BIOLOGICAL-VISION INSPIRED DSA SYSTEM FOR UAVS

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Abstract: Uses of unmanned Aerial Vehicles (UAVs) have increased dramatically during the past several years, but currently still do not have convenient access to civil airspace because there is no onboard pilot, and it's impossible for UAVs to "see and avoid" other aircraft. So a Detect, Sense and Avoid system is needed to provide the UAV with instructions to steer the UAV clear of any potential collision with other traffic. An optical based DSA system is discussed in this paper to provide the UAV with "see and avoid" capability of at least equivalent to a piloted aircraft. DSA minimum detection range assessment, optical resolution requirement and image array size requirement are also discussed in this paper. Also an efficient natural vision system is presented in this paper for DSA system.

1 INTRODUCTION

Unmanned Aerial Vehicle (UAV) is a device that is used for flight in the air that has no onboard pilot. It performs a useful mission and can be remotely controlled or has autonomous flight capability. UAVs need to at least replicate a human pilot's ability to see and avoid problems before they will be accepted into the national air space. So an on board "Detect, Sense and Avoid (DSA)" system is needed.

2 DETECT, SENSE AND AVOID SYSTEM

2.1 DSA Minimum Detection Range

"Detect, sense and avoid" (DSA) system is an onboard system that is able to provide the UAV with detection capability with sufficient time to identify, assess, and take action in accordance with the situation encountered. The goal of any DSA system is to perform those collision avoidance functions normally provided by a pilot in a manned aircraft.
Therefore, a DSA system will have to detect the traffic in time to process the sensor information, determine if a conflict exists, and take actions according to the right-of-way rules. If pilot interaction with the system is required, transmission and decision time must also be included in the total time between initial detection and the point of minimum separation.

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Research has been worked on about UAV DSA system requirements, and it has come to an agreement that for the aircraft to pass "well clear", 500 feet can be chosen as the minimum separation distance. Which means when the DSA system detects a possible conflict, it must take proper actions in sufficient time so the UAV and other aircraft can miss each other by at least 500 feet. (Ebdon and Regan, 2004).

The UAV must be able to react to all the obstacles that it might encounter in the operating environment. Figure 1 shows the several steps needed for the DSA system to avoid collision with another aircraft. First, the detect part, onboard sensors detect the environment continuously,

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collecting data about the environment to see if there is any approaching aircraft. If an aircraft is detected, then based on the collected data, determine if the data indicate a collision in the near future. Then calculate an action that the UAV can take to avoid the collision.

If we assume that the approaching aircraft is non-cooperative and non-maneuvering, then it is desirable to know how long it will take the UAV to deviate from its initial flight path by 500 feet in the x direction, banking to the right according to FAA rules. A worst-case scenario is a head-on potential collision: an aircraft is flying directly at the nose of the UAV. In this case the visual cross-section of the approaching aircraft is smallest and most difficult to detect, and the closing speed is the greatest. (Grilley, 2005).

This problem has been analyzed using MATLAB for several situations.

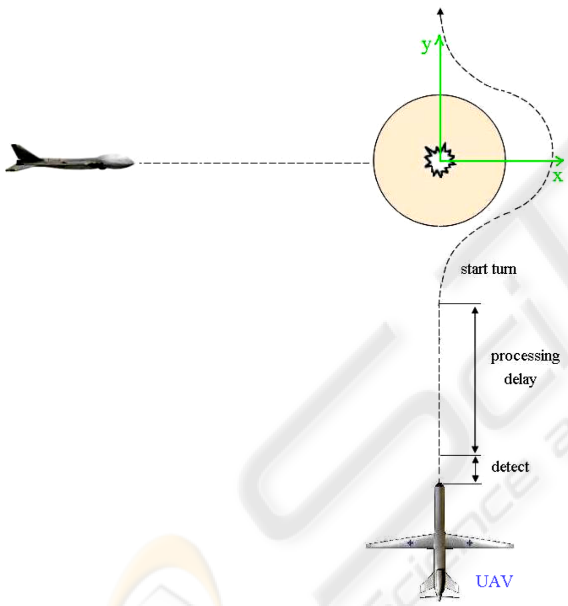

Figure 1: Several steps to avoid collision.

Suppose a UAV is flying with a straight and level flight when it detects an oncoming aircraft flying directly at it towards the nose of the UAV with the same altitude and directly inline with the UAV's flight path. The speed of the non-cooperating approaching aircraft is 250 knots. As a result, the UAV takes evasive action by turning to the right with a bank angle of β degrees. Assuming the oncoming aircraft takes no evasive action. Figure 2 is the results for different bank range.

