An approach to surveillance an area using swarm of fixed wing and quad-rotor unmanned aerial vehicles UAV(s)

Aldo Jaimes, Srinath Kota, Jose Gomez
Autonomous Control Engineering Lab
University of Texas at San Antonio
San Antonio, USA
E-mail: aldo.jaimes@gmail.com, srinath27@gmail.com, jose-f-gomez@hotmail.com

Abstract *– This paper presents an approach to obtain surveillance through a swarm of fixed wing airplanes and quad-rotor UAV (unmanned aerial vehicle). The approach is presented on a realistic situation where an autonomous fixed wing airplane and semi-autonomous swarm of quad-rotor UAV(s) work together to surveillance an area. The fixed wing airplane UAV determines the altitude, surveillance area, GPS location and provides communication and image recognition capabilities among the swarm and the ground station. The swarm quad-rotor UAV(s) are autonomous and can accept directives from the ground station and the fixed wing. Sensors deployed from the quad-rotor UAVs, directly communicate with the quad-rotors swarm. In this scenario, heterogeneous systems and human control interact in a system of systems architecture.*

Keywords - *networking architectures, quad-rotor, fixed wing, dragonflyer, UAV, connectivity, autonomy, emergence, unmanned and system of systems.*

I. Introduction

An unmanned aerial vehicle (UAV) of limited size and cost is a very useful and interesting tool. It can be used for a series of different tasks where access from the air is the best solution, where it is unnecessary or dangerous to use a manned vehicle or when a high level of accuracy and systematism is called for. Examples of UAV applications are: Inspections of power lines, pipe lines, bridges, oil platforms, crop dusting, search, rescue operations and fire detection and fire fighting.

Unmanned aerial vehicles (UAVs) are flying vehicles that fly either autonomously or controlled by remote control. They have many potential applications. For instance, a UAV can provide surveillance and assess hazardous situations from the air by its airborne sensors. Or, a group of UAV(s) can fly to remote locations and deploy sensors that can send information to land robots to perform long term surveillance from the ground.

A problem of interest is the formation of a group of UAVs that fly together to carry out assigned missions along with land robots; Having defined the desired surveillance area, control laws are designed to achieve formations according to one of the following scenarios: 1) Each UAV takes off toward its corresponding surveillance area and locks onto it in finite time; 2) UAVs take off independently of each other and one at a time; 3) All UAVs take off simultaneously towards their corresponding surveillance area and lock onto them at the same instance of time. Examples are presented to illustrate the efficiency of the designed GPS waypoint navigation. One scenario to form such a group is as follows. Have one master unmanned aerial vehicle equipped with sensors, cameras, and a communication system. The master UAV can then determine a safe and surveillance area for itself and other UAVs. It can then communicate with the other UAVs and let them know the areas they should monitor. The follower UAVs should be able to fly towards their corresponding surveillance areas put forward by the leader quickly and locks onto them (ideally in finite time). When all UAVs are locked onto their area and fly together, resembling a flock of birds flying.

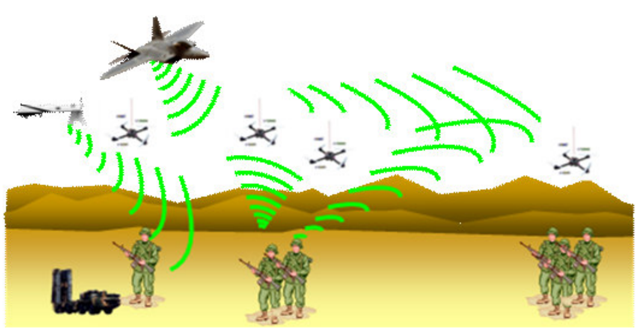

Figure 1. Illustration of UAVs working in a military scenario

Our goal in this paper is to devise methodologies and innovative ways of UAVs collaboration among each other. This goal is achieved by means of GPS and image recognition that lock the flight paths of the follower UAVs onto those put forward by the master UAV in finite time.

