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Control Algorithm of Multiple Unmanned Electrical Aerial Vehicles for Their Collision Prevention

Anna Beinarovica[a*], Mikhail Gorobetz[a], Anatoly Levchenkov[a]

[a]*Riga Technical University, Institute of Industrial Electronics, 12 Azenes street, Riga, LV-1048, Latvia*

Abstract

Authors propose the algorithm to prevent collisions between various unmanned electrical aerial vehicles (UAV) performing the common goal or moving at the same area. The developed algorithm is proposed for use in case of some unmanned vehicles are moving towards or through the same coordinates of the target point or the trajectory. All the vehicles are communicating with each other. The algorithm is implemented in the developed embedded device of each UAV that corrects the flight height and sets necessary motor rotation speed to avoid the collision. The computer models of the quadcopters, as an example of UAV system, are presented in the paper and prove the workability of the algorithm.

Keywords: unmanned electrical vehicle, anti-collision system, aerial vehicle, electric drive

1. Introduction

The use of aerial vehicles for industrial purposes began relatively recently. Photographers all over the world offer to use modern technologies to gain a better result of taking photos of celebrations, such as wedding. In Australia drones are equipped with artificial intelligence powered software that can distinguish sharks from dolphins, wales, boats, and other marine life in real-time with 90% accuracy. Drones could help detect potential terrorists in public spaces, merely by measuring anomalies in their heart rates, according to Chahl, a Professor of Sensor Systems in

* Corresponding author. Tel.: +371 25998958
E-mail address: anja19892@inbox.lv

UniSA's School of Engineering. Amazon legally delivered its first Prime order in the United Kingdom in December 2016. All these possibilities of use aerial vehicles prove the relevance of the topic.

In most cases, man-operator, who sets the speed and the trajectory of motion by using the remote control, controls the aerial vehicle. However, it is not productive use of human time and force in the automatization and optimization century. Moreover, man, who is driving aerial vehicle, has ability to make mistakes, caused by human factor. For example, a woman was seriously injured by a falling drone in 2016 in Quebec, a drone crashed through a Manhattan woman's 27th-floor window, and a New Jersey man was arrested for accidentally crashing a drone into the Empire State Building.

All over the world, companies are trying to embed artificial intellect (AI) in the vehicles and to provide the autonomous drive, and unmanned aerial vehicles, such as drones or quadcopters, not an exception. This may help to minimize amount of aerial vehicles collisions caused by human factor. In 2016. S. Roelofsen, A. Martinoli and D.Gillet proposed a collision avoidance algorithm for unmanned aerial vehicles with limited field of view constraints [1]. Authors presented a safe collision avoidance algorithm based on potential fields for fixed-wing unmanned aerial vehicles (UAVs) with constrained field of view sensors such as cameras. They demonstrated the effectiveness of the proposed method with several simulations, including one with randomized trajectories covering a large set of possible configurations. In difference with a mentioned research, this paper deals with a collision avoidance of rotorcraft vehicles. In [2] conflict resolution was achieved with obstacle trajectory data taken from a simulated camera and range-finder in the presence of their respective measurement uncertainties. M. Hehn and R. D'Andrea proposed an algorithm for the real-time trajectory generation for quadcopters [3]. The ability to plan trajectories from nonrest conditions was used in conjunction with waypoints i1n order to guide vehicles around obstacles without stopping. In this study, the main focus is still on the trajectory generation for the multiply UAV collision prevention between themselves.

2. Problem formulation

Usually unmanned aerial vehicles are operated by the human. Therefore, providing totally unmanned control system for the aerial vehicle needs the assessment of all the possible risks. The most common risks are: collision with other objects, fast or undelayed battery discharge, wrong route planning etc. In cases of solving tasks with several UAV, one more risk appears – risk of collision between UAV. Let's suppose, that three UAV are looking for the same object, and each of them is programmed to reach his goal. It means that each of them will try to reach approximately the same point coordinates. So, how can each of them reach an aim without interfering each other? The algorithm described in this paper solves this problem and prevents collisions between UAV in tasks of several UAV working in one area.

