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UNMANNED AERIAL VEHICLE COLLISION AVOIDANCE USING DIGITAL ELEVATION MODEL

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Abstract. *In the article the important role of Digital Elevation Models for Unmanned Aerial Vehicle collision avoidance and flight planning have been discussed. The web sources of Digital Elevation Models with their descriptions and data transformation procedure for the further processing were represented. The principle of the collision avoidance using Digital Elevation Model has been represented. An obstacle overfly in the vertical plane was shown.*

Keywords: collision avoidance, Digital Elevation Model, flight planning, LIDAR, obstacle, Unmanned Aerial Vehicle.

1. Introduction

The usage of Unmanned Aerial Vehicles (UAVs) has been increasing rapidly. Their usage has been characterized as the next great step forward in the evolution of civil aviation. Compared with their manned counterparts, the UAVs have the advantages of small weight and space-occupancy, low cost, good concealment, excellent robustness and flexibility thus are excellent in executing the dull, dirty or danger tasks.

Such aircraft are capable to plan their own trajectory in the transition between desired locations and it can also avoid any obstacles in their path.

2. Literature overview

A lot of scientific researches were devoted to the development of the reliable UAV's collision avoidance method (Gardiner, Waseem 2011; Loe 2007; Han, Bang 2004; Liao 2012; Kharchenko, Kuzmenko 2012). But all of these methods have the lack of information about obstacle and represent it as a geometrical shape. None of these methods can provide the precise form and position of an obstacle that is not convenient for use in real life.

Thus, from the literature overview it is obvious that it is necessary to develop more reliable UAV collision avoidance method that will include exact data of the surrounding environment.

The usage of Digital Elevation Models (DEM), Digital Terrain Models (DTM) and Digital Surface Models (DSM) is one of the possible ways to provide information awareness that is a key element in the safety of aviation.

The purpose of the article is analysis of existing DEM web sources and development of the UAV geometrical collision avoidance method in the vertical plane using DEM.

3. Digital Elevation Model

A Digital Elevation Model is a digital model or 3D representation of a terrain's surface commonly for Earth, moon, or asteroid created from terrain elevation data.

The term digital surface model represents the earth's surface and includes all objects on it.

In contrast to a DSM, the digital terrain model represents the bare ground surface without any objects like plants and buildings.

The term DEM is often used as a generic term for DSMs and DTMs, only representing height information without any further definition about the surface.

The DEM could be acquired through techniques such as:

– LIDAR;
– Stereo photogrammetry from aerial surveys;
– Block adjustment from optical satellite imagery;
– Interferometry from radar data;
– Real Time Kinematic Global Positioning Systems;
– Topographic maps;
– Doppler radar;
– Focus variation;
– Inertial surveys;
– Surveying and mapping drones.

The uses of DEMs include:

– Extracting terrain parameters;
– Creation of relief maps;
– Rendering of 3D visualizations;
– 3D flight planning;
– Creation of physical models;
– Geographic Information Systems (GIS);
– Engineering and infrastructure design;
– Global Positioning Systems;

– Line-of-sight analysis;
– Base mapping;
– Flight simulation;
– Surface analysis.

4. Digital Elevation Model data sources

The web sources of DEM data are the following:

1. NASA Reverb (http://reverb.echo.nasa.gov/reverb/). Search the entire ASTER data archive. The following products are available to all users at no cost: ASTER L1B data over the U.S. and territories, the ASTER Global Digital Elevation Model (GDEM), and the North American ASTER Land Surface Emissivity Database (NAALSED).
2. GDS IMS (http://ims.aster.ersdac.jspacesystems.or.jp/ims/html/). Search the entire ASTER data archive. All billable orders for ASTER data must be placed using the GDS IMS system.
3. Earth Explorer (http://earthexplorer.usgs.gov/). Free ASTER data for all users: ASTER L1B data over the U.S. and territories, the ASTER GDEM, and NAALSED products.
4. GloVis (http://glovis.usgs.gov/). Search the entire ASTER data archive using a browse-based map interface. The following products are available to all users at no cost: ASTER L1B data (day and night) over the U.S. and territories.
5. GDEx (http://gdex.cr.usgs.gov/gdex/) Free ASTER GDEM data for all users. User-friendly geographic interface.
6. Data Pool (https://lpdaac.usgs.gov/get_data/data_pool). Free ASTER L1B data over the U.S. and territories for all users.
7. Shuttle Radar Topography Mission (SRTM) (http://dds.cr.usgs.gov/srtm/version2_1/SRTM3). Free SRTM data.
8. Bluesky (http://www.bluesky-world.com/). LiDAR 1m DSM.

