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Implementation of Collision Detection and Avoidance Algorithm for Point Mass Model UAV

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Abstract—The UAVs have become more and more sophisticated. Militarily these systems are gaining tremendous importance, as they can conduct precision strikes on distant targets without collateral damage. On military missions, UAVs work in dangerous environments, and therefore, it is crucial to always keep their routes away from any type of threat and restricted zone. The original routes that are obtained offline are no more valid in dynamic environments where the position of all the threats is not known earlier. Therefore, the collision avoidance planner must be able to also work online in order to propose a new path during the UAVs mission when a sudden pop-up threat appears. UAV is designed using Matlab simulink and obstacles are simulated as Point with position in three dimensions. The proposed work clearly identified obstacles along the path and generated alternate path for smooth navigation of UAV.

Keywords—**UAV, Point Mass model, collision avoidance, trajectory planning**

I. INTRODUCTION

More and more intelligence needs to be built into the machine for proper functioning of UAV and to achieve the objectives of its design. So this project aims to fill the gap by designing an auto pilot system for UAV in real time where sudden obstacle may pop up thereby making UAV completely automatic. Decentralized algorithms providing collision detection and avoidance for UAV needs to be addressed to implement an automatic *Sense-and-Avoid* capability to provide safe operation from the collision avoidance (CA) perspective. The objectives of this work are

- To implement the “obstacle sense and avoid” algorithm and the logical decision making system that would provide the UAV and MAV with the ability to re-route its current path to a safer flight course
- To develop escape maneuver from moving obstacles and find new way points for guiding the UAV and MAV with limited change in the planned trajectory
- To determine the optimized path for UAV navigation when sudden threat pops up along the trajectory of UAV

The rest of the paper is organised as follow. Section II contain the Litertaure Survey, Section III contain the proposed Methodology, Section IV contain the Collision AVOIDANCE module, Section V contain the Results and Discussion and Section VI contain the Conclusion.

II. LITERATURE SURVEY

Many researchers have worked on designing collision avoidance strategies for smooth navigation of UAV. The work carried out in few literatures are summarized below:

Saunders et al [1] used rapidly exploring random trees (RRT) to find dynamically feasible collision-free paths. But the downside is the RRT scheme requires more computation times. Xiaohua [2] designed a novel algorithm using modified Grossberg neural network (GNN) for obstacle avoidance. Eva et al [3] offered a path planner for multiple unmanned aerial vehicles (UAVs) based on evolutionary algorithms (EAs) for real time scenarios. Liangfu and Yunsong [4] proposed a new generation of traffic alert and collision avoidance systems based on the Global Positioning System (GPS) and Automatic Dependent Surveillance Broadcast (ADS-B). David et al[5] designed the task of conflict detection and resolution as an optimization problem searching for a heading control for cooperating airplanes using communication. Per-Johan and Fredrik [6] put forth a probabilistic method to calculate the near mid-air collision risk as a function of predicted flight trajectory. Fethi solved the collision avoidance problem by resolving the workspace into horizontal and vertical planes as collision in 3-D[7]. Chunbo et al tackled the problem of constant positioning and collision avoidance on UAVs in outdoor (wildness) search scenarios by means of received signal strength (RSS) from the onboard communication module[8]. Prachya and Mehran [9] presented an approach for the deconfliction problem for a pair of constant altitude, constant speed unmanned aerial vehicles (UAVs) modelled as unicycles in the presence of static constraints. Naifeng et al [10] proposed a method for UAV online path-planning a dangerous environment with dense obstacles, static threats (STs) and dynamic threats (DTs). Several works suggest autonomous collision avoidance and dynamic trajectory modification for UAV flying along with other aircrafts[11,12]. UAV controlled by Internet of Things was detailed in [13].

III. METHODOLOGY

The basic function of the proposed sense and avoid algorithm is to continuously evaluate each trajectory by the surveillance function, to determine if any collision hazard exists in future requiring avoidance action, and to select and communicate the avoidance manoeuvre. The algorithm should continue to evaluate the trajectories following the start of the manoeuvre, and should be capable of issuing a correction in case threat exists in future. Collision avoidance to be done with the added requirement that vehicles stay as close as possible to their original intended trajectories.

A. Assumptions

The following assumptions are made in the implementation of this work

- TCAS details of obstacle are obtained at a time interval of 1 s
- In the absence of radar data predict the future position
- Azimuth of the nearest point of the obstacle and Elevation of obstacle known from EW system onboard
- Intruder aircraft or moving obstacle will not maneuver
- Collision avoidance for both single threat and multiple threats
- Both stationary obstacle and moving obstacle avoided
- Lateral, vertical separation gaps considering error in Sensor data
- Flat Earth Model is assumed (Radar range < 10 km)
- UAV assumed as Point Mass Model and obstacle Point (3d Position)
- Altimetry error is given consideration in radius of safety sphere

B. Functional Block Diagram

The proposed system consists of 4 modules namely the Main Module, Radar Module, Flight Controller Module and Collision Avoidance Module. Figure 1 shows the functional block diagram of the proposed work. The proposed work consists of following steps.