In 2014 anti-collision system for navigation inside an UAV, using fuzzy controllers and range sensors [4] was proposed. In that research authors were working to provide a system that will help to prevent UAV collisions with obstacles, but nothing about collisions with other UAV was said. In 2013 a comparative study of collision avoidance techniques for unmanned aerial vehicles was presents and published by A. Alexopoulos and others [5]. The first collision avoidance method in that study was based on a geometric approach which computes a direction of avoidance from the flight direction and simple geometric equations. The second technique used virtual repulsive force fields causing the UAV to be repelled by obstacles. The last method was a grid-based online path re-planning algorithm with A* search that finds a collision free path during flight. Various flight scenarios were defined including static and dynamic obstacles. In difference of that research, we provide a system, were dynamic obstacles are UAV, and all these dynamic obstacles are communicating with each other. This proves the novel of the proposed research.

3. Anti-collision system structure

The proposed anti-collision system is not centralized and is distributed among the vehicles. All calculations and decision-making are made by the anti-collision system embedded in each UAV separately. Figure 1 shows the structure of the proposed system.

There are communication components ensuring data transmission, such as satellite positioning system – GNSS (such as GALILEO, GPS etc.) and radio frequency modules – RF.

Each UAV has embedded electronic device D_{TR} – control components to obtain the position, to calculate the motion parameters, to communicate with other devices and to control the electric drive of UAV.

Authors assume that D_{TR} is embedded into each mechanical vehicle for the most effective proposed control system operation.

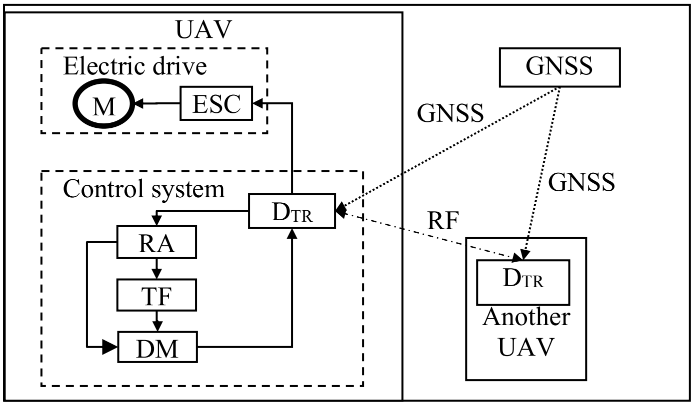

Fig. 1. Structure of the anti-collision system of UAVs

D_{TR} device of the UAV receives the information about UAV location by GNSS and information about other vehicles location, speed and movement direction by RF. Risk assessment module (RA) calculates the distance between UAV. If the distance is smaller than specified, the necessary safe height of flight is found out by target function (TF) and decision about height change is made. In decision, making module (DM) the necessary engine speed is calculated also and is send to the D_{TR} device. D_{TR} controls the UEVs electric drive (electronic speed controller and electric motor M) and affects the engine speed.

4. Mathematical model of the proposed system of UAV

The team of the UAVs is a group of autonomous unmanned aerial vehicles whose actions agree with certain rules and with only common interests.

The set of UAVs is given:

$$\mathrm{UAVS} = (\mathrm{UAV1}, \ldots \mathrm{UAVn}). \quad (1)$$

The **utility** function as a common interest function is:

$$U = w(x, a1, a2, \ldots, an) \rightarrow opt; \quad (2)$$

where u – **utility** function – common interest function;
x – **state** of the environment;
a_i – **action** of the i-th UAV.

The **information** of each UAV depends on the state of environment:

$$yi = \alpha i(x); \quad (3)$$

where y_i – **information** of i-th UAV.

The **decision rule** of i-th UAV results an action of i-th quadcopter and depends on the information:

$$ai = \beta i(yi)l; \quad (4)$$

where β_i – **decision rule** of i-th UAV.

Interaction between i-th and j-th UAV:

$$q_{ij} = \frac{\partial w}{\partial a_i \partial a_j}. \quad (5)$$

A set of decision rules is optimal if:

$$E(S) = E(\ w(\ x, (\ \beta 1(y1), ..., \beta n(yn)\ )\ ) \rightarrow \text{max for a given probability distribution on x.} \quad (6)$$

The location L^{UAVS} of UAVs is represented by three subsets $<\chi_c^{UAVS}, \psi_c^{UAVS}, \eta_c^{UAVS}>$, that are latitutde χ, longitude ψ and altitude η:

$$\chi_c^{UAVS} = \{\chi_c^{UAV_1}, \chi_c^{UAV_2}, \ldots, \chi_c^{UAV_n}\}, \psi_c^{UAVS} = \{\psi_c^{UAV_1}, \psi_c^{UAV_2}, \ldots, \psi_c^{UAV_n}\}, \eta_c^{UAVS} = \{\eta_c^{UAV_1}, \eta_c^{UAV_2}, \ldots, \eta_c^{UAV_n}\}; (7)$$

where χ_c^{UAV} – Latitude of the current point;
ψ_c^{UAV} – Longitude of the current point;
η_c^{UAV} – Altitude of the current point.

