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Asynchronous wide area multilateration system

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ABSTRACT

A new method for a location service in the wide area multilateration (WAM) system is outlined. This method, which is called asynchronous WAM (AWAM), enables calculation of the geographical position of an aircraft without knowledge of relative time differences (RTDs) between measuring ground stations (sensors). The AWAM method is based on the measurement of round trip times (RTTs) between the aircraft and the serving ground station, and the solution of a nonlinear system of equations with ten variables. The elimination of the RTD parameters significantly simplifies the localization process in real-life WAM system. The proposed asynchronous method could be an alternative solution for the synchronous one as a backup method during the system's failure or as an independent method. The paper concentrates on the description of the method, solving the nonlinear system of equations with ten variables and simulation results.

1. Introduction

The currently available aircraft radio navigation systems are based on two techniques: passive in which the aircraft navigates on received radio information only, and active in which the aircraft participates both as receiver and transmitter of information. The first group is counted mainly: automatic direction finder (ADF), very high frequency (VHF) omnidirectional radio range (VOR), instrument landing system (ILS), microwave landing system (MLS) and global position system (GPS). The distance measuring equipment (DME), the radio altimeter (RA) and the wide area multilateration (WAM) systems belong to the second group. This paper focuses on the multilateration (MLAT) solution. The MLAT is a technology for determining the position of an emitter (e.g., aircraft transponder) by measuring the time difference of arrival (TDOA) of a signal between several known and carefully surveyed observation points (e.g., MLAT sensors or ground stations) [10]. The MLAT employs a number of ground stations, which are placed in strategic locations around an airport that covers the larger surrounding airspace. Generally speaking, the multilateration system utilizes signals from the secondary surveillance radar (SSR) system. The SSR consists of a ground component (the radar) and an airborne component (transponder) onboard an aircraft. The radar emits a signal (at 1030 MHz) which triggers a response from the airborne transponder (at 1090 MHz). This response is the basic signal for the WAM system [9]. A critical aspect of a working WAM system is precise synchronization of the ground stations (sensors) among each other [11]. In order to calculate the position of an aircraft, it is necessary to know the time difference from a signal arriving at one antenna (sensor) in the system to the arrival of the signal at another antenna (sensor) in the system and relative time differences (RTDs) between measuring ground stations (sensors). The RTDs are compensated in the process of synchronization. The methods of synchronization complicate positioning architecture in the WAM system. When the synchronization procedures to estimate the position of the aircraft are not needed, the location service is cheaper.

In this paper, a new method, asynchronous WAM (AWAM), which enables the calculation of the geographical position of an aircraft without knowledge of relative time differences, is outlined. This method is supported by round trip time (RTT) and a system of nonlinear equations [13,14]. With respect to this, the paper concentrates on description of new method and solving the nonlinear system of equations with ten variables. In this context, the new method was tested using software simulation.

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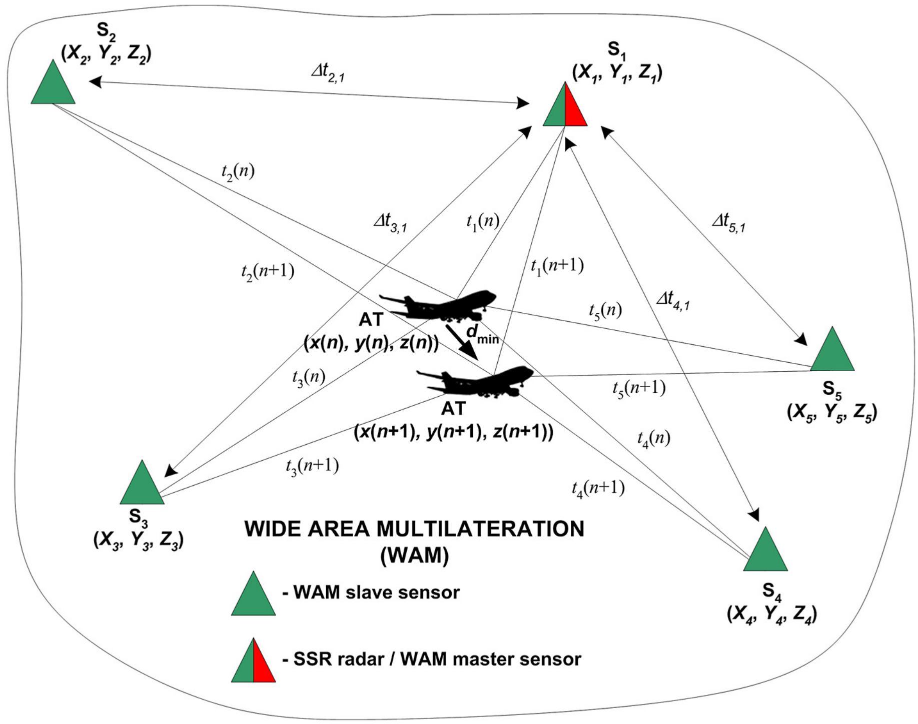

