2 + y_3}{3} \quad (13)$$

The center of created triangle can be calculated count as an arithmetic average of the intersections. The computed coordinates of the triangle center can be considered as coordinates of the 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 STRUCTURE OF THE TRACKING SYSTEM**

Figure 6 describes the principle of determining the position by three positioning outpost, measuring the bearing to transmitter – object. By using the triangulation method and digital map is possible to determine the accurate position of the object on this map.



Figure 6 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 7 is described block scheme of mentioned system.

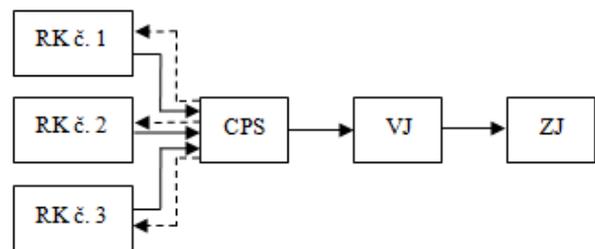


Figure 7 Block scheme of local positioning system design.

Where RK – represents the III. generation radio compass, which measures bearing to the 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 requested by operator on a simple command.

The developed software application as the local positioning system communicates with hardware device, which replaces the real positioning outposts. Figure 8 describes 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 8 Hardware device – imitation of positioning outposts.

### 5.1 Software application of 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 9.



Figure 9 Basic parts of application for object position calculating.

Description of Figure 9:

- 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.

For proper use, it is necessary to describe functionality of separate buttons, which are shown in Figure 10.

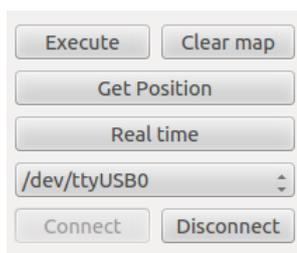


Figure 10 Application buttons.

By pressing EXECUTE the object position is calculated and drawn into the map. The GET POSITION

button is used to send signal to hardware device to ask for bearing angle from positioning outposts, calculating and drawing it's position into map. The REAL TIME button is used for receiving data from positioning outposts in real time and displaying the object position on map. Next button with port name on it, is used to choose the concrete port through which the communication will run with hardware device after clicking on the CONNECT button. DISCONNECT button ends this communication and closes the port.



Figure 11 Application check box.

Application contains 3 check boxes (Figure 11). The first is used for displaying the track of the object through his movement, second one is used to display the position of positioning outposts – radio compasses on map and last one is used to show the lines between radio compass and partial calculated object's positions as illustration for calculating the object's position.

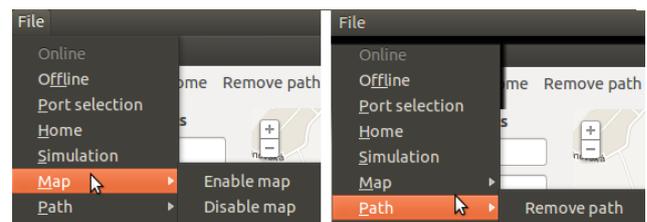


Figure 12 Application file menu.

In this file menu (Figure 12) it is possible to change the application mode to offline and back to online. Port selection is used to load all available ports, through which the application will communicate with hardware device. Function Home centers the map to area where positioning outposts are placed. Function Simulation is used to simulate the movement of motor vehicle on LF area. Next, it is possible to change map settings to disable manipulation with map. It's also possible to turn these settings back on. Last option is to remove path, which represents tracking the object's movement. The path will be then recording all over again.

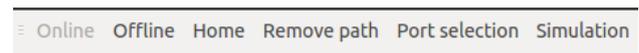


Figure 13 Application toolbar

In toolbar (Figure 13) is possible to choose between online maps, which use Google Maps Api and offline map of the concrete area in case of internet unavailability. HOME button is used to center online maps to position of positioning outposts area. REMOVE PATH button removes the path recorded by given movement and starts all over again. Another PORT SELECTION button is used to load all available ports,

through which can be used to communicate with hardware device, same as in File Menu. Last option is SIMULATION button, which simulates movement of motor vehicle in LF TUKE area. This option exists just to simulate the real situation for tracking the vehicle. Example of displaying the path throughout the object's movement in LF TUKE area is shown in Figure 14.