The organization of the paper is as follows. In Section II, contains an overview of the proposed system and its components. In Section III describe the hardware components of a fixed wing airplane UAV, quad-rotor UAV and architecture of the ground station. In Section IV we present the proposal for the future work. Finally we present the conclusions of our present work.

II. System overview

A. About fixed wing UAV

The fixed wing UAVs considered for this project are two airplanes with a flight control and autopilot configured and designed according the project requirements. The airplane's flight dynamic rotations: Yaw, Pitch and Roll are controlled by servos connected to the airplane's rudder, elevators and ailerons respectively. A glow engine powers the airplane's propeller. The main advantage of a glow motor is the higher power to weight ratio than a comparable electric motor. The capabilities of a fixed wing airplane considered suitable for the project are: payload capability and long-range operation. The actual payload capacity allows for the installation of instrumentation and sensors needed to fulfill the requirements of the mission. The long-range operation will allow for wider area surveillance. The master fixed wing UAV has the task of patrolling and surveillance a specific area using a video camera. The operator in the ground station defines the area of operation. The master UAV will continuously patrol the area sending images to the ground station, until the operator identifies a target, then the master UAV will receive a new set of instructions or will continue with the flight plan.

Figure 2. Picture of the MicroPilot UAV.

B. About quad-rotors UAV

A quad-rotor UAV can be highly maneuverable, has the potential to hover and to take off, fly, and land in small areas with its four motors located at the front, rear, left and right ends of across frame. Changing the speed of rotation of each motor controls the quad-rotor. The front and rear rotors rotate in a counter-clockwise direction while the left and right rotors rotate in a clockwise direction to balance the torque created by the spinning rotors.

Increasing the speed of the left motor by the same amount as the speed of the right motor is decreased, will keep the total thrust provided by the four rotors approximately the same. In addition, the total torque created by these two rotors will remain constant. Similarly, the pitch rate is controlled by varying the relative speed of the front and rear rotors. The yaw rate is controlled by varying the relative speed of the clockwise (right and left) and counter-clockwise (front and rear) rotors.

Figure 3. Picture of the Draganfly quad-rotor.

A quad-rotor UAV has some advantages over other rotary wing UAVs. It is mechanically simple and is controlled by changing the speed of rotation for the four motors. Since changing motor speed controls the yaw rate, a tail rotor is not required to control yaw rate and all thrust can be used to provide lift. Additionally quad-rotor UAV may also be able to fly closer to an obstacle than conventional helicopter configurations that have a large single rotor without fear of a rotor strike. The vehicle's dynamics are good for agility and its four rotors can allow increased payload.

C. About ground station

The ground station would be the brain of the operation, since the information sent by the UAVs will be received and processed by it. The ground station consists of a laptop, RF transceivers and LCD monitors. The LCD monitors will be used to display the video feed from the different UAVs. The video feed will be processed to find objects, faces, etc.

Communication between the different UAVs will be done using RF modems. Each of the units will have an encrypted signal for security reasons. It is important to maintain constant communication with all units to have better response time. Using a separate modem we will maintain a live video feed which will enable us to relate the data much faster to the quad-rotors. The quad-rotors, after receiving the GPS location of interest and orders on what type of sensors to drop in that area will then be dispatched.

Once the quad-rotors arrive to their destination they will deploy the sensors to acquire the data necessary. There are many options as to the type of sensor that can be deployed by the quad-rotors. The only limit to the type of sensor that can be delivered by the quad-rotors is the weight of the sensor itself. The total gross payload depends on the dimensions of the quad-rotor and thrust provided by the rotors. Some of the instrumentation that could be deployed by the quad-rotors is that to acquire levels of toxic gases, IR bombs, or simply carrying a heat sensing video camera to easily detect any living object that may be moving through the area, homing beacons, etc.

