The Time Synchronization Model of Sensors and Reference-Transponders for the Aircraft Navigation System

Dmitriy Novopashin
Saint-Petersburg State University
7-9, Universitetskaya nab.,
St. Petersburg, 199034, Russia
veshchiy@yandex.ru

ABSTRACT

We consider a system of navigation for the aircraft consisting of sensors that use technology MLAT. The main purpose of the paper is to solve applied problems of sensors time synchronization using reference-transponder within the group of sensors. One of the most important conditions for using this technology is bringing a group of sensors to a single timeline concerning the timing-pulse generator frequency of one of the sensors. Additionally, determination of the conditions is needed for a finding of solid zero-point timing within this group of sensors. Also applied problems of time synchronization of several groups of sensors are solved.

Categories and Subject Descriptors

J.2 [**Computer Applications**]: Physical sciences and engineering – *aerospace, engineering.*

General Terms

Theory.

Keywords

Time synchronization model; sensors; reference-transponders; MLAT; aircraft navigation system.

1. INTRODUCTION

In previous works we have dealt with the issue of aircraft maintenance in terms of software for processing and filtering of the signals received on the side of the controller [1]. At this time, we consider the problem which arises at an earlier stage – between the reception of the signal and processing by the observer. We consider a system located in the territory of difficult terrain, working on technology Multilateration (MLAT) [2].

One of the most important conditions for this technology is time synchronization of all sensors. Each sensor calculates the timing of receiving or sending signals based on the frequency of its internal timing-pulse generator.

Frequency of timing-pulse generator is not a static value, it can have an error in the direction of increasing and decreasing or alternately one or the other. This may occur due to overheating of the sensor at the sun in summer or overcooling in winter, also the reason may be the aging of the generator or the deterioration of the equipment interacting with the generator. Furthermore, each sensor is activated asynchronously with the other and has its own starting counter value generator.

Thus the problem of synchronization involves bringing time of all sensors to a single timeline and, in some cases, finding a solid zero point.

2. DESCRIPTION OF MODEL

Let us consider a situation where for the coordination of sensors is used reference-transponder – a special device that sending and receiving the test messages and have access to satellite time.

A group of one reference-transponder and *N* sensors that are within reach of the transponder's signal and sufficiently frequently receive the synchronization signal will be called the domain. The model of calculation the internal time has the form:

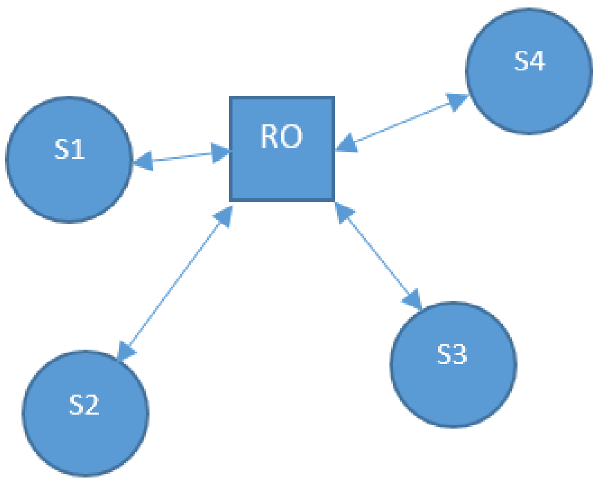

Figure 1: Example of domain. RO is reference-transponder, S1, S2, S3, S4 are sensors.

$$N_s = N_0 + f_s(T_s - T_0 + S),$$

where N_0 is the counter of timing-pulse generator clock at a time T_0, T_0 is the time at some point, conditional zero, T_s is the time at the moment of emission timing signal, S is the time during which the signal reaches the sensor (temporal distance), f_s is a conversion function from seconds of real time to sensor timing-pulse generator cycles, inverse of timing-pulse generator frequency, N_s is the value of generator counter at the moment of receiving a synchronization signal.

Based on the geometrical position reference-transponder and sensors, temporal distance of i-th sensor is calculated by the formula [3,4]:

$$S_i = \sqrt{(x_i - x_r)^2 + (y_i - y_r)^2 + (z_i - z_r)^2} / V_{light},$$

where x_r, y_r, z_r are coordinates of reference-transponder, x_i, y_i, z_i are coordinates of i-th sensor.

