VIRTUAL REALITY MODELING, ANALYSIS AND SIMULATION OF FORMATION FLYING OF TWO UNMANNED AERIAL VEHICLES

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Abstract-* *The objective of this paper is to show a complete simulation and implementation of multiple unmanned aerial vehicles (UAV), with emphasis on the requirements needed and the benefits realized in making the simulation functional for an arbitrary number of vehicles. Cooperative control is shown for an autonomous set of vehicles in performance of tasks such as formation, reconnaissance, surveillance, search, jamming and decoy or target attack. The simulation is developed using a Commercial off the Shelf (COTS) software package that allows for a hierarchical block diagram representation to include control laws and vehicle models. Visualization is achieved by having the simulation drive a VRML (Virtual Reality Modeling Language) world allowing the interactions of the vehicles in their environment to be seen as the simulation is running. Implementation is done using Micropilot an auto pilot system developed by Canadian based company, which can be interfaced with Horizon. The HORIZON ground control software is a user-friendly interface for Communicating with your MicroPilot Autopilot. The control law is implemented with position estimation.

INTRODUCTION

In recent years, formation flying problems have been one of the leading research. In comparison with a single UAV, a group of UAVs that work cooperatively will provide a better performance to complete difficult work, which is the motivation for further research in formation control problems. Formation control is achieved by using consensus algorithms for multi-agent systems was studied in the literature, [1]–[11] can be classified as leader-follower,[1]–[4] behavior-based model,[5]–[7] and virtual structure [8]–[11]. In the applications like surveillance of convoy for protection, protection and monitoring of natural resource, reconnaissance and surveillance of geographical area is required to continuously monitor an area of interest from all the directions. In all these applications multiple UAV systems are finds a suitable position, since UAV has various advantages like better performance, reliability, handling, robustness, efficient, availability and scalability. To achieve a common goal all these UAV will work in cooperation. In this paper we present a displacement-based control for multiple autonomous UAV, it makes them to move from any position to the target and try to keep maintain formation around the point of interest so that we can have a better monitoring by the UAVs when they are distributed around it. Formation flying in circle is best suited for monitoring target, where all the UAVs move constantly while keeping a distance between them and also the target. Circular formation based on Vision is described in [12] - [18]. A vision-based control for circular formation with bearing angle of adjacent UAV [12]. All the vehicle is equipped to have a vision-based sensor to provide bearing angle which is defined in body frame. All the UAVs finally get into a circular formation but the convergence about the point of interest in formation is specified initially to achieve formation over the target. Tracking of multiple Ground vehicle using multiple UAVs based on vision is described in [17] where tracking of targets and formation control of UAVs are separately designed. In this paper control of formation is based on position and distance measurements and formation flying of UAV is a function of position of UAV and the target. Target monitoring using bearing angle and cyclic formation is discussed in [18]. Each UAV requires bearing angle of the adjacent UAV. Here it is described as all the gains of UAVs in formation are same and they can visualize the target. In this paper different gain value has been chosen to keep the UAV in formation which provides with different sensing capability of the sensors. We can obtain different formations by selecting appropriate formation gains. Which provides us with a special case where in the target available only in the field of view of few UAV. We studied for stationary target and analysis was carried out to keep the formation flying using simple schemes in designing Micropilot model for each UAV. The results are verified with virtual reality model-based simulator (VRML). It is assumed that each UAV can identify its adjacent UAV and it can measure distance with respect to each other.

Unmanned Air Vehicle as applications in various sectors such as Intelligence, border patrol, maritime, security, crowd control, search & rescue and environmental monitoring. Exploiting planned advances in intelligence, surveillance, reconnaissance, and the development of unmanned aerial vehicles (UAV) can address future military needs. Through all-source coordinated intelligence fusion, it will be possible to supply the war fighter with all-weather, day or night, near-perfect battle space awareness. This information will be of precision targeting quality and takes advantage of multiple sources to create a multidimensional view of potential targets. The obvious extension of these developments is to expand UAV use to include lethal missions where the pilots could not take risk. Here the simulation of such a co-operative control of multiple UAVs and also to implement it by creating a MicroPilot. The HORIZON ground control software is a user-friendly interface for communicating with the MicroPilot Autopilot. It can act as a setup tool to create and load flight programs, change feedback gains, and configure sensors and servos. Its main function, however, is to allow us to observe and interact with the UAV while it is in flight.