The data bases are generally in one of the following different resolutions:

– 30-meter data: point elevation values on a 30-meter grid;
– 1-second: point elevation values on a 1-second (approximately 30-33 m) grid;
– 3-second: point elevation values on a 3-second (approximately 90-100 m) grid;
– 30-second point elevations:- point elevation values on a 30-second (approximately 1 km) grid;
– 30-second averaged elevations: averaged elevation values on a 30-second (approximately 1 km) grid.

5. Digital Elevation Model file extension

Data can be obtained with file extension .xyz, .las, .hgt. These types of file extension can be converted to the .txt file with the help of different converting programs such as LASUtility and VTBuilder.

Obtained data involve 3 columns and denote x, y and z data in meters in the local coordinate system that can be easily used for the further processing.

6. Collision Avoidance Guidance

The task of UAV missions is based on the input of initial position, coordinates of the destination and obligatory flight .points as a set of latitude, longitude and elevation data.

Further, the appropriate DEM for the desired flight region should be obtained. The initial flight plan data should be also converted to the local coordinate system of DEM format.

Collision avoidance method is based on the conflict detection that is shown in Fig. 1.

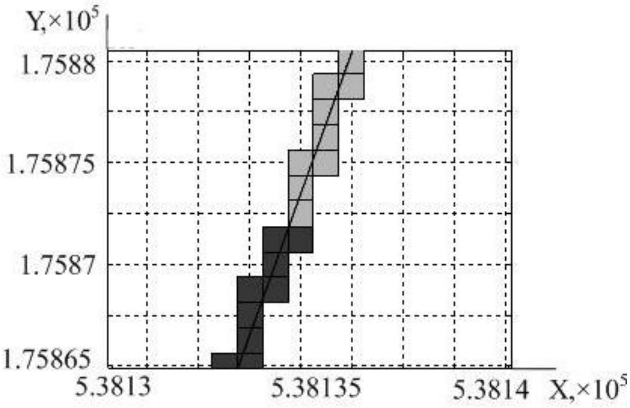

Fig. 1. Cell conflict detection with initial flight plan trajectory

Using cell coordinates of DEM it is possible to determine the intersection of trajectory line with each cell side.

Then, to determine the point of flight plan and surrounding obstacle intersection, the algorithm of the method determines the intersection of rectangular which tops are located at the cell coordinates and trajectory line. This step is applied to all the cells that are involved at the flight plan.

If the point of intersection exists and the conflict is determined, the points of obstacle overfly are added to the initial flight plan as it is shown in Fig. 2.

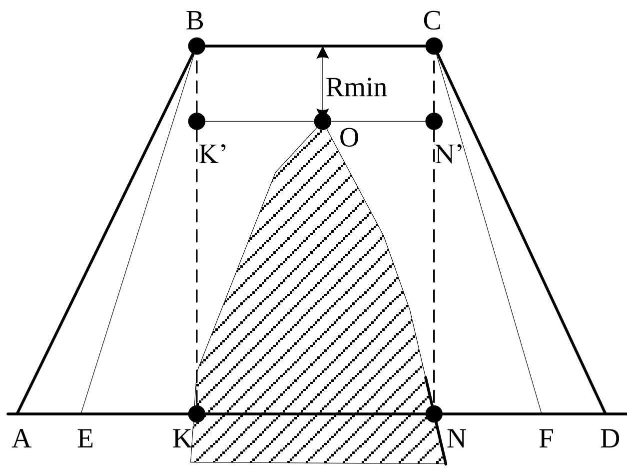

Fig. 2. Obstacle overfly using extended flight plan:
AD – the initial flight trajectory;
KON – obstacle;
K, N – starting and ending points of trajectory and obstacle intersection;
O – maximum obstacle height;
K', N' – starting and ending points of trajectory and obstacle intersection elevated to the maximum obstacle height;
B, C – starting and ending points of trajectory and obstacle intersection elevated to the maximum obstacle height with minimum safe altitude Rmin;
E, F – critical points for overfly performance that take into account UAV velocity and heading

The possible values of UAV velocity and heading are in the boundaries:

$$V_{\min} \le V \le V_{\max},$$

$$\psi_{\min} \le \psi \le \psi_{\max}.$$

where V, Ψ are UAV velocity and heading.

In order to increase flight safety, it is necessary to chose points A (initial point of the flight plan final part) and D for beginning and finishing an overfly performance.