The common goal defined in this paper is to reach the same target point TP = $<\chi_{tp}, \psi_{tp}, \eta_{tp}>$.
Geographical coordinates of the target point are defined by following set:
χ_{tp} – Latitude of the target point;
ψ_{tp} – Longitude of the target point;
η_{tp} – Altitude of the target point.

But the common safety, i. t. collision prevention, criterion is:

$$D = |UAV_i UAV_j| = \sqrt{(\chi_c^j - \chi_c^i)^2 + (\psi_c^j - \psi_c^i)^2 + (\eta_c^j - \eta_c^i)^2} > S; \quad (8)$$

where S is safety distance limit for each pair of $< UAV_i, UAV_j >$, $i = 1..n$, $j = 1..n$, $i \neq j$.

It is obvious that in case if $\chi_c^{UAV_i} = \chi_c^{UAV_j} = \chi_{tp}$ AND $\psi_c^{UAV_i} = \psi_c^{UAV_j} = \psi_{tp}$ AND $\eta_c^{UAV_i} = \eta_c^{UAV_j} = \eta_{tp}$ the safety criteria cannot be satisfied, because $D = 0$.
So, the common target function with anti-collision criteria is following:

$$\begin{cases} \eta_c^{UAV_i} = \eta_c^{UAV_j} \rightarrow \eta_{tp} \\ \chi_c^{UAV_i} = \chi_c^{UAV_j} \rightarrow \chi_{tp} \\ \psi_c^{UAV_i} = \psi_c^{UAV_j} \rightarrow \psi_{tp} \\ D = |UAV_i UAV_j| > S \\ i = 1..n, \\ j = 1..n, \\ i \neq j \end{cases}. \quad (9)$$

Each UAV is tending to reach the target point, but if it is not possible than the altitude becomes a subject to be changed first. If it is impossible to change the altitude, then latitude and longitude might be changed.

If the distance D till other UAV is less or equal to S, the collision possibility is high and the decision about the altitude η_c^p change is made.

5. Control algorithm of multiple UAV for their collision prevention

Control algorithm of multiple electrical UAV for their collision prevention was developed:

STEP 0. Initialization: Let's assume that all UAVs have the common goal TP. The UAV_1 is the vehicle, where the following algorithm is working. And it is assumed that the same algorithm is working at any other UAVS.

STEP 1. Determination of the UAV_1 own coordinates: χ_c^{UAV1}, ψ_c^{UAV1}, η_c^{UAV1}.

STEP 2. Selecting the UAV_i and requesting of its coordinates.

STEP 3. Receiving coordinates of other UAV_i: χ_c^{UAV2}, ψ_c^{UAV2}, η_c^{UAV2}.

STEP 4. Calculating the distance D between the UAVs using (8).

STEP 5. Decision making about speed change if D<=S.

If $\eta_c^{UAV1} \geq \eta_c^{UAVi}$ then UAV_1 sets the η_{tp}^{UAV1}=$\eta_{tp}^{UAV1} * 1.5$.

If $\eta_c^{UAV1} < \eta_c^{UAVi}$ then UAV_1 sets the η_{tp}^{UAV1}=$\eta_{tp}^{UAV1} * 0.5$.

If distance D is bigger or equal than allowed, then nobody is changing the height and $\eta_{tp}^{UAV1} = \eta_{tp}$.

STEP 6. Calculating target rotation speed (tw) for each motor.

STEP 7. Target Euler angles of motion (rotP – pitch, rotR – roll, rotY – yaw) calculation.

STEP 8. Traction forces (F_Z, F_{XY}) calculation.

STEP 9. Energy calculation.

STEP 10. Battery capacity calculation.

STEP 11. Processing the decision to control motors.

STEP 12. i = i+1, if i>n then i=2.

STEP 13. Starting from the STEP 1 and checking the collision risk with another UAV_i.

6. Computer models and experiment

Any maneuvres of the quadcopter requires to know the exact rotation speed of the propeller engines and necessary Euler angles. For this purpose, a Simulink model for the quadcopter UAV for angles calculations was developed (Fig. 2).

