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Model of the Motion of a Navigation Object in a Geocentric Coordinate System

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ABSTRACT: In this paper we describe the creation of a model of the motion of a flying object in a geocentric coordinate system (ECEF - Earth-Centered, Earth-Fixed). Such a model can be used to investigate the accuracy and resistance of radio navigation systems to interference. The essence of the design of the model lies in the mathematical description of the motion of a flying object in a geocentric coordinate system. The flight trajectory of a flying object consists of one straight section and two turns. When creating a model, we assume a flight at a constant altitude. In this paper, we present one of the possible procedures for modelling the motion of a flying object in a geocentric coordinate system. We chose the initial coordinates of the flying object according to flightradar 24. We used the Matlab software for computer simulation.

1 INTRODUCTION

Some of the results presented in this paper were obtained by evaluating the accuracy and resistance of radio navigation systems to interference. In [1] we modeled the motion of five flying objects. The results of this modeling were used to obtain information about the geocentric position of users of the aviation communication network. The aim of the research was to evaluate the accuracy of determining the position of flying objects (LO) using the telemetry method. The first part of our research is devoted to a general model of the motion of a flying object. We determined the initial LO coordinates from the real flight situation from flightradar24. We have created a general model of the trajectory of the aircraft's motion, which consists of a straight flight and two turns. The advantage of the model created in this way is that it is flexible and we can modify it. It can be used to model the motions of any flying object located on Earth, whose initial coordinates are in the geodetic coordinate system connected with WGS-84. We subsequently used this model in the creation of LO trajectories and evaluation of accuracy and resistance of radionavigation systems to interference. The disadvantage of this model was the use of multiple coordinate systems, which causes complications in performing the simulation. Modeling of the motion of a flying object using several coordinate systems is given in [2]. The authors of this paper used such a model to evaluate the accuracy of a navigation system. In the work [6] the methodology of creating a model of the motion of a flying object is presented. Even in this case, the authors of the model use several coordinate systems. The advantage of this model is its flexibility and the ability to model different types of flight trajectories. The disadvantage of this model is its complexity and relatively large computational time. In work [3] is presented a recursive least squares (RLS) algorithm to extract and predict the position of a flying object in a 3D environment. The authors of the article state that the recursive nature of the computations lets use this model for real-time applications although it is relatively complex. In the work [4] the authors state the algorithm for tracking moving objects is based on the extension of simple online and real-time tracking. This algorithm it was developed by integrating a deep learning-based association metric approach with simple online and real-time tracking, which uses a hypothesis tracking methodology with Kalman filtering and a deep learning-based association metric. The results of the experiment confirmed that target detection algorithm performed very well. The work [7] contains algorithms for satellite motion control. The proposed method shows considerable intelligence and certain universality, and has a strong application potential for future intelligent control of satellites performing complex space tasks. Such models are not very suitable for modeling the flight trajectory of aircraft because they are relatively complex. In work [8] is a description of the model of the flying object is given. In this model, the flying object consists of four objects: the delegates that encapsulates the implementation, the message handler that interprets the messages, the event handler that provides adaptation strategies and the context object that holds a state beyond the adaptation. Such a model is complex and not suitable for evaluating the accuracy of navigation systems. In our paper, we present one of the possibilities of modeling the flight trajectory of a flying object in a geocentric coordinate system based on a mathematical description of spatial curves. When creating the model, we used some of the findings presented in [1, 5]. The advantage of the presented solution is its simplicity, flexibility and high speed of simulation. Such a model is suitable for evaluating the accuracy of navigation devices. Also when designing a communication network of flying objects and performing relative navigation in this network. Simple models of the motion of flying objects are suitable for solving the mentioned tasks, which must be sufficiently accurate and correspond to the physical meaning of the solved task.