In such a way overfly points B and C are added to the extended flight plan that can be easily calculated using UAV technical characteristic.

Extended flight plan data can be used for UAV's flight performance.

There are a lot of different models of UAV movement. Each of them is used for the particular tasks connected with UAV trajectory simulation. Besides, the choice of the model depends on the UAV type and its dynamic peculiarities.

For the simulation of UAV movement the simplified model that takes into account wind influence can be used. It is described by the following navigation formulae (Chawla, Padhi 2011):

$$\dot{x}_i = U\cos\theta\cos\psi + V(\sin\phi\sin\theta\cos\psi - \cos\phi\sin\psi) + $$

$$+ W(\cos\phi\sin\theta\cos\psi + \sin\phi\sin\psi);$$

$$\dot{y}_i = U\cos\theta\sin\psi + V(\sin\phi\sin\theta\sin\psi + \cos\phi\cos\psi) + $$

$$+ W(\cos\phi\sin\theta\sin\psi - \sin\phi\cos\psi);$$

$$\dot{h}_i = U\sin\theta - V\sin\phi\cos\theta - W\cos\phi\cos\theta,$$

where U, V, W – velocity components.

Speed parameters can be defined by total UAV speed as:

$$U = V_T\cos\alpha\cos\beta;$$

$$V = V_T\sin\beta;$$

$$W = V_T\sin\alpha\cos\beta,$$

where V_T – UAV speed;

α – angle of attack;

β – side slip angle.

Influence of forces on UAV is described by following differential equations (Singh, Padhi 2009):

$$\dot{U} = RV - QW - g\sin\theta + X_a + X_t;$$

$$\dot{V} = RW - RU + g\sin\phi\cos\theta + Y_a;$$

$$\dot{W} = QU - PV + g\cos\phi\cos\theta + Z_a,$$

where P, Q, R – roll, pitch and yaw rates respectively about the body axis;

X_a, Y_a, Z_a – the aerodynamic forces per unit mass;

X_t – the force per unit mass in direction X due to thrust.

Equations of rotation moments are represented by the formulae:

$$\dot{P} = c_1RQ + c_2PQ + c_3L_a + c_4N_a;$$

$$\dot{Q} = c_5PR + c_6(P^2 - R^2) + c_7(M_a + M_t);$$

$$\dot{R} = c_8PQ - c_2RQ + c_4L_a + c_9N_a,$$

where L_a, M_a, N_a – the aerodynamic moments about the body axis;

M_t – the moment around the Y axis caused by thrust offset from the center of gravity of the UAV;

c_1-c_9 – inertia coefficients.

Kinematic equations of UAV movement are the following:

$$\dot{\phi} = P + Q\sin\phi\tan\theta + R\cos\phi\tan\theta;$$

$$\dot{\theta} = Q\cos\phi - R\sin\phi;$$

$$\dot{\psi} = Q\sin\phi\sec\theta + R\cos\phi\sec\theta;$$

$$\dot{h} = U\sin\theta - V\sin\phi\cos\theta - W\cos\phi\cos\theta,$$

where ϕ, θ, ψ – euler angles;

h – the height above ground.

7. Results of modeling

The modeling of developed geometrical UAV collision avoidance method in the vertical plane using DEM is represented in Fig. 3. Modeling was performed in Matlab software for British region.

8. Conclusions

Collision avoidance methods have a lot of drawbacks connected with precise 3D obstacle determination. The developed geometrical UAV collision avoidance method allows obtaining an accurate data of surrounding environment and avoiding collision due to obstacle overfly in the vertical plane.