The sensors that will be used must also be equipped with their own transmitter, to immediately send the acquired data to the ground station.

D. About software algorithm

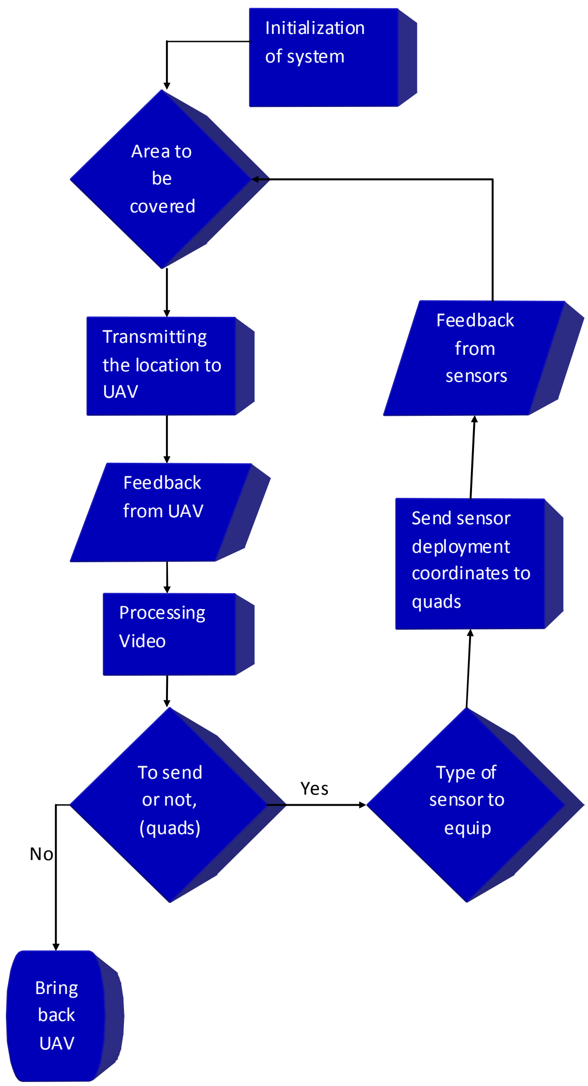

Figure 4. Software algorithm flowchart diagram.

As discussed previously the ground station will begin by sending the GPS coordinates of the area that the fixed wing airplane will cover. Once the airplane has been dispatched and after arriving at its destination, the airplane will send live video feed to be analyzed. While the ground station receives the video it will automatically start to run it through the image recognition software, which will allow it to recognize any previously specified object. Depending on whether there was something out of the ordinary or the target was found in the area, the quad-rotors will be sent to that particular area.

The quad-rotors will be equipped with sensors that will depend on the type of data to be acquired. After the quad-rotors have received the coordinates for the sensor deployment the quad-rotors will begin to approach the designated area. Once the quad-rotors have arrived at the designated coordinates they will deploy the sensors. The deployed sensors will immediately begin to transmit their results to ground station. Given the gather data a decision could be reached as to what is the next course of action.

III. SYSTEM HARDWARE

Description of hardware considered for this project.

A. Fixed wing UAV

Fixed wing UAV has some operative limitations that need to be considered on the design stage. One of these is the flight time, which directly related to the amount of fuel carried by the UAV and the other is the gross takeoff weight (GTOW) related with the payload capacity of the fixed wing. In order to take care of these two limitations we decided to work with two fixed wing airplanes with both big wingspan and big wing area. The first one (master UAV) is a UAV of Micropilot with wingspan 69 inch, wing area 793 sq inch and max payload 2 pounds [1]. The second fixed wing airplane has wingspan 80 inch, wing area 1180 sq inch and approx. payload 3 pounds.