2 COORDINATE SYSTEMS USED IN FO MOTION MODELLING

Furthermore, in accordance with the literature [1, 5], we will present the coordinate systems that we will use in creating a model of the trajectory of a flying object. When creating the flight trajectory of a flying object, we placed the main emphasis on the fact, to the proposed model was not very complex and corresponds to the physical meaning of the solved task. Our task was to create a model of the flight trajectory of a flying object in a geocentric coordinate system. Because we determined the initial conditions of the flight trajectory in accordance with the real flight trajectories of transport aircraft from flightradar24, we also used the geodetic coordinate system.

2.1 *ECEF Geocentric Coordinate System*

It is a three-dimensional coordinate system with a centre in the centre of the Earth. The X axis of the system passes through the intersection of the zero meridian and the equator, the Y axis is pointing from west to east, the Z axis is having the north-south direction. It is a rectangular coordinate system and is shown in Fig. 1. [1, 2, 5]. In this coordinate system we will be model the trajectory of the motion of a flying object.

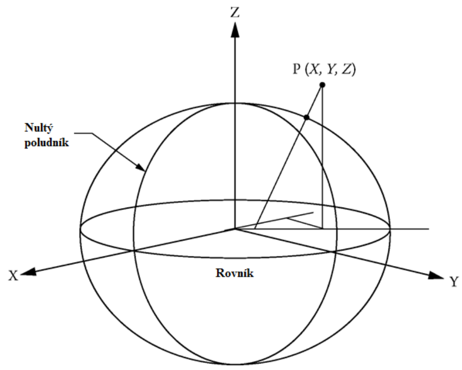

Figure 1. ECEF Geocentric Coordinate System [5]

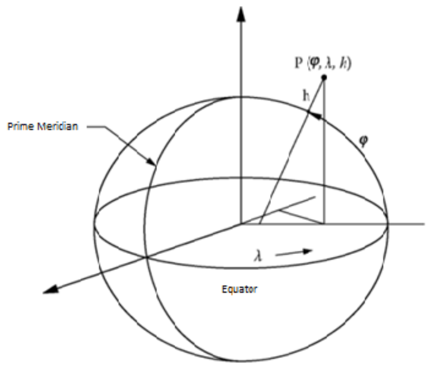

Figure 2. Geodetic coordinate system [5]

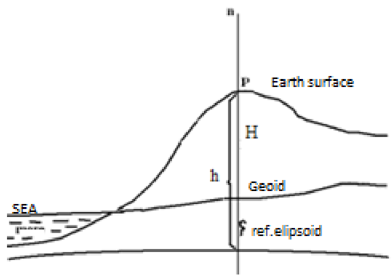

Figure 3. Ellipsoidal height h and the normal height H [5]

2.2 *Geodetic coordinate system*

The local model of FO motion is necessary to transfer to the geodetic coordinate system. The Geodetic Coordinate System (LLH) is shown in Fig. 2 and used in aviation in the processing of data in the autonomous navigation, in radio air navigation devices and the like. The geodetic coordinate system determines the position of the point on the surface of the ellipsoid. The latitude φ, the longitude λ and the ellipsoidal height h are coordinates. The difference between the ellipsoidal height h and the normal height H (Fig. 3) is the so called height anomaly for which: ς = h-H, where: H - altitude, ς - height of geoid or quasi geoid [1, 2, 5]. The area of a quasi-godium is defined by models of density and topography of the terrain, satellite ellite models of the Earth and ground - based measurement of gravity acceleration.

3 THE MODEL OF FLYING OBJECT MOTION

The model of FO motion is designed to verify the accuracy and resistance of radionavigation systems against interference. The model of FO motion serves to gain information about their geocentric location in space. We have abstracted from the forces acting on FO during the flight. For the purpose of simulating the radionavigation systems, we may consider this fact irrelevant. To clarify the principle of the model of FO motion, we chose the real point according to flightradar24, in which we place the FO and simulate its further movement [1, 2]. As initial co-ordinates (starting point) LO, we have chosen real FO coordinates, i.e., FO ETD 37A with coordinates: latitude 0,8500800654 rad, longitude 0,3771307447 rad. See Figure 4 and text below. Height above ellipsoid 10933 m and altitude 10973 m. Geoid curl 40 m. These coordinates are considered as the reference and represent the starting point of the XP flight trajectory Xp [xp, yp, yp].