Fig. 1. Graphical representation of the problem under consideration.

2. Description of the AWAM method

The proposed new method is as follows. In a separate area (WAM) are deployed at least five ground stations (sensors) and the secondary surveillance radar. The SSR is located in the same place as the selected measuring sensor – master (serving) sensor (Fig. 1). The SSR transmits interrogation pulses on 1030 MHz. The target aircraft's transponder replies on 1090 MHz a signal containing the requested information, which is received by all ground stations (sensors). In the study case, ground sensors network works asynchronously – the sensors are not synchronized with each other. All sensors in the WAM perform measurements in the rhythm of their own clocks. Only the master sensors can measure true distance to the aircraft, because is synchronized to the SSR. Between the master sensor and neighboring sensors occur the relative time differences (RTDs) in the synchronization. The proposed method is based on elimination of RTDs in the location service.

The classic TDOA method, in a three-dimensional plane for five measuring sensors (the case is illustrated in Fig. 1),[1] is reduced to the solution of the following system of nonlinear equations [2]

$$c \cdot \left[t_i(n) - t_1(n)\right] = \sqrt{\left[X_i - x(n)\right]^2 + \left[Y_i - y(n)\right]^2 + \left[Z_i - z(n)\right]^2} - \sqrt{\left[X_1 - x(n)\right]^2 + \left[Y_1 - y(n)\right]^2 + \left[Z_1 - z(n)\right]^2} \quad \text{for } i = 2, \dots, 5, \tag{1}$$

where $t_1(n)$ and $t_i(n)$ denote the measured signal of transfer times from the sensors S_1 to S_5 to the aircraft transponder (AT) at the same discrete time n, (X_1, Y_1, Z_1) and (X_i, Y_i, Z_i) represent the coordinates of the sensors, $(x(n), y(n), z(n))$ are the coordinates of the aircraft transponder at the discrete time n and c is the speed of light. When the sensors work asynchronously, the master sensor measures observed time difference of arrivals (OTDOAs) $t_{i,1}(n)$ (for $i = 2, \dots, 5$) using current data and measurement data from the auxiliaries sensors (slave sensors):

$$t_{i,1}(n) = t_i(n) + \Delta t_{i,1} - t_1(n), \tag{2}$$

where $\Delta t_{i,1}$ describe the relative time differences between the serving sensor S_1 and auxiliaries S_i. However, it is only possible to solve this system of Eqs. (1) when we know relative time differences, i.e. $\Delta t_{i,1}$ (normally, in the WAM system the RTDs are compensated by the synchronization procedures). In connection with this, a second system of nonlinear equations at the discrete time $n + 1$ is proposed

$$c \cdot \left[t_i(n+1) - t_1(n+1)\right] = \sqrt{\left[X_i - x(n+1)\right]^2 + \left[Y_i - y(n+1)\right]^2 + \left[Z_i - z(n+1)\right]^2} - \sqrt{\left[X_1 - x(n+1)\right]^2 + \left[Y_1 - y(n+1)\right]^2 + \left[Z_1 - z(n+1)\right]^2} \quad \text{for } i = 2, \dots, 5. \tag{3}$$

Analogously to the expression (2), at the discrete time $n + 1$ the master sensor measures observed time difference of arrivals $t_{i,1}(n + 1)$ (for $i = 2, \dots, 5$):

$$t_{i,1}(n+1) = t_i(n+1) + \Delta t_{i,1} - t_1(n+1). \tag{4}$$

[1] In a three-dimensional plane are needed only 4 sensors, but to explain the principle of the AWAM method at least five sensors are necessary.