The UAV of Micropilot has been installed with: an autopilot, a video camera, a data link transmitter, 5-channel FM receiver RC link and a set of batteries. The autopilot board is fully integrated with 3-axis gyros/accelerometers, GPS, pressure altimeter, pressure airspeed sensors. These sensors give the UAV the capability of altitude hold, airspeed hold and GPS waypoint navigation. In addition, the board offers the possibility to install ultrasonic sensors needed for autonomous take off and landing. The 2.4GHZ radio modem enables a live telemetry feed from the aircraft. The data-link will also let us change certain functions of the aircraft while in-flight.

The second fixed wing UAV has been installed with: a flight control board, an autopilot system, Inertia Measurement Unit (IMU), a GPS, a modem, a video camera, a 5-channel receiver RC link and a set of batteries. The flight control board is the brain of each UAV. Its task includes: monitor and control the autopilot system, data acquisition from IMU and GPS module, video processing and communication with ground station and UAVs. The fixed wing UAV will be using the gumstix's verdex motherboard as a control board [2]. The vertex motherboard is equipped with a PXA270 processor with a speed of 600MHz, 64MB of SDRAM. Utilizing one of gumstix's extension boards we could add a microSD storage card increasing the amount of data that could be stored. The size of the vertex motherboard is relatively small and because of that the vertex has only a Hirose 60-pin connector. By using gumstix robostix expansion board we gain more manageable I/O pins, which will be used for interfacing the rest of the hardware.

The autopilot PICOPILOT-NA consists of two circuit boards, wire harness and a GPS receiver [3]. These characteristics will let perform GPS navigation, roll control (wing leveling) and altitude hold. The autopilot is designed to interface directly to a common RC receiver which provides the possibility of manual commands needed for the takeoff and landing. The IMU is the 3DM-GX2® is a high-performance gyro enhanced orientation sensor [4]. This unit utilizes miniature MEMS (Micro Electro-Mechanical Systems) sensor technology to combine a triaxial accelerometer, triaxial gyro, triaxial magnetometer, temperature sensors, and an on-board processor running a sophisticated sensor fusion algorithm. The outputs include Euler angles, rotation matrix, deltaAngle & deltaVelocity, acceleration and angular rate vectors. This data will be used by the flight control board and send to the ground station with monitoring and control purposes. The video camera has a horizontal resolution of 480 TV lines and effective pixel NTSC: 768(H)-494(V).

The LEA-5A u-blox 5 GPS module will be used for the positioning part of our project [5]. The GPS horizontal position accuracy is less than 2.0 m with a maximum update rate of 4 Hz, capable of accurately tracking a vehicle moving at 1854 km/h. Although it is true that there are other more accurate GPS modules than LEA-5A, for the purpose of creating a prototype this one meets all of our requirements. Like the rest of the modules this module was also chosen for its small weight (2.1 g) and dimensions (17.0 mm X 22.4 mm).

The radio frequency transceiver that will be in charge of the data transfer is the XStream module from Maxstream [6]. This transceiver has a data a rate of 57.6 Kbps and supports peer-to-peer, point-to-point, point-to-multipoint and repeater. The transceiver was also chosen because of its small size (4.06 cm x 7.17 cm x 0.89 cm), weight (24 g) and a range of 16 km. The MX-6000 video transmitter will be used for the live video feed. This transmitter has the range of 8 km, has a weight of 6 g and dimensions of 2.1 cm X 1.8 cm X 0.89 cm. We were looking to satisfy the same criteria as that of the data transceivers. The complementary receiver for the MX-6000 is the VRX-24LTS audio/video receiver.

A glow engine type is used in both fixed wings. A 0.40 cubic inch, 1 HP, 2-cycle glow engine is used in the master UAV and 0.9 cubic inch is used in the second fixed wing. Two 5- channel RC receivers are used to control manually each airplane for takeoff, landing and emergency. This stage of the project does not consider autonomous take off and landing in either UAV

B. Quad-rotors UAV

The quad-rotor UAV is a complex electromechanical system, but for the purpose of this paper we can focus on just a few key hardware components including four motors that adjust the yaw, roll and pitch drive the airframe itself. The payload compartment is located at the center of the quad-rotor.