1. The avoidance algorithm/main controller program would "ping" or request information from the radar unit
2. The radar unit would respond by providing a list of the obstacles located in the scan zone, in the form of an array which contains an ID, range, elevation, azimuth angles and velocity of the obstacle.
3. Main program estimates collision possibility with another aircraft or any obstacle, i.e. estimating if the separation distance between the UAV and obstacle is under the safety limit. If a collision is predicted, the program would initiate the collision-avoidance algorithm
4. The Collision Avoidance Module requests details from the flight controller regarding the UAV's current heading, next way points, trajectory and the distance to that way point. It also interacts with the radar unit to get the details of obstacle.
5. The avoid algorithm would instruct the flight controller to change the flight path of the UAV to new way point in the case of an imminent collision based on the closest point of approach for the obstacle. This contains the following information: coordinates of the new waypoint, distance to that waypoint from current locations, time to reach that waypoint, rate of turn and time to perform manoeuvre.
6. Retract to the original path predefined earlier from the current collision avoidance waypoint.
7. Once the danger has passed, the collision avoidance algorithm would relinquish control back to the main program.

The functional block diagram is shown in Figure 1.

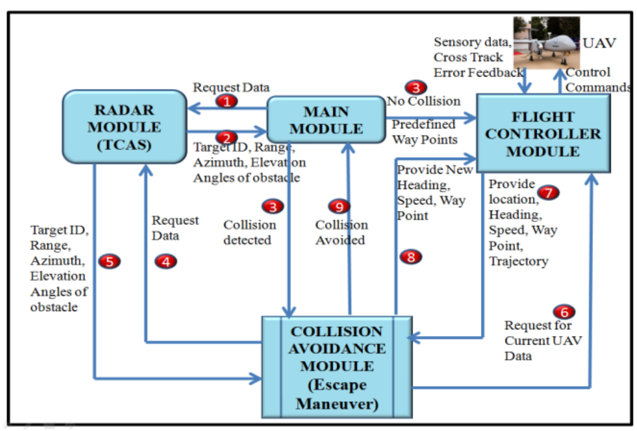

Figure 1. Functional Block Diagram

C. Main Module

Main module creates a model of UAV and MAV using Point Mass Model and generates necessary control signals for navigating it. It also generates the Way Points and smooth trajectory based on the source and destination points. It also gets input from the Radar Module about the possible threats to the UAV along its trajectory. If there is no collision, the predefined trajectory will be provided to the Flight Controller Module. When the distance between the obstacle and the projected instantaneous velocity vector of UAV falls below the threshold value collision is detected and control is transferred to the Collision Avoidance Module for generating escape manoeuvre. Main Module consists of three major components namely UAV Model Creation, Trajectory Planning for UAV navigation and Collision Detection. Figure 2 represents the components of UAV module.

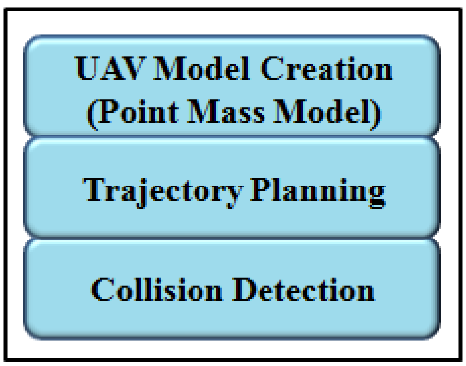

Figure 2. Components of Main Module

D. *UAV Model Creation*

UAV is represented in Point Mass Model. The present position of UAV is calculated from the velocity components along North *(v sin(heading))* and velocity component along East *(v cos(heading))*.

Rate of Turn ROT

(Rate of Change of Heading) = $g \tan \vartheta / v$ (1)

g =9.81m/s^2

ϑ - Banking angle

$$\tan \vartheta = \frac{V^2}{gR} \qquad (2)$$

V – Velocity of UAV

Adjust heading hold and bank angle command based on cross track error feedback to navigate the UAV to the intended trajectory.

IV. COLLISION AVOIDANCE MODULE

A. Collision Detection

Collision will be detected if collision distance < RS accounting for errors in radar measurements where RS is the Radius of Safety Sphere around UAV

Collision Distance: $CD = \sqrt{R_x^2 + R_y^2 + R_z^2}$ (3)

If CD < RS, then threat exists. To apply collision avoidance manoeuvres the Main Module handover the control to Collision Avoidance Module to design escape manoeuvre.