Simulation

Simulation is done using VRLM tool box in which is shown in fig. 1. The VRML subsystem allows for a virtual world to be driven by the simulation. All vehicles are represented in the VRML world with their position and orientation being driven by the simulation. This is extremely useful in being able to visualize the formation as a whole and get immediate user feedback as to how the vehicles are moving with respect to each other or obstacles/targets in their path. It is this virtual reality world that allows choosing which vehicle to follow, or choose between different views such as side, rear, and top. This is in contrast to analyzing sets of time histories in order to reconstruct motions for each vehicle and how they moved relative to each other or to their environment.

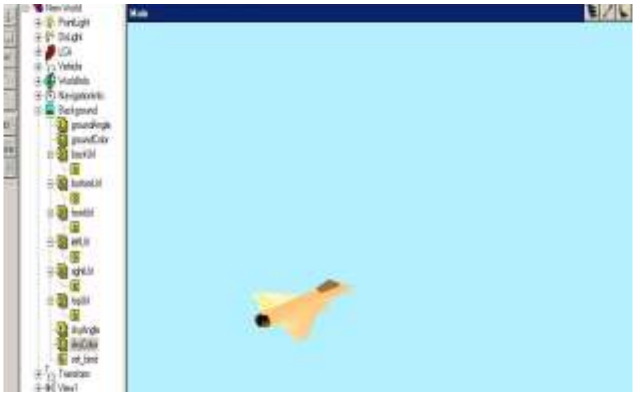

Fig 1. Simulation using VRML

The simulation is broken into 3 major parts/subsystems.

1. The vehicle(s), which takes the commands as inputs and then outputs state of each vehicle.
2. The instincts, which takes the states of all vehicles as inputs and then outputs the desired states for each vehicle based on the instinct calculations.
3. The control law, which takes the desired and actual states and computes the commands to drive each vehicle to the desired state. The commands generated by the control law are then the inputs into the vehicles, thus forming an autonomous loop closure that constitutes the multi UAV simulation model.

MATERIALS AND METHODS

Flight Plan

There has been a considerable amount of research conducted on explicit coordination and motion control of mobile robots. For large groups of robots, some principal concepts of "robot swarms" or "army-ants" have been explored a s a means to accomplish complicated tasks using many simple robot devise. Since the dynamics of the robots are fairly simple, the control algorithms generally involve position commands sent to each robot. As long as the robots can freely communicate with each other, various geometric formation patterns can be achieved while keeping the robots from colliding with one another.

Another area of robot research is implementing herding behavior. In this application, robots are required to move together as well as to maintain a fixed relative position. One might imagine a herd of land animals running together. For this application, the dynamics of the individual robots must be considered such that a constant relative velocity is maintained.

Velocity vector command can be used to control the UAVs. The desired velocity vector for each aircraft is constructed as weighted average of several vectors. Each of these vectors is related to one of the basic behavioral instincts of the formation members. Following Reynolds, we have introduced the following four possible instincts, listed in the order of precedence:

1) Collision Avoidance
2) Obstacle Avoidance
3) Target Seeking
4) Formation Keeping

1.Obstacle Avoidance

Steer-to-avoid is a better simulation of a natural bird guided by vision. The obstacles are considered only if it is directly in front of it. (It finds the intersection, if any, of its local velocity vector with the obstacle.) Working in local perspective space, it finds the silhouette edge of the obstacle closest to the point of eventual impact. A radial vector is computed which will aim the UAV at a point one body length beyond that silhouette edge.