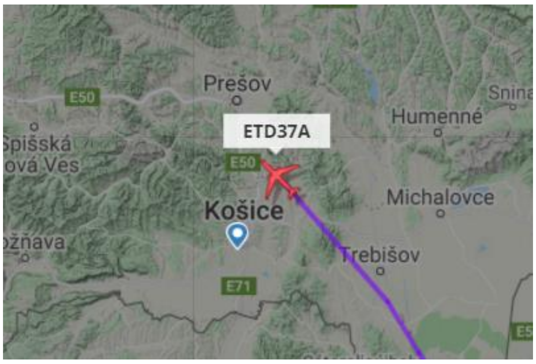

Figure 4. Trajectory of motion of FO ETD37A

FO coordinates in the geographical coordinate system. Identification ETD37A, starting point:
- latitude, degree 48.706
- longtitude, degree 21.608
- height above ellipsoid, m 10933
- geoid curl, m 40,0

Identification ETD37A, end point:
- latitude, degree 49.136202
- longtitude, degree 20.333297
- height above ellipsoid, m 10933
- geoid curl, m 40,0

FO coordinates in the a geocentric coordinate system. Identification ETD37A, starting point:
- X, m 3927434.0
- Y, m 1555616.0
- Z, m 4777290.0

End point:
- X, m 3927194.0
- Y, m 1455308.0
- Z, m 4808781.0

The coordinates of the starting point are determined by flightradar24 in the geographical coordinates (LLH). The model created represents the FO flight in the a geocentric coordinate system ECEF. In modelling FO trajectories, each part of its trajectory is modelled in the geocentric coordinate system (Figure 1). The FO trajectory is composed of a direct flight and two turns. Based on this, it will be possible to evaluate the accuracy of FO position determination in the navigation system not only in the level flight, but also in FO manoeuvres. Trajectory model input parameters that can be changed according to current requirements are:
- the initial position of the FO,
- the duration of the level flight or in turns,
- trajectory of motion,
- radius of curvature.

Therefore, we must make the corresponding transformations of the starting point FO. The process of transforming the co-ordinates of the resulting FO motion with the start in the given initial coordinates in the LLH system to the ECEF includes the transformation of geodetic starting point coordinates into the ECEF system. We use the Matlab function llh2xyz to transform coordinates. Function llh2xyz serves to transform initial co-ordinates from LLH to ECEF. The function serves to convert the geographical coordinates (latitude, longitude and altitude in WGS-84) into the rectangular geocentric coordinates X, Y, Z in meters. The latitude and longitude are given in radians and the ellipsoidal height in meters is given. The task our solution is to determine and display the FO position in the ECEF rectangular coordinate system with the centre at the Earth's ground. After performing simulation, we can visualize the model of FO motion in the ECEF system. The FO position will be determined in each second by the coordinates x, y, z in meters. The model of first phase of FO flight (straight movement) we created as follows. The first phase of the FO motion, straight and level flight, is 400 s at an altitude of 10973,0 m. Altitude of flight does not change. We chose the initial coordinates for local movement as follows: x = 3927434.0 m, y = 1555616.0 m, z = 4777290.0 m.

The model of first phase of FO flight we created as follows. We started from the equation of a line in three dimensional space. We assume that the line is uniquely given by two points or one point and a direction vector. Line Xk Xp can be defined as follows. The line passes through the starting point XP [xp, yp, yp] and endpoint Xk [xk, yk, zk]. The coordinates of the end point are given in table no. 1 and 2. We express the direction vector Ū in the form:

$$\overline{U} = Xk - Xp = \left[xk - xp, yk - yp, xk - xp\right] = \left[u1, u2, u3\right] \quad (1)$$

Then the parametric expression of the line Xp Xk has the form:

$$x = xp + t \cdot u1;\ y = yp + t \cdot u2;\ z = zp + t \cdot u3;\ t \in \langle 0;1 \rangle \quad (2)$$