The values of N_0 and T_0 are abstract and used in the model only for convenience, as in the subsequent calculations used only intervals ΔN and ΔT.

3. SYNCHRONIZATION MODEL OF SENSORS ISIDE A DOMAIN

For synchronization of one domain we will consider two consecutive signals from the reference-transponder on i-th sensor:

$$N_{S_i}^{(1)} = N_0 + f_i\left(T_r^{(1)} - T_0 + S_i\right),$$

and

$$N_{S_i}^{(2)} = N_0 + f_i\left(T_r^{(2)} - T_0 + S_i\right),$$

then

$$\Delta N_{S_i}^{(2)-(1)} = f_i \Delta T_r^{(2)-(1)}.$$

Since the time between signals $\Delta T = T_r^{(2)-(1)}$ is equally for all sensors then we obtain:

$$\frac{\Delta N_{S_i}^{(2)-(1)}}{f_i} = \frac{\Delta N_{S_j}^{(2)-(1)}}{f_j},$$

for any i-th and j-th of sensors in the domain.

Therefore it is possible to scale a timeline concerning to the frequency i-th sensor for all sensors of the domain:

$$f_j = \frac{\Delta N_{S_j}^{(2)-(1)}}{\Delta N_{S_i}^{(2)-(1)}} f_i.$$

By adding to the domain, which synchronized concerning to the i-th sensor, one reference-transponder and sending at the same time synchronization signals from each transponders, we obtain:

$$N_{S_i}^{ro_1} = N_0 + f_i\left(T^{ro_1} - T_0 + S_{1,1}\right),$$

$$N_{S_i}^{ro_2} = N_0 + f_i\left(T^{ro_2} - T_0 + S_{1,2}\right),$$

$$N_{S_j}^{ro_1} = N_0 + \alpha f_i\left(T^{ro_1} - T_0 + S_{2,1}\right),$$

$$N_{S_j}^{ro_2} = N_0 + \alpha f_i\left(T^{ro_2} - T_0 + S_{2,2}\right),$$

where $\alpha = {f_j}/{f_i}$.

Let present the $N_{S_i}^{ro_2} - N_{S_i}^{ro_1}$ and $N_{S_j}^{ro_2} - N_{S_j}^{ro_1}$, considering difference $T^{ro_2} - T^{ro_1}$ as one variable ΔT:

$$N_{S_i}^{ro_2} - N_{S_i}^{ro_1} = f_i\left(\Delta T + S_{1,2} - S_{1,1}\right),$$

$$N_{S_j}^{ro_2} - N_{S_j}^{ro_1} = \alpha f_i\left(\Delta T + S_{2,2} - S_{2,1}\right).$$

Therefore we can uniquely express f_i:

$$f_i = \frac{\Delta N_{S_j} - \alpha \Delta N_{S_i}}{\alpha(S_{2,2} - S_{1,2} + S_{1,1} - S_{2,1})}$$

4. SYNCHRONIZATION MODEL OF DOMAINS

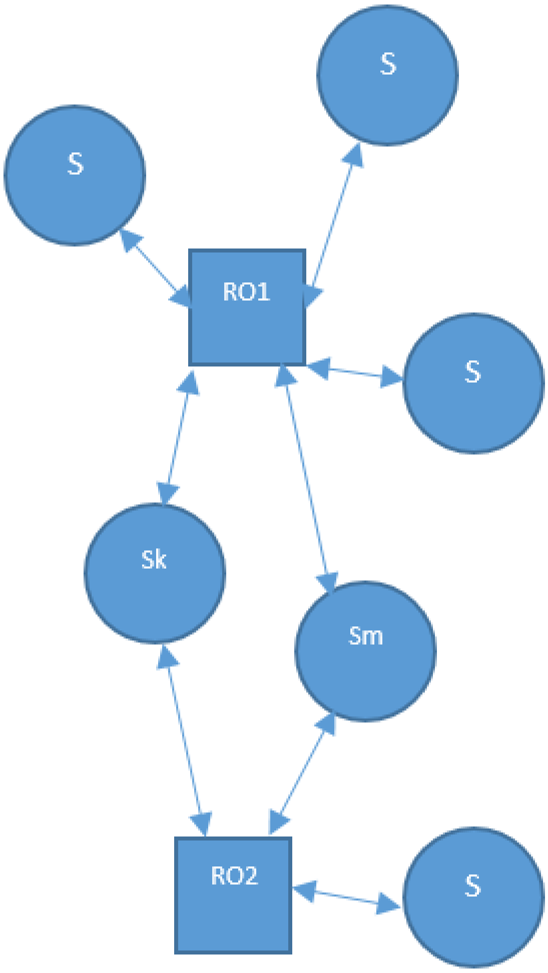

Figure 2: Example layout of two domains.