Instead of accelerations, desired velocity vector command can be used. The desired velocity vector for each aircraft is constructed as weighted average of several vectors. Each of these vectors is related to one of the basic behavioral instincts of the formation members [1]. Here it is assumed that velocity and height are constant and are not varied. Here range estimation algorithm is used to estimate the distance between the UAV and the obstacle. A boundary around the obstacle is estimated so that UAV will avoid those regions.

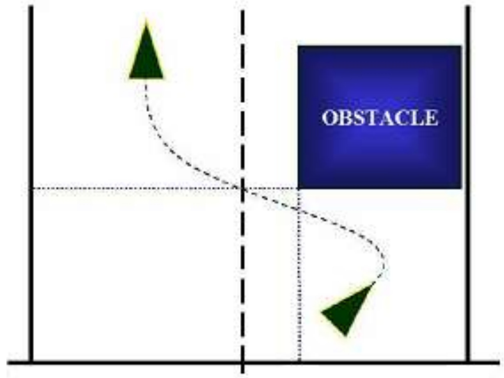

Fig. 2 Obstacle Avoidance

The figure 2 shows the path taken by the UAV represented as a triangle, the square block represents the obstacle and the thin dashed line represents the path taken by the UAV by avoiding the obstacle.
The figure 3 describes the regions in which the UAV should fly are given by a set of limits and Φ1, Φ2, Φ3 describes the regions around the obstacle. The various constrains that define the path of the UAV such that it will avoid the obstacle is given by a set of equations 1, 2 and 3.

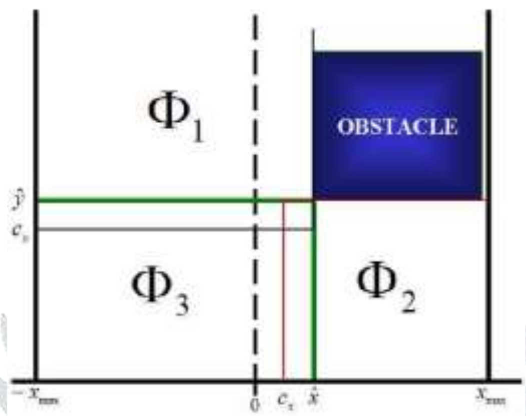

Fig. 3 Region Description

$\Phi_1 = \{(x,y)|-x_{max} < x < \hat{x}, y \geq c_y$ (1)
$\Phi_2 = \{(x,y)|c_x \leq x < x_{max}, 0 \leq y < \hat{y}$ (2)
$\Phi_3 = \{(x,y)|-x_{max} < x \leq \hat{x}, 0 \leq y \leq \hat{y}$ (3)
X_{max} - boundary limit.
C_x - distance from obstacle edge along X-axis.
C_y - distance from obstacle edge along Y-axis.
$\hat{x}$ - edge of obstacle along X-axis.
$\hat{y}$ - edge of obstacle along Y-axis.
Φ_1, Φ_2, Φ_3 - various regions around the obstacle.

2. Formation Flying

The starting position of all the Unmanned Aerial Vehicles is given along with the various positions of obstacles. A small region around the obstacle is defined so that the Unmanned Aerial Vehicles should avoid those regions where there is the possibility of colliding with the obstacle. It is not only that the Unmanned Aerial Vehicles should avoid the obstacle alone and also avoid colliding with the adjacent Unmanned Aerial Vehicle. Finally all the Unmanned Aerial Vehicles should be in formation also [7].

Algorithm For Formation Flying

- Get the obstacle locations
- Get starting point for all UAVs
- Calculate the separation between UAVs
- Keep the formation
- Avoid the obstacles
- Avoid collision
- Reach the destination
- End

1. Obstacle Locations

Locations of the various obstacles are pre-defined, that is we consider a region with obstacles in known locations. Since the location is known computation burden will be less. As the UAV starts moves the system compares the current location of the UAV with the location of the obstacle, if the UAV is any where near the obstacle then the system instructs the UAV to change the path by avoiding the obstacle.