Based on RC Toys Draganflyer V Ti model, the electric motors driving the rotors are Mabuchi 380 brushed DC motors [7]. Each motor works with an optimal voltage of 7.2V. The motors spin at a load-less 26,000 rpm, but with a loaded max efficiency of 19,000 rpm, drawing 6 amps, and producing 375.0 g/cm of torque. These motors are more than capable of producing the thrust necessary to lift the nylon/carbon fiber frame of the Draganflyer, as well as its electronics package.

Helicopters are difficult to control, and thus the Draganflyer uses Thermal Intelligence (Ti) to differentiate the infrared temperature between earth and sky. The sky is always at a relatively lower infrared temperature, while the infrared signature of the Earth is always relatively warmer. Thermal Intelligence uses four infrared sensors, so when a change is detected in the UAV, thermal Intelligence incorporates a microcomputer to interpret input from the sensors and modify signals between the aircraft's receiver and the motors controlling roll and pitch to bring the UAV to a stable level flight. Thermal Intelligence can be activated or deactivated using a 6-channel transmitter, which is also used to control the UAV in semi-autonomous mode.

C. Ground station

The ground station must be as small and light weight as possible to maintain versatility and movement. Taking this into account we decided to use the same data transceiver to communicate with the air and ground units, the XStream module discussed in a previous section. Also, the complementary receiver for the MX-6000 video transmitter, the VRX-24LTS audio/video receiver, will be used to obtain the live video feed, which is only 120 g. The VMS-2 LCD monitor will be used for the display of the incoming video.

D. Kinematic and Dynamic equations

The absolute position of the UAV is described by the three coordinates (x_o,y_o,z_o) of its center of mass with respect to an earth fixed inertial reference frame [8].

Its attitude is described by the three Euler angles (ϕ,θ,ψ).

ϕ : Roll angle $-\pi/2 < \phi < \pi/2$

θ : Pitch angle $-\pi/2 < \theta < \pi/2$

ψ : Yaw angle $-\pi < \psi < \pi$

A. Body Axis Orientation Equations

We will use the Euler angle relationships, with the Euler angles (flat earth assumption) from the transformation from the local horizontal to the body axes.

$$(\dot{\phi},\dot{\theta},\dot{\psi}) = M(\phi,\theta,\psi)\,\omega(p,q,r) \tag{1}$$

where:

$\omega(p,q,r)$: angular velocity expressed with respect to a body reference frame

$M(\phi,\theta,\psi)$: relation matrix

The resulting matrix equation is:

$$\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = \begin{bmatrix} 1 & \sin\phi\tan\theta & \cos\phi\tan\theta \\ 0 & \cos\phi & -\sin\phi \\ 0 & \sin\phi\sec\theta & \cos\phi\sec\theta \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix} \tag{2}$$

The absolute velocity $V_o(u_o,v_o,w_o)$ with respect to an earth fixed inertial frame is the derivative with respect to time of the position (x_o,y_o,z_o) and is given by:

$$V_o(u_o,v_o,w_o) = (\dot{x}_o,\dot{y}_o,\dot{z}_o) \tag{3}$$

B. Body Axis Navigation Equations

The position, of the UAV relative to the Earth, is found by integrating the UAV's velocity along its path, or by representing the velocity in Earth-fixed coordinates and integrating each component. The relation is given by:

$$V_o(u_o,v_o,w_o) = R(\phi,\theta,\psi)V(u,v,w) \tag{4}$$

where:

V(u,v,w): absolute velocity expressed in a body fixed reference frame.