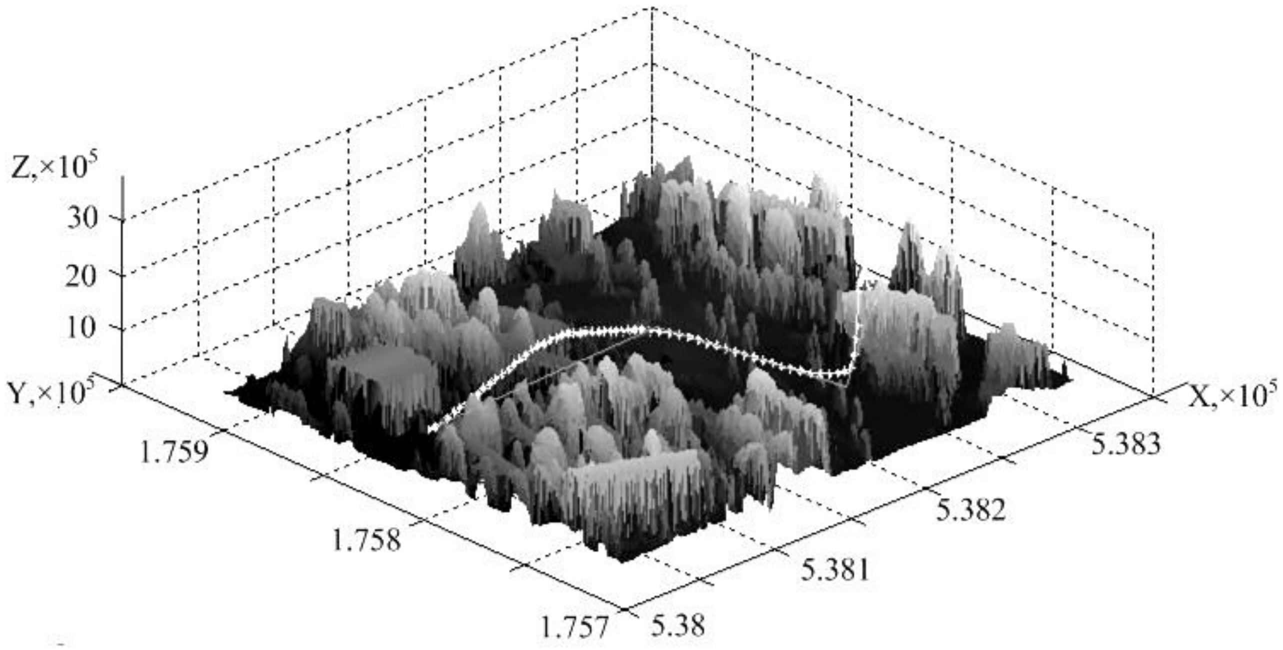

Fig. 3. Representation of collision avoidance method using DEM

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В.П. Харченко[1], Н.С. Кузьменко[2]. Усунення зіткнень безпілотних літальних апаратів із використанням цифрової моделі місцевості
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Розглянуто одну з найбільш важливих проблем безпеки польотів – запобігання зіткнення безпілотних літальних апаратів із перешкодами. Установлено роль цифрових моделей місцевості під час усунення зіткнень безпілотних літальних апаратів та планування польоту. Наведено існуючі інтернет-ресурси цифрових моделей місцевості, їх опис та процедуру підготовки даних до використання. Запропоновано геометричний метод усунення зіткнень безпілотних літальних апаратів у вертикальній площині з використанням цифрових моделей місцевості, в основу розробки якого покладено виявлення конфлікту, обліт перешкоди з урахуванням розширеного плану польоту, мінімальні та максимальні допустимі значення швидкості та кута зміни курсу безпілотних літальних апаратів. Комп’ютерне моделювання виконано за допомогою програмного забезпечення Matlab із використанням реальних даних цифрових моделей місцевості. Проаналізовано результати моделювання з траєкторією руху безпілотних літальних апаратів для певної місцевості.
Ключові слова: безпілотний літальний апарат, ЛІДАР, перешкода, планування польоту, усунення зіткнень, цифрова модель місцевості.

В.П. Харченко[1], Н.С. Кузьменко[2]. Устранение столкновений беспилотных летательных аппаратов с использованием цифровой модели местности
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Рассмотрена одна из наиболее важных проблем безопасности полетов – предотвращение столкновений беспилотных летательных аппаратов с препятствиями. Установлена роль цифровых моделей местности при устранении столкновений беспилотных летательных аппаратов и планировании полета. Приведены существующие интернет-ресурсы цифровых моделей местности, их описание и процедура подготовки данных к использованию. Предложен геометрический метод устранения столкновений беспилотных летательных аппаратов в вертикальной плоскости с использованием цифровых моделей местности, в основу разработки которого положены выявление конфликта, облет препятствия с учетом расширенного плана полета, минимальные и максимальные допустимые значения скорости и угла изменения курса беспилотных летательных аппаратов. Компьютерное моделирование выполнено с помощью программного обеспечения Matlab с использованием реальных данных цифровых моделей местности. Проанализированы результаты моделирования с траекторией движения беспилотных летательных аппаратов для определенной местности.
Ключевые слова: беспилотный летательный аппарат, ЛИДАР, планирование полета, препятствие, устранение столкновений, цифровая модель местности.

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