2. Calculating Separation Between UAV'S

We have the location of an UAV at any given point; since we know the starting point of the UAV it is easy to update the location of the UAV at each point, so at any instant of time we know the location of each UAV in the formation. By knowing the location of each UAV it is easy to calculate the separation between them by using the trigonometric formulas.

Distance between two UAVs located at the points (Cx1,Cy1) and (Cx2,Cy2), then the distance between the two UAVs Ψ is given by the equation 4.

$$\Psi = \sqrt{(C_{x2} - C_{x1})^2 + (C_{y2} - C_{y1})^2} \qquad (4)$$

If the calculated distance is less than the threshold value that is the separation between the UAV is less than the fixed value say 5 meters then the UAV is given an appropriate command to change its path such that it will avoid collision and also avoid the obstacle.

3. Keep the Formation

Aim of this simulation is to keep the formation. While keeping the formation the UAV should avoid the obstacles in order to survive in the real time, hence obstacle avoidance is given highest priority. If the distance of separation as calculated from the equation 4 between the UAVs is larger than the threshold value say 10 meters then a command is given to change the position of UAV such that it will not collide with any obstacle.

4. Avoid the Obstacle and Prevent the Collision

While the UAVs are flying in formation they should not collide with each other on the other hand they should avoid the obstacles as they approach the destination. All these steps mentioned such as obstacle avoidance, collision avoidance and formation keeping are done by calculating the distance of separation between UAVs and the obstacles. In this process of formation flying we also make survey of the land area which will be one of the main use of the UAV in the enemy territory and also help the rescue team to serve the needy during natural disasters. This algorithm is fully designed based on the equation 4.

5. Scheme of Control of UAV

The MicroPilot Autopilot which is perfect choice to stabilize and guide a wide range of UAVs, from highly functional high speed UAVs through backpack UAVs to handheld micro UAVs. The MicroPilot Autopilot is the only micro UAV autopilot designed for fully autonomous operation from launch through recovery. Capabilities include airspeed hold, altitude hold, turn coordination,GPS navigation as well as autonomous launch and recovery. Extensive data logging and manual overrides are also supported, as is a highly functional command buffer. All feedback loop gains and flight parameters are user programmable and feedback loops are adjustable in flight. The MicroPilot Autopilot also includes the HORIZON ground control software for mission creation, parameter adjustment, flight monitoring and mission simulation. The autopilot and the flow of signals for control is shown in figure 4.

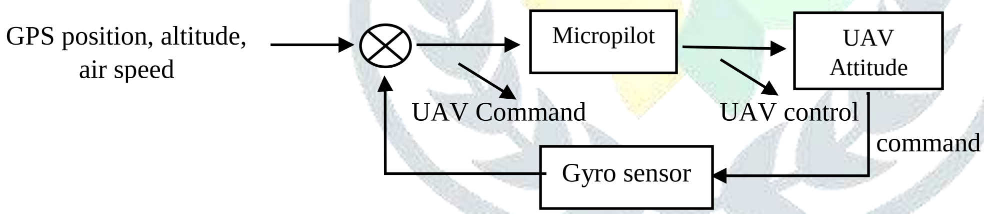

Fig. 4 Control flow using autopilot

- Altitude hold, airspeed hold, and GPS waypoint navigation.
- Fully integrated—all sensors required for complete airframe stabilization are integrated into a single circuit board.
- Controls up to 24 servos or relays.
- Complete autonomous operation from launch to recovery.
- Autonomous launch methods include runway takeoff, hand launch, bungee launch, and catapult launch.
- Autonomous recovery methods include runway landing, parachute recovery and deep stall landing.
- Supports manually directed and autonomous flight modes, as well as an integrated RC override.

Implementation is done using Micropilot and Horizon. Autopilot is used to control the UAV. Where the code to control the UAV is generated using XTENDER, which is another software development tool which uses C++ for basic programming. These codes can be given to the autopilot by using HOIZON the ground control software. Where simulation can be shown using HORIZON software.