B. Collision Avoidance Module

The input output and Algorithmic components are as below

Input **:** (i) Velocity, Range, Azimuth and Elevation of obstacle with respect to UAV from radar
(ii) Velocity, Current Position of UAV from Flight controller module
(iii) Trajectory along which the UAV has to fly
(iv) UAV constraints

Output **:** New Way Point , New Trajectory, distance to that waypoint from current locations, time to reach that waypoint, rate of turn and time to perform manoeuvre

Algorithm Components:

The Collision Avoidance Module identifies evasion maneuvers from the list $M = \{m_L, m_R, m_U, m_F, m_S, m_O\}$ which represents turn-left, turn-right, climbup, descend-down, fly-faster, fly-slower, and no-change. The evasion manoeuvres depends upon the position of obstacle, current position of UAV and its constraints as below.

a) **Horizontal Separation Minimum** – Change Speed or Direction
b) **Intruder climb/descent –** Reduce Speed or Host UAV descent/climb
c) **Intruder Crossing Altitude –** Climb up/down
d) **Intruder in level** – Climb up/down or Change Direction
e) **Faster aircraft or head on collision** – Change Direction
f) **Vertical Separation minimum –** Change Altitude

The task of manoeuvers are listed below

a) **Altitude Change** **–** Up or Down depends upon the climb/descent rate and the current altitude of UAV

b) **Direction Change** – Changing the direction to either left or right depends upon the trajectory of the moving obstacle

c) **Change Speed** - Increase or decrease speed depends upon the current speed and distance of separation

New Way Points will be identified based on the manoeuvres and a new trajectory will be generated and sent to the flight controller module. CD represents the Collision Distance, whereby if that distance CD < *RS* at some future time t then there is a collision possibility with that aircraft in t seconds. This will be the prime condition for the UAV to identify a safe velocity or travel path to avoid the potential collision.

The algorithm estimates:

- The closest point of approach for the target (occurs at point Q).
- The value of the minimum distance (d) to the UAV and the time (t_Q) it takes for the aircraft to reach that point Q.

The time to reach closest point of approach Q i.e point of minimum separation is given by Eqn.16 from its current location

$$t_Q = \frac{R_X V_{AUX} + R_Y V_{AUY} + R_Z V_{AUZ}}{V_{AUX}^2 + V_{AUY}^2 + V_{AUZ}^2} \quad (4)$$

$$d = \sqrt{R_{xt}^2 + R_{yt}^2 + R_{zt}^2} \quad (5)$$

The alternate path identification is shown in Figure 3.

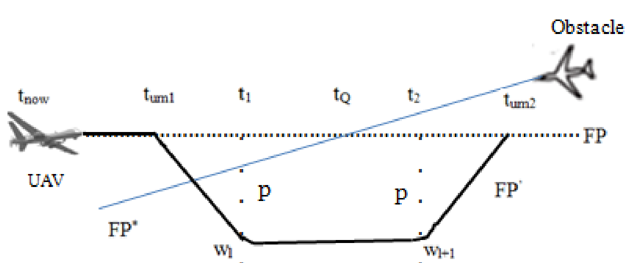

Figure 3 . Change in Direction Manoeuvre

The location of the UAV at the time of collision (t_Q) can be determined from the formulas given below.

$$R_{xt} = R_x + V_x \times t_Q$$

$$R_{yt} = R_y + V_y \times t_Q$$

$$R_{zt} = R_z + V_z \times t_Q$$

(6)

The minimum separation (d) will occur at the instant when the vector (d) is perpendicular to the travel path of the aircraft. If the value of the smallest separation distance (d) is less than *RS*, the avoidance algorithm will initiate a request to manoeuvre to adjust the flight path of the UAV, and increase the separation. The time to collision (t_Q) is the time available for the UAV to complete its avoidance manoeuvre. So, the turning manoeuvre has to be applied before this location (R_{xt}, R_{yt}, R_{zt}) . Hence two locations t_{um1}, t_{um2} before and after t_Q (R_{xt}, R_{yt}, R_{zt}) has to be identified to start turning and to return to the original trajectory after the threat is avoided. From the position t_1, t_2 in the original trajectory a safe distance *RS* is to be provided to find the new way points w_l, w_{l+1} keeping altitude constant.