$R(\phi,\theta,\psi)$: rotation matrix

The resulting matrix equation is:

$$\begin{bmatrix}\dot{x}_o\\ \dot{y}_o\\ \dot{z}_o\end{bmatrix} = \begin{bmatrix}\cos\theta\cos\psi & \cos\psi\sin\theta\sin\phi - \cos\phi\sin\psi & \cos\phi\cos\psi\sin\theta + \sin\phi\sin\psi\\ \cos\theta\sin\psi & \sin\theta\sin\phi\sin\psi + \cos\phi\cos\psi & \cos\phi\sin\theta\sin\psi - \cos\psi\sin\phi\\ -\sin\theta & \cos\theta\sin\theta & \cos\theta\cos\phi\end{bmatrix}\begin{bmatrix}u\\ v\\ w\end{bmatrix} \tag{5}$$

C. Body Axis Force Equations

Using the Newton's law about the center of mass one obtains the dynamic equations for the UAV.

$$\dot{V}(u,v,w) = \frac{1}{m}\sum F_{ext} + \omega(p,q,r)\times V(u,v,w) \tag{6}$$

$$J\dot{\omega} = -\omega(p,q,r)\times J\omega(p,q,r) + \sum T_{ext} \tag{7}$$

where:

m: mass

J: inertia matrix given by:

$$J = \begin{bmatrix} Ix & 0 & 0\\ 0 & Iy & 0\\ 0 & 0 & Iz\end{bmatrix}$$

In Figure 5 we present the simulation of the dynamic equations for a quad rotor.

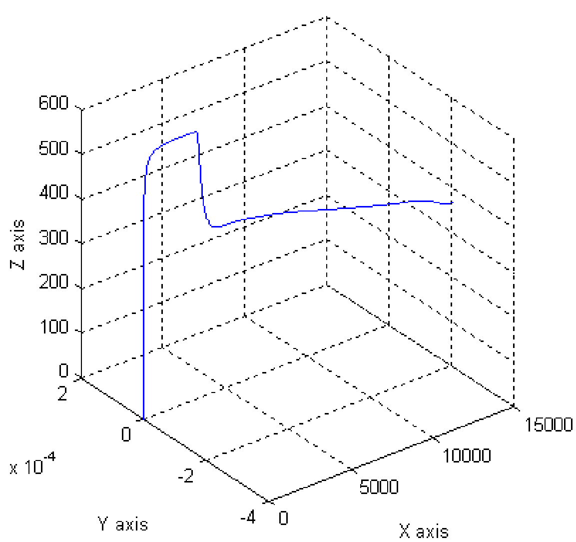

Figure 5. Simulation of dynamic equation for a Quad –Rotor

IV. FUTURE WORK

The future work of this project is focused on the improvement of communication and control algorithms for the UAV swarm. The simulation of dynamic equations of control algorithms for each UAV were implemented on Matlab, we will use those simulation as a platform to validate the control algorithms and path planning for each UAV as part of a swarm.

The further development will consist of changing the UAVs from a semi-autonomous to a completely autonomous system. Also, land rovers could be added in order to extend the capabilities of the project. The land rovers will be in charge of retrieving the deployed sensors, carry heavier sensors that the SUAVs could not carry. The land rovers could also be equipped with an arm which will aide with further interaction with the designated area. Addition of flexible solar panels to both the fixed wing and quad rotor unmanned aerial vehicles.

V. CONCLUSION

We have proposed a surveilliance project utilizing a fixed wing airplanes and quad-copter helicopters. Although we are still commisioning the fixed wing aircrafts, the components of the system can perform autonomous way-point navigation while transmitting a live video to the ground station. Our research has focused on the development of modelling and simulating that enables visual tracking of targets within the defined surveillance area. By combining GPS, navigation sensors and image recognition, the foundation for a useful system has been laid that could be used in applications such as law enforcement or low level surveillance tasks.