RESULTS AND DISCUSSIONS

Obstacle Avoidance

Flying of an UAV by avoiding the obstacles is shown in figure 5 and 6 where the rectangular boxes are obstacles and the thin line shows the path taken by the UAV. In figure 5 the UAV starts at (5,1) and in the figure 6 the UAV starts at (5,0).

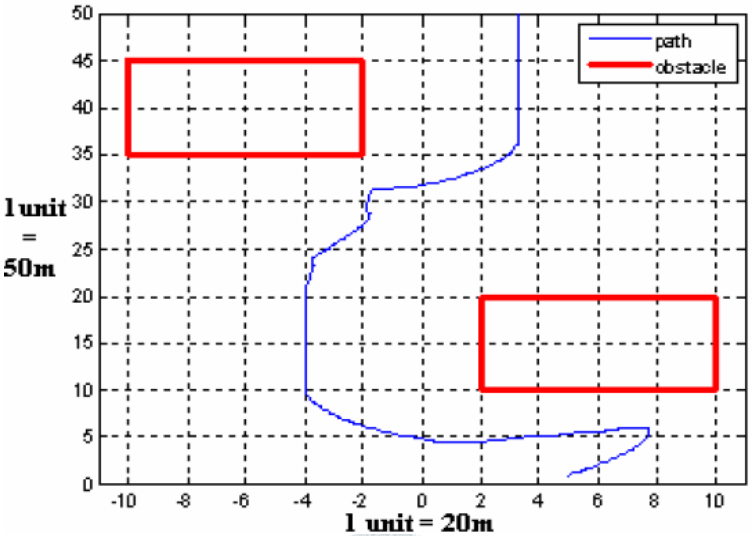

Fig. 5 Obstacle Avoidance Of An UAV

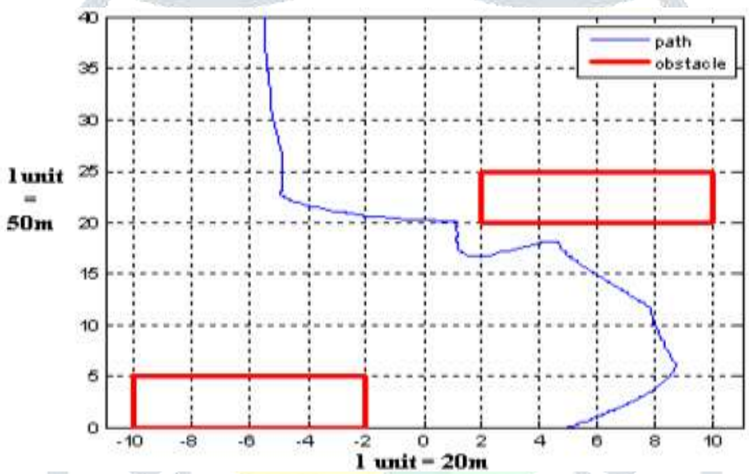

Fig. 6 Path Of UAV For Change In Obstacle Position

Formation Flying

In the previous section we have seen that an UAV is flying by avoiding the obstacles, now we will see the formation flying of three UAVs along with the collision avoidance and obstacle avoidance. The figure 7 shows the starting points of the UAVs as squares for three UAVs at (1, 2), (1, 4) and (4, 1). The circles represent the location of the obstacles at (8, 10), (10, 10), (12, 10), (18, 20), (15, 15) and (24, 20).