The Radius of Turn is given by

$$R = \frac{V^2}{g \times \tan\vartheta} \quad (7)$$

where
R- Radius of curvature of turn
V_0 is the velocity
g is the acceleration
ϑ is the banking angle in radians
RS represents the radius of safety sphere
Find out t_1 and t_2 at a distance *RS* from t_Q

$$\text{Rate of Turn} = \frac{g \times \tan\vartheta}{V} \quad (8)$$

$$\text{Curve Time} = \frac{1}{\vartheta} \times \cos^{-1}\left(1 - \frac{Midway}{Radius}\right) \quad (9)$$

If the UAV is moving along y direction

$$\text{Horizontal Travel} = \sqrt{RS^2 - R_{yt}^2 - R_{zt}^2} \quad (10)$$

New Waypoint1 w_l = (R_{xt1} + Horizontal travel, R_{yt1}, R_{zt1}) (11)

New Waypoint2 w_{l+1} = ((R_{xt2} + Horizontal travel, R_{yt2}, R_{zt2}) (12)

After the UAV reaches the safe midway point w_{l+1} , it would reverse its rate of turn in order to return to the initial UAV heading so that it retracts the original path plan at location t_{um2} .

V. RESULTS AND DISCUSSION

The UAV can be controlled to fly through all the waypoints along the designated trajectory. Velocity and altitude can be changed as desired for obstacle avoidance. UAV is modelled using Point mass model and the obstacle avoidance is simulated using MATLAB Simulink. The proposed experiments were carried out in Pentium duo core processor.

The simulation results for obstacle avoidance is shown in Figure.4&5. The animation results for obstacle avoidance is shown in Figure.6&7.

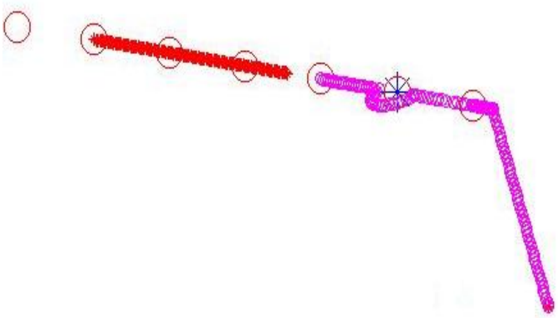

Figure 4. UAV avoiding stationary obstacle

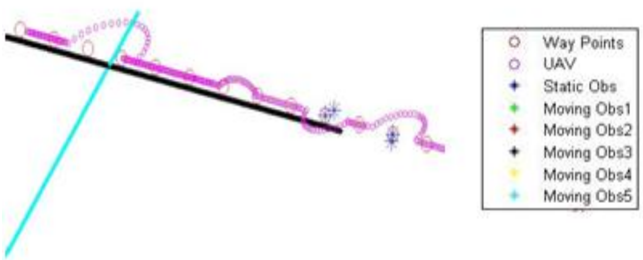

Figure 5. UAV avoiding both moving and stationary obstacle

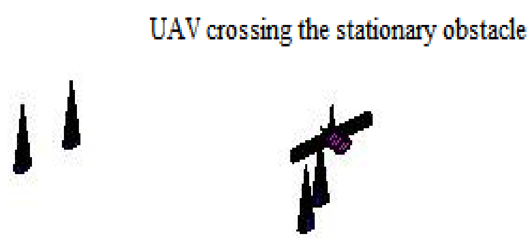

Figure 6. Animation results of UAV avoiding stationary obstacle

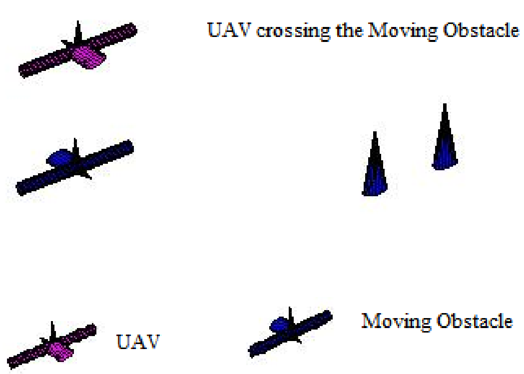

Figure.7 Animation results of UAV avoiding Moving obstacle

The avoidance algorithm works perfectly upto 60 stationary obstacles. As the number of stationary obstacles increases to 70, the avoidance algorithm fails as it could not find alternate path. But in the presence of moving obstacles, the algorithm could identify alternate path only upto 30 stationary and 6 moving obstacles. The avoidance results are shown in Table 1

Table 1: Collision Avoidance Results

S.No	No of stationary obstacles	No of Moving obstacles	Collision Avoided/Not Avoided
1	10	0	Avoided
2	20	0	Avoided
3	30	0	Avoided
4	40	0	Avoided
5	60	0	Avoided
6	70	0	Not Avoided
7	10	2	Avoided
8	20	4	Avoided
9	30	6	Avoided
10	40	8	Not Avoided

VI. CONCLUSION

The obstacle avoidance algorithm was implemented for a Point Mass Model UAV designed using Matlab Simulink. The results clearly showed that the proposed algorithm clearly avoided both stationary and multiple obstacles. The algorithm can be extended to include mountain like obstacles. Also, the UAV model can be changed to 6DOF model to suit real time applications.

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