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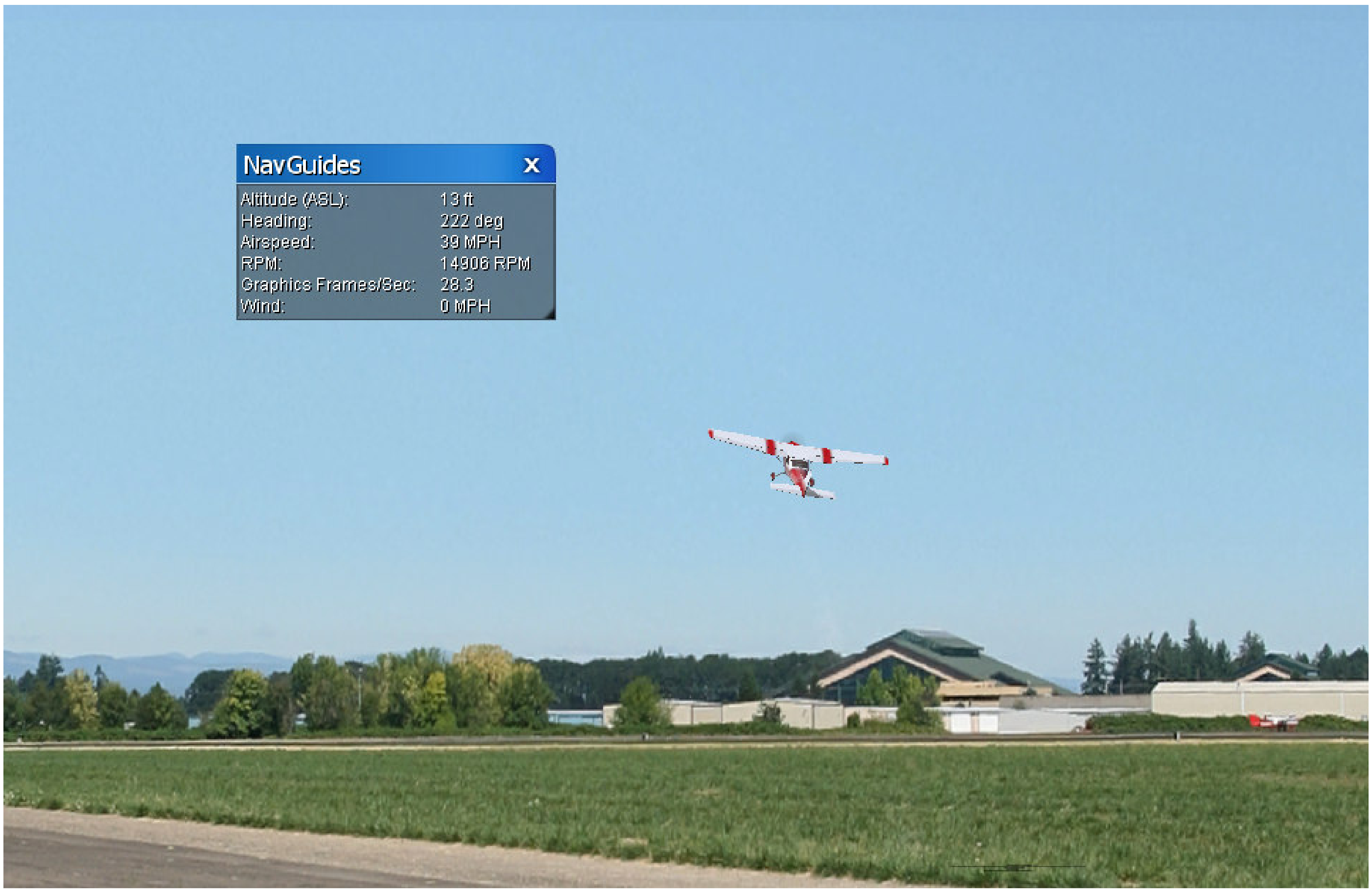

Real flight using computer simulation to surveillance a defined area.