When creating a model, we choose the end point of the flight trajectory arbitrarily in the geographical coordinates. In Figure 5, the end point of the straight flight is marked with a red asterisk. Subsequently, we create a flight model of a flying object, which consists of two turns. When creating this model, we assume that the flying object flies in a constant height. We will model the curves using circles. The radius of the circle is denoted by the letter r. We assume that the radius r can be arbitrary. If we have the point S [x; y] = S [0; 0], so for all points of the circle:

$$x^2 + y^2 = r^2 \quad (3)$$

If we have a point S [x; y; z] = S [0; 0; 0], so the implicit expression of a circle is:

$$x^2 + y^2 - r^2 = 0; \;\; z = 0 \tag{4}$$

We express the parametric equations of this circle as follows:

$$x = r \cdot \cos(t), \; y = r \cdot \sin(t), \;\; z = 0, \;\; t \in \langle 0, 2\pi) \tag{5}$$

In our case, we assume that the center of the turn of the flying object is at the point Xk [xk, yk, zk] and zk = constant. We will express the parametric equations of such a circle as follows:

$$x = r \cdot \cos(t) + xk, \; y = r \cdot \sin(t) + yk, \;\; z = const, \;\; t \in \langle 0, 2\pi) \tag{6}$$

Based on equation (6), we can simulate flight after a circle . The parameters of the model (6) are the radius of the circle r and the angle t.

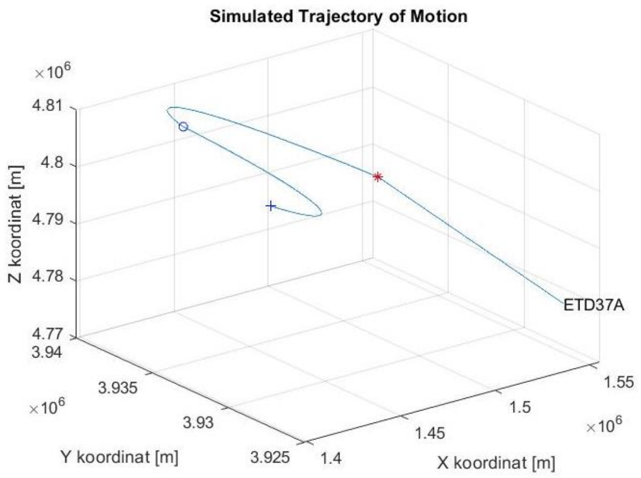

Figure 5. Trajectory of motion of FO ETD37A

In Figure 5, the end point of the flight in a turn is marked with a blue ringed. According to equation (5), we modeled the flight in the second turn. In accordance with algorithms 1 through 6, we have simulated FO trajectory. The FO motion trajectory is shown in Fig. 5. From figure 5 it is clear that said algorithms allow us to simulate the flight of a flying object, which consists of a straight section and two turns. The advantage of this solution is that the model is simple and does not require a long simulation time.

4 CONCLUSION

The result of modelling is a model describing FO motion in a geocentric coordinate system. For the simulation to be as accurate as possible, we have performed air traffic observation over the territory of the Slovak Republic via the Flightradar24 application. We randomly selected FO and his geographic coordinates and altitudes have been implemented in our model. For the purpose of solving the problem, it was necessary to transform his coordinates into a geocentric coordinate system. The simulation results have confirmed that the created model sufficiently accurately describe FO flight in real-world conditions. The generated simulation model can be used for further research and development of communication, navigation, radar systems or anti-collision system. Also for examination the accuracy and resistance of radio navigation systems to interference. In order to solve this problem, we strive to create such models that allow us to simulate the trajectory of a flying object under conditions that are close to real. Therefore, we have created a model of a flying object, which is characterized by flexibility and by changing the parameters of this model it is possible to get as close as possible to real flight conditions. At this stage of the research, we do not consider the turbulence of the atmosphere and other factors that affect the flying object. We created our model so that the flight trajectory consists of a straight flight and two turns.

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