Fig. 7 Starting Point and Obstacles Location

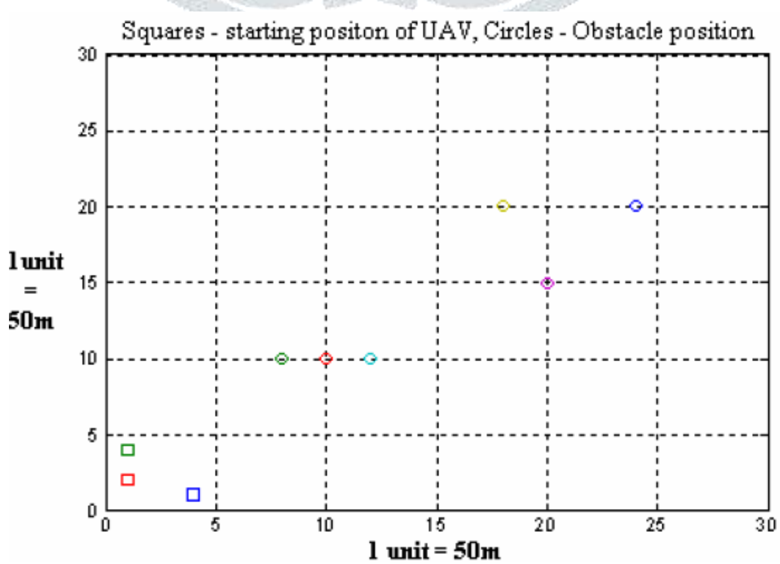

Figure 8 shows the formation flying of three UAVs with the path taken by the UAVs by avoiding the obstacles. Where the thin lines give the path taken by the three UAVs and the dark circular pattern represents the region around the obstacles where there is more likelihood for the UAV to collide with the obstacle.

Figure 9 shows the change in the path taken by the three UAVs in thin lines for the change in the starting point of an UAV at (8, 1) and all other UAVs starting at the same point as in the figure 8.