A more complex case of placing sensors is the situation when two domains share one common k-th sensor. Let us consider the domains as two groups – the domain of reference-transponder 1 (ro_1) and the domain of reference-transponder 2 (ro_2). Let us find the equation concerning the emission time synchronization signals for each sensor in the domains, which will look like:

$$N_i^{ro_1} = N_0 + f_i(T^{ro_1} - T_0 + S_{i,ro_1})$$

or

$$N_j^{ro_2} = N_0 + f_j\left(T^{ro_2} - T_0 + S_{j,ro_2}\right).$$

Synchronizing the sensors in each domain concerning to the k-th sensor we obtain:

$$N_i^{ro_1} = N_0 + \alpha_{i,k} f_k(T^{ro_1} - T_0 + S_{i,ro_1})$$

or

$$N_j^{ro_2} = N_0 + \alpha_{j,k} f_k\left(T^{ro_2} - T_0 + S_{j,ro_2}\right).$$

Thus, the time of both sensors can be scaled to a common timeline concerning to the frequency of k-th sensor. It does not matter by which sensor's frequency of generator time was synchronized within each domain.

Adding to a model with two domains one more common m-th sensor we obtain the sub-domain that consists of two sensors and two reference-transponders on the intersection of domains coverage area. This will allow due to the sensors synchronization algorithm within the domain with two reference-transponders uniquely express the frequency of k-th or m-th sensor and thus bind to the solid zero point sub-domain, and through it both domains.

5. CONCLUSIONS

In such a way it can be argued that having a system of N domains, intersecting by one sensor, is enough to place in the intersection area of adjacent reference-transponders one additional sensor, frequently enough receiving a time synchronization signal from these two transponders, that in the acquired sub-domain it can be uniquely calculate the frequency of synchronizing sensor and thereby bind the system to a common time scale with solid zero point.

Should be noted that the algorithms developed in this article and in [1] in the future will become a part of the intellectual system support aircraft. It is planned to use them to identify the trajectory of the aircraft in various modes. In addition, to improve the quality of this identification is expected to use the methods of mathematical theory of control [5, 6] and the multi-program control [7-9].

6. REFERENCES

[1] Novopashin D.V. 2014. Statistical data processing of the secondary radiolocation using orthogonal Chebyshev polynomials. *Control Processes and Stability*. Vol. 1, No. 1, 352-356.

[2] Multilateration & ADS-B Executive Reference Guide. URL: http://www multilateration.com/.

[3] Malikov M.F. 1949. *Fundamentals of metrology*. Kommerpribor, Moscow (in Russian).

[4] Potapov, A. A. 2005. *Fractals in radiophysics and radiolocation. The topology of the sample*. University Book, Moscow (in Russian).

[5] Andreev, Yu. N. 1976. *Control for n-dimensional linear objects*. Nauka, Moscow (in Russian).

[6] Solis-Daun, J., Suarez, R. and Alvarez-Ramirez, J. 2000. Global stabilization of nonlinear systems with inputs subject to magnitude and rate bounds: a parametric optimization approach. *SIAM J. Control Optim.* Vol. 39, No 3, 682-706.

[7] Zubov, V. I. Synthesis of multiprogram stable controls. *Reports Academy of Sciences USSR*. Vol. 318, No 2, 274-277 (in Russian).

[8] Smirnov, N. 2012. Multiprogram Control for Dynamic Systems: a Point of View. *Proceedings of the Joint Intern. Conference on Human-Centered Computer Environments* (Aizu-Wakamatsu, Japan, Duesseldorf, Germany, March 8-13, 2012), HCCE 2012. ACM, New York, NY, 106-113. DOI=10.1145/2160749.2160773.

[9] Smirnov, N. V., Smirnova T. E., Shakhov Ya. A. 2012. Stabilization of a given set of equilibrium states of nonlinear systems. *Journal of Computer and Systems Sciences International*. Vol. 51, No. 2, 169-175.