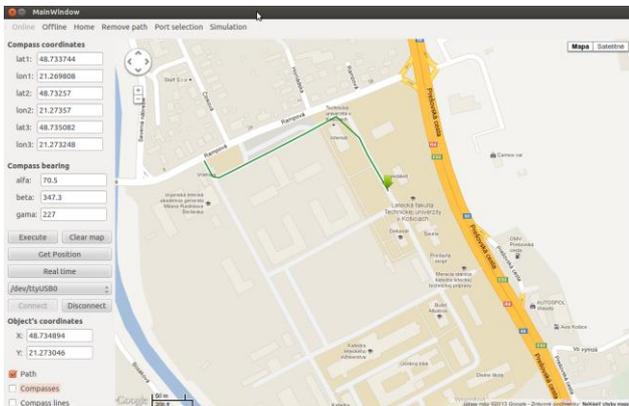


Figure 14 Object surface tracking.

The advantage of using Google Maps Api is, that it provides all map advantages Google, including zooming and panning without limits 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. This mode provides all standard functions, but with limits on given area. Mentioned offline mode is shown in Figure 15.

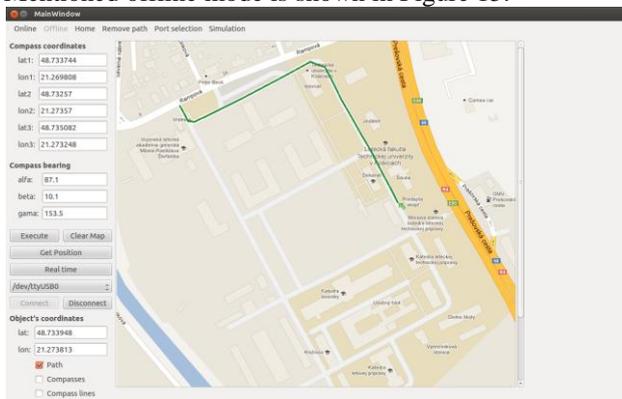


Figure 15 Application offline mode.

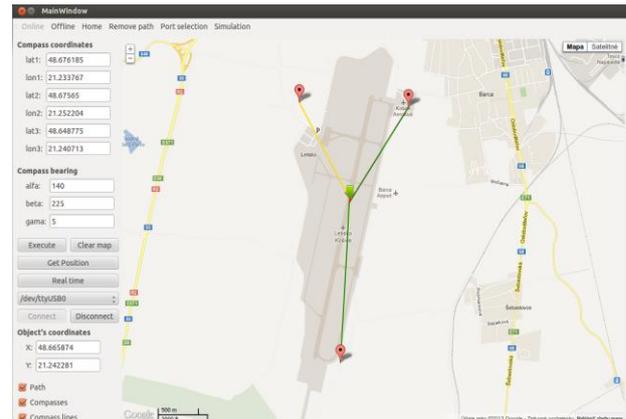


Figure 16 Usage of local positioning system on Košice airport area.

Thanks to options, which application Google Maps Api offers, it is possible to use this software application and so called local positioning system use theoretically anywhere without limits of map for object's position displaying. Figure 16 shows the situation of using this system at the Košice airport area while displaying the aircraft position on runway.

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. The system is capable of working with more positioning outposts, which could increase the accuracy of object tracking.

## 5 CONCLUSION

Using the developed mathematical model of triangulation method and calculated bearing angle after decoding output quadrature signal from at least three III. generation radio compasses made it possible to calculate the position of transmitter. This fact was used to help develop software application, which are based on positioning outpost coordinates and their respected bearing angles, displaying the position of object on map. The application is using Google Maps, providing great advantages for working with map. Also solved is 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 the advantages and mentioned facts, it enables development of a local positioning system for surface tracking of

aircraft and motor vehicle at airports but also for normal operation outside the airport area using III. generation radio compasses.

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