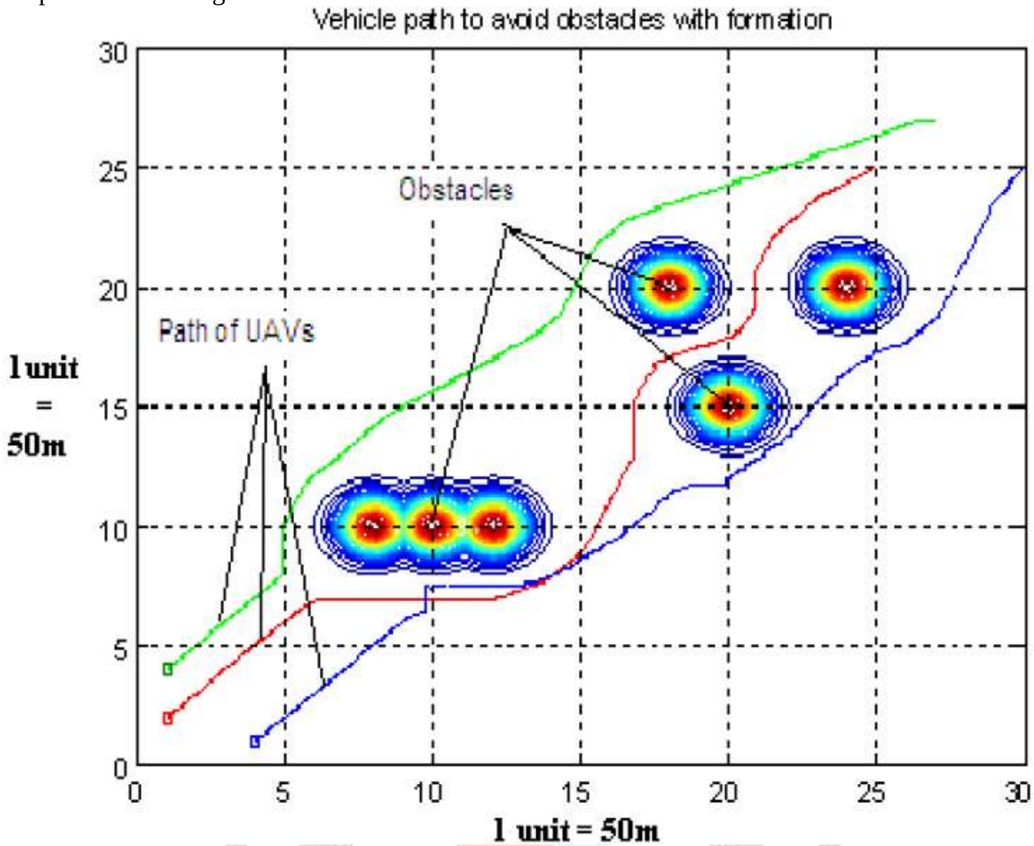

Fig. 8 Formation Flying

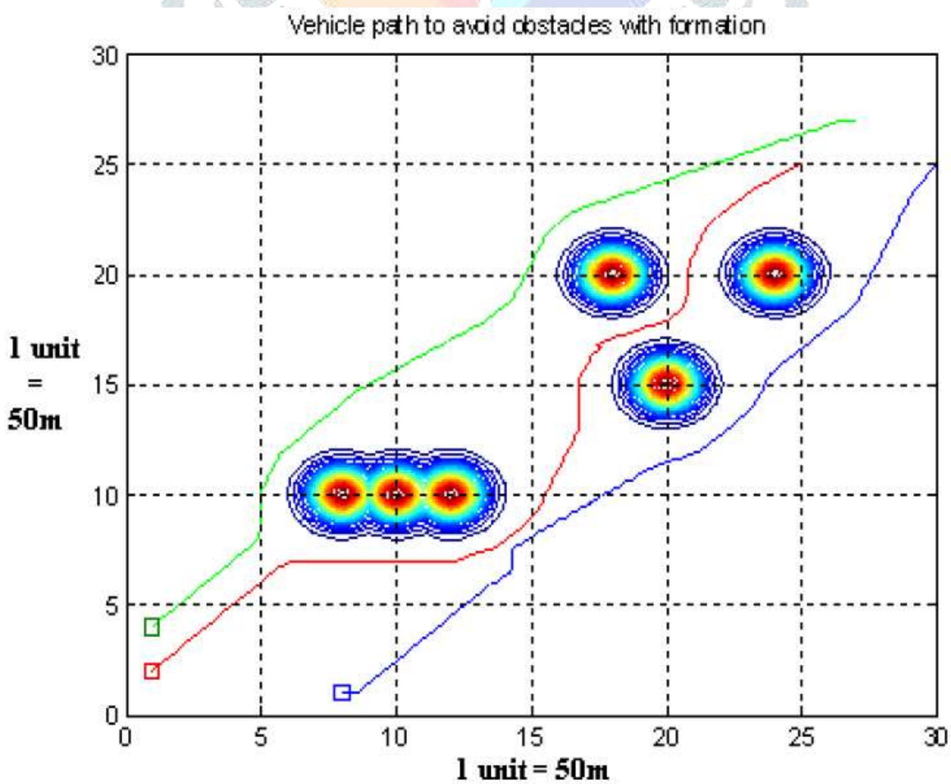

Fig. 9 Change In Path Of UAV

Virtual Reality Modelling and simulation

In figure 10 shows the simulation of two UAVs in formation flying using virtual reality world. Here we observed that the distance keeping in formation flying is maintained through the process in three dimensions as the UAV is entering the flight. The position estimation algorithm stated which is simple and effective in executing the formation flight