For the experiment target, point (300; 300; 100) was chosen. Additionally, program shows parameters for each UAV:

- time (t) of UAV's engine work;
- current coordinates (X, Y, Z);
- Euler angles of motion (rotP – pitch, rotR – roll, rotY – yaw);
- engines speeds (w1, w2, w3, w4);
- force vector on z axis (Fz);
- force vector on xy axis (Fxy);
- traction force (F);
- energy;
- battery capacity.

Start of the experiment is shown in the Figure 3. Three UAVs have different start point and each of them starts to move towards coordinates of the target point. After they are close enough to each other, they start to change height in case of prevention collision.

In Figure 4 the result of the experiment is shown. Three UAV reached the target point coordinates without collide and each of them has changed their height according to the developed algorithm. The first UAV took up a position at the height of 200, the second one is almost on the target height, but the third one is descended to the height 50. As the result, collision possibility was reduced to zero by changing only one target coordinate Z – height.

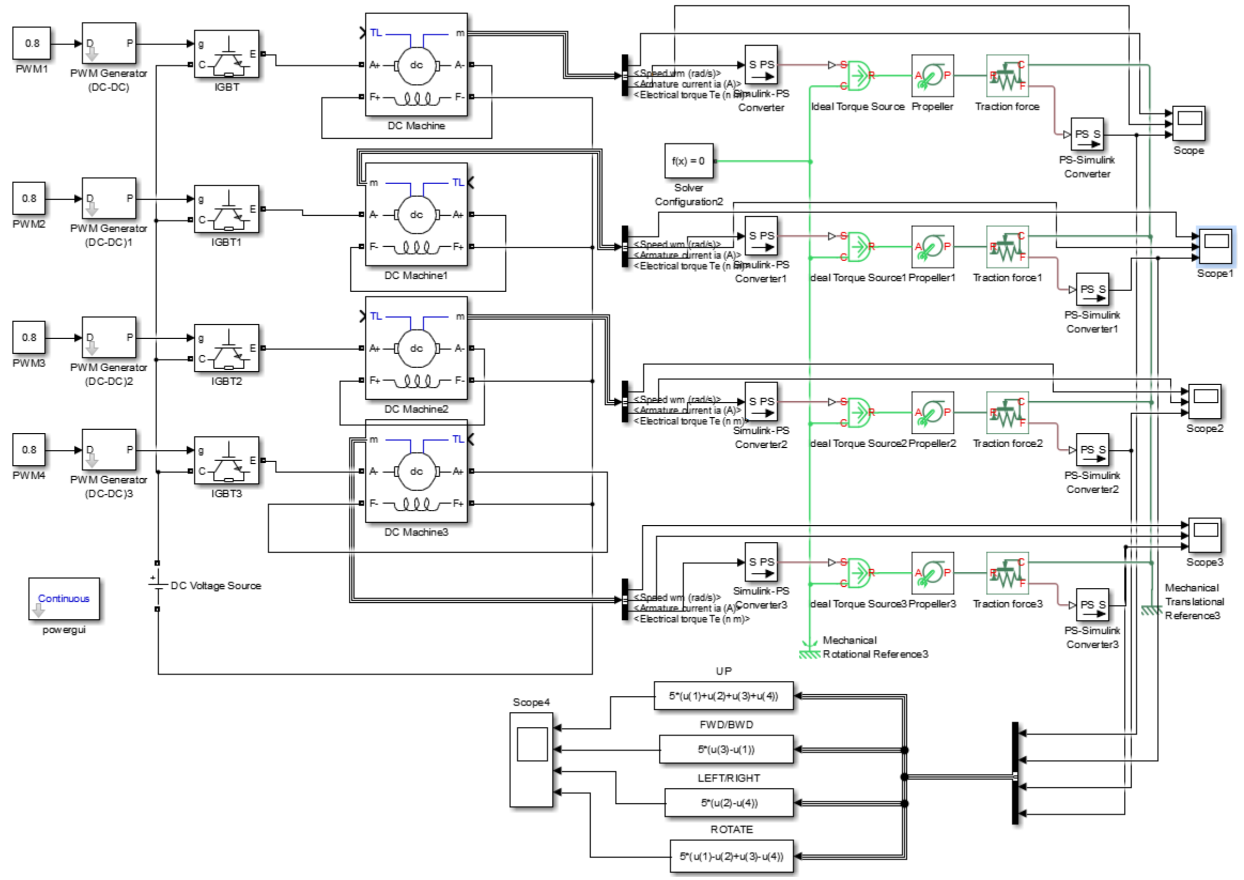

Fig. 2. Simullink model for the quadcopter UAV

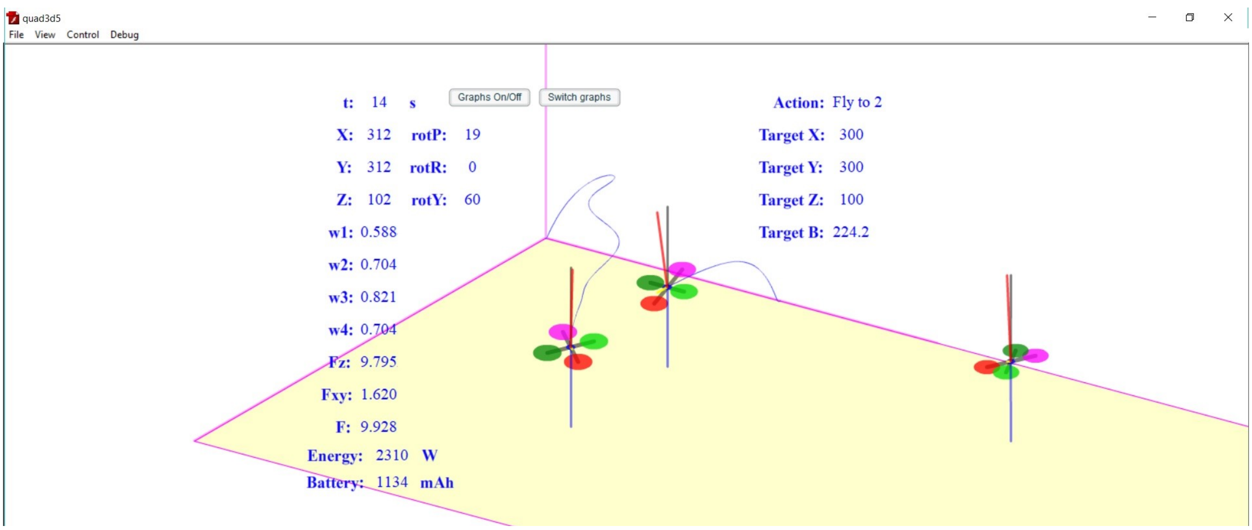

Fig. 3. Start of the experiment of multiply UAV collision prevention algorithm

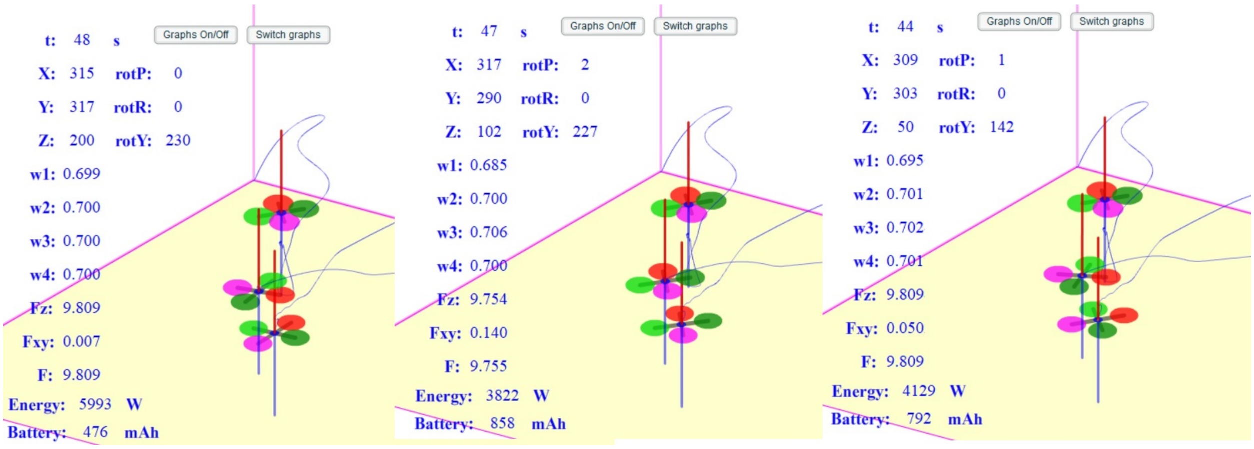

Fig. 4. UAV reaching the target point coordinates without collide

Conclusions

The proposed in this paper algorithm is working correctly. Experiment shows, that all three unmanned aerial vehicles reached their target point without any collisions by changing only one target coordinate – height of the flight.

As the proposed devices are embedded into the UAVs there is no necessity to involve infrastructure and devices can work regardless of location, also in forest or over reservoirs.

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