TRANSNAV International Journal on Marine Navigation and Safety of Sea Transportation
Volume 2
Number 2
June 2008

Accuracy of Relative Navigation in Automated Systems of Data Communication

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ABSTRACT: The architecture of wide-band synchronous automated systems of data communication (ASDC) enables utilization of high accuracy measurement of the signal reception times to relative navigation in the network. In this contribution an operation analysis of such systems in the relative navigation mode is conducted. The accuracy and possibilities of the utilization of these systems were examined by modeling in air navigation.

1 INTRODUCTION

Wide-band ASDC, utilizing the TDMA (Time Division Multiple Acces) technique feature high capacity of transferring digitalized and coded data. Each user has a “synchronized clock” and is alocated a necessary portion of throughput of the system in accordance with the task under solution. In the instances of time alocated for transmission the user is “transmitting data”, which can be used by the rest of the users. Digital processing of the signal enables each user access to all kinds of information transmitted by other users, while it is unimportant for him to know who produced them.

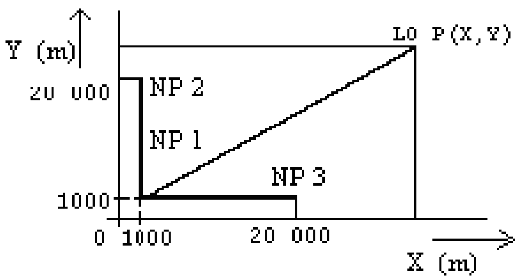

Fig.1. The ASPD for relative navigation within the network of users

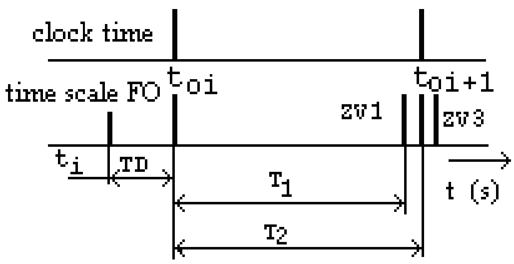

Fig. 2. Clock time and time scale FO

This is achieved by filters with variable parameters ensuring high accuracy of measuring time of the signal when received from other users and also make it possible to use the ASPD for relative navigation (RELNAV) within the network of users of the given system (Fig. 1, 2).Suppose ASDC terminals are on board of flying objects (FO), or non-flying objects (NFO). Adding the ASDC board computer with a program module one can perform RELNAV function and absolute navigation without the need to complement the board of the flying object by a new, extra piece of a navigation equipment. This way, one can enhance the ASDC capabilities and, on the basis of it, design unified systems of data communication and navigation [1, 2].

2 DEFINING THE TASK

Suppose we have a right angle coordinate system XOY, wherein there are navigation points (NP) marked with digits from 1 to N. For the sake of simplification let us reduce the three-dimensional task of determining the position of the FO to a two-dimensional one. In that two-dimensional coordinate system, let there be located N number of NPs with known coordinates x_k, y_k, where k = 1, 2,....N and the flying object FO with y, x coordinates is to be measured (Figure 3).

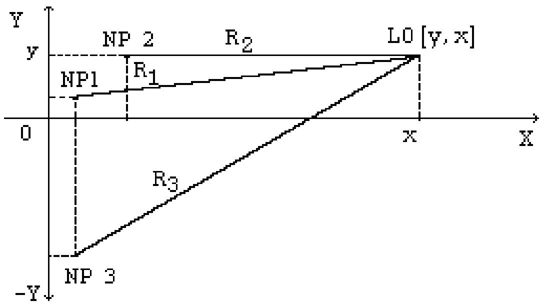

Fig. 3. Determining position of a flying object

Difference R_i can be obtained by expression:

$$R_1^2=(y_1 - y)^2 + (x_1 - x)^2; \quad (1)$$

$$R_2^2 = (y_2 - y)^2 + (x_2 - x)^2; \quad (2)$$

$$R_3^2 = (y_3 - y)^2 + (x_3 - x)^2; \quad (3)$$

Solving the equations (1-2) the y is expressed as follows:

$$y = c.x + e, \quad (4)$$

where

$$c = a/b; \; e = d/2.b; \quad (5)$$

$$a = x_2 - x_1; \; b = y_2 - y_1; \quad (6)$$

$$d = - y1 + y2 - x1 + R21 - R22; \quad (7)$$

Subsituting (4) into (3) we arrive at expression:

$$h.x^2 + f.x + g = 0, \quad (8)$$

where $h = c^2 + 1$; $f = 2.e.c - 2.y_3.c - 2.x_3$;

$$g = e^2 - 2.y_3.e + y_3^2 + x_3^2 - R_3^2; \quad (9)$$

Then, by solving the equation (8), we obtain the coordinates of the flying object (FO point) by the following functions:

$$X_{LO1} = (- f - (D)^{0,5})/2.h; \quad (10)$$

$$Y_{LO1} = c.X_{c1} + e;$$

$$X_{LO2} = (- f + (D)^{0,5})/2.h \quad (11)$$

$$Y_{LO2} = c.X_{c2} + e;$$

where $D^2 = f_2 - 4.h.g$.