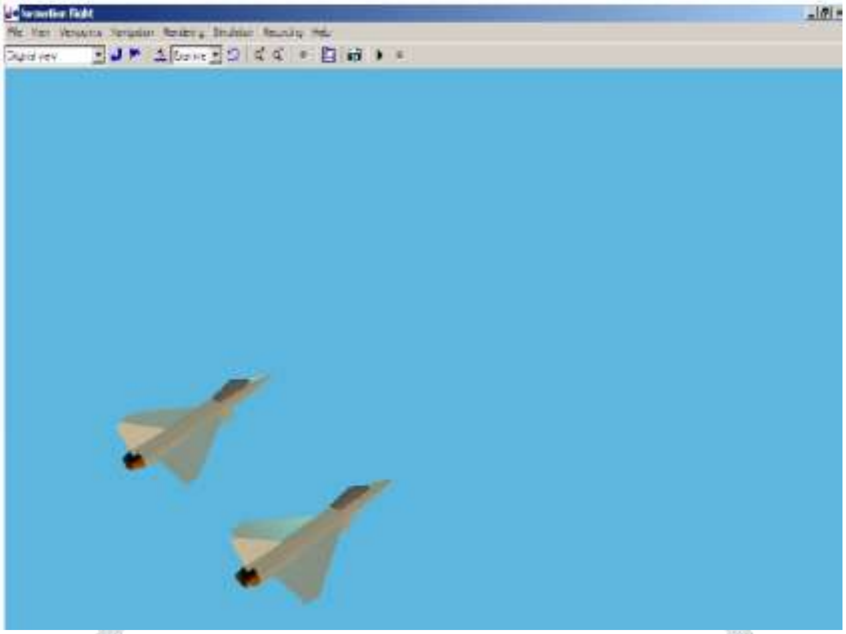

Fig. 10 Formation Flying

Where the simulation and implementation is being shown using HORIZON software. The real time flight of the vehicle based on position estimation is shown in the simulation window of the HORIZON with two UAVs which is shown below in the figure 11.

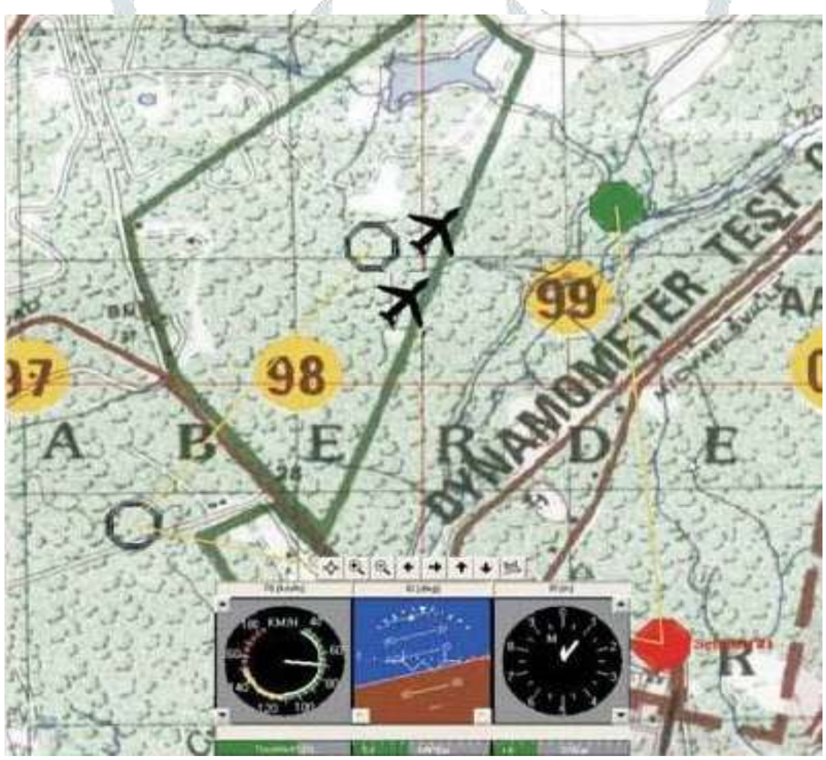

Fig. 11 Formation flying shown in HORIZON

Conclusion

Guidance laws for close formation flight of aircraft can be developed from consideration of the natural instincts of animal groups. The resulting formation clearly demonstrates cooperative behavior. It is analogous to the theory of cooperative games, yet a tractable solution can be found without having to optimize over discrete maneuvers. The concept of formation instincts also greatly simplifies the problem of finding appropriate objective functions. This approach to close formation guidance can lead to improved maneuverability and efficiency beyond that which is capable with traditional leader follower formations.

The heading change example demonstrated that formation five aircraft can stay together while performing a simple maneuver and avoiding environmental obstacles. This example revealed how the basic formation instincts are heightened at different points in time as the individual aircraft maneuver together. The second example demonstrated that the formation can split into several subgroups or coalitions. This behavior is a key component of cooperative game theory and illustrates how the formation aircraft can cooperate to achieve a common goal.

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