From expressions (10-11) it is evident that the task of determining the coordinates of a FO is ambiguous. As it follows from Figure 1, this problem can be solved through proper choice of the coordinate system and choosing the proper coordinates of the FO (X_{LOi}, Y_{LOi}) on the basis of known coordinates of NB and the distance R_i.

3 THE INFLUENCE OF THE ACCURACY OF MEASURING R_I ON ACCURACY OF DETERMINING THE POSITION OF THE FO

Expressions (10) and (11) can be used in modelling the influence of inaccuracy of measuring the distance dR_i onto the accuracy of determining the position of the FO which can be expressed using the quadratic error of determining the position of the FO(SKLO) S_r . Values of dR_i and S_r is calculated the following way:

$$dR_i = R_i - R^*_i$$

$$S_r=(dx^2+dy^2)^{0.5}, \quad (12)$$

where R^*_i stands for the measured position of the FO,; dx, dy are errors of determining the coordinates of the FO as a result of errors in measuring the distance dR_i.

Further I am going to present examples of modelling the influence of dR_i onto the accuracy of determining the position of the FO. To perform simulation of the function of the ASDC in RELNAV mode a new program was developed in the Delphi program environment. We expect that determining the position will be effected in compliance with the derived algorithms on a selected area of the Slovak Republic. NP as FO and their coordinates on the map are given in pixels.

Figure 4. illustrates the dependence of S_r upon dRi, for the case when $dR_1 = dR_2 = dR_3$ and these coordinates are (Figure 3): x_1 = 31.0 pixels; y_1 = = 457.0 pixels; x_2 = 11.0 pixels; y_2 = 230.0 pixels; x_3 = 28.0 pixels; y_3 = 1.0 pixel; x = 615.0 pixels; y = 231.0 pixels.

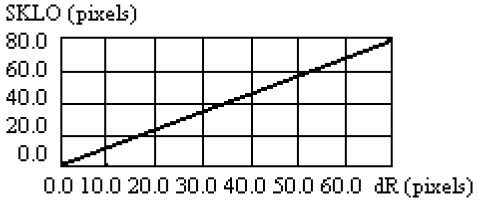

Fig. 4. Dependence of SKLO upon dRi, for the case when $dR_1 = dR_2 = dR_3$

This is a typical example of relative navigation of FO within the tactical system of data transfer [1, 2]. Based on the graph it is obvious that by increasing the inaccuracy in measuring the distance dR_i the error in determining the position is increasing. Dependence of S_r on dR_i is almost linear and S_r is roughly equalling to $1{,}15.dR_i$. Modelling has proved the theoretical premises about the fact that a highly accurate measuring of the position of a FO makes it inevitable to perform highly accurate measurement of distance R_i.

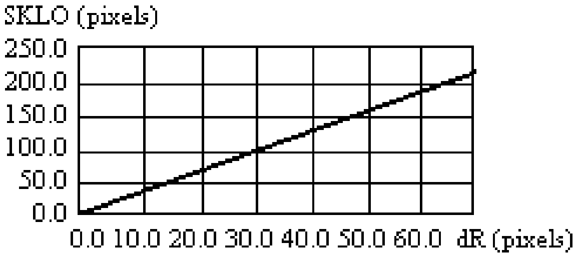

Fig. 5. Dependence of S_r upon dR_i, for the case when $dR_1 \neq 0$, $dR_2 = dR_3 = 0$

Figure 5 is illustrating the dependence of SKLO upon dRi, for the case when $dR1 \neq 0$, $dR_2 = dR_3 = 0$. Figure 6 is revealing the dependence of SKLO upon dR_i, for the case when $dR_1 = dR_3 \neq 0$, $dR_2 = 0$ and these coordinates (Figure 3): $x_1 = 31.0$ pixels; $y_1 = 457.0$ pixels; $x_2 = 11.0$ pixels; $y_2 = 230.0$ pixels; $x_3 = 28.0$ pixels; $y_3 = 1.0$ pixel; $x = 615.0$ pixels; $y = 231.0$ pixels.

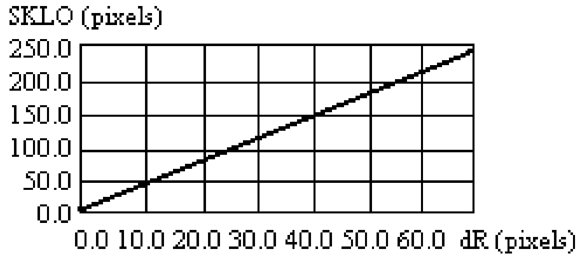

Fig. 6. Dependence of SKLO upon dRi, for the case when $dR_1 = dR_3 \neq 0$, $dR_2 = 0$

This example is typical for relative navigation of FO. Even in these cases it has been confirmed that if want to be able to exactly determine the position of FO, then we have to measure correctly all the distances R_i. Accuracy in determining the position is also influenced by system geometry.

4 CONCLUSION

The method submitted enables modelling the influence of errors of measuring distance of FO from the NP exerted on the accuracy of determining its position within the ASDC run in the mode of relative navigation. Modelling has confirmed the theoretical assumption stating that a highly accurate determination of the FO position within the ASDC run in relative navigation mode necessitates highly accurate measuring of all distances of the FO from the NP. The accuracy of determining the position of the FO is influenced by the system geometry, too.

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