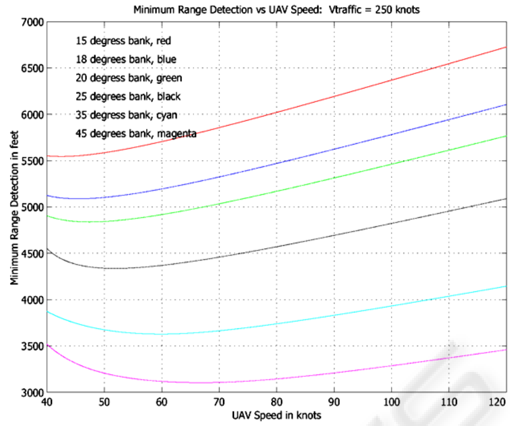

Figure 2: Minimum range detection versus UAV speed and turning bank angle. Oncoming noncooperative head-on traffic speed is 250 knots.

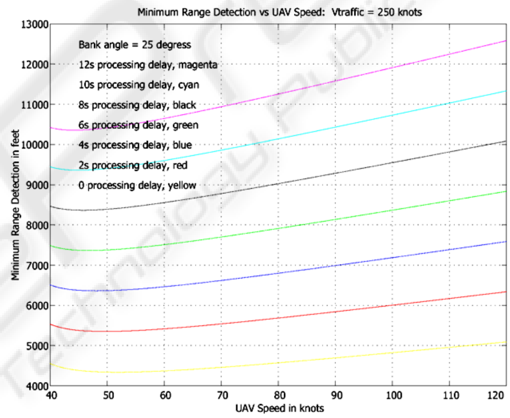

Figure 3: Minimum range detection versus UAV speed and processing delay. Oncoming non-cooperative head-on traffic speed is 250 knots. Turning bank angle is held constant at 25 degrees.

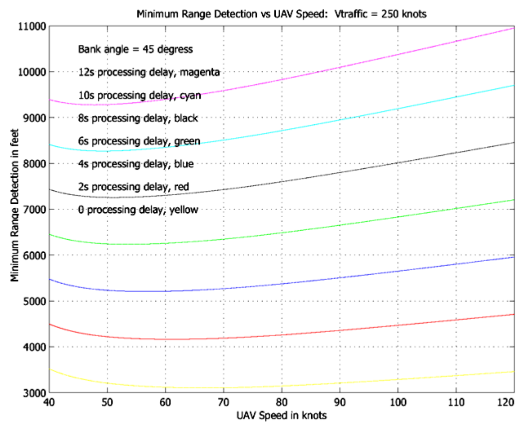

Figure 4: Minimum range detection versus UAV speed and processing delay. Oncoming non-cooperative head-on traffic speed is 250 knots. Turning bank angle is held constant at 45 degrees.

Same situation as above except that here a processing delay is considered. When a target is detected there are several delays that add up to the accumulative processing delay before the turn is executed. These times are the time it takes to detect the target, the time it takes to track the target, and the time it takes to make the decision that a turn to avoid collision is required. The sum of these times are referred to here as the processing delay. Due to the processing delay the target moves closer to the UAV before the UAV begins its turn, and the UAV also moves towards the target. Figure 3 is the results for 25 degrees bank angle. Figure 4 is the results for 45 degrees bank angle.

As can be seen from Figures 2, 3, and 4, the minimum range for detection is dependent on the bank angle and the processing delay. Therefore it is highly desirable to minimize the processing delay as much as possible and to bank the UAV as much as possible. With a UAV speed of 60 knots the minimum range for a bank angle of $15°$ and a processing delay of 12 seconds is about 10,700 feet (2.03 *smi*). With a UAV speed of 60 knots, the minimum range for a bank angle of $45°$ and a processing delay of 2 seconds is about 4,200 feet (0.8 *smi*). For the purposes of this study, we will let the bank angle be 25° and the processing delay be 8 seconds. Under those conditions, for a UAV speed of 60 knots the minimum detection range is 8,600 feet (1.63 *smi*).

Given that the horizontal angle of view for the nose camera is 60° and that the vertical angle of view is $30°$, and that the minimum detection range is 8,600 feet, and assuming a oncoming non-cooperative aircraft has a visual frontal cross-section of 4.47 feet (worst-case), (Grilley, 2005), Then cross-section of 4.47 feet is equivalent of $0.027°$ of horizontal and vertical resolution, or $0.47\,mrad$. From above, for the image to occupy an area of four pixels at the minimum detection range, then the array would need to be 2,222 pixels by 4,444 pixels (9.87Mpixels).

2.3 Optical based DSA System

The optical based DSA system usually consists of three major components: optical sensors, detection processors and a track processor.

2.3.1 Comparison of Optical Sensors

Both CCD and CMOS sensors can be used as optical sensors to capture images for DSA system. To decide which kind of sensor is better for DSA system, a thorough comparison is needed.

Generally CCD has high sensitivity, high resolution, large dynamic range, and large array size, while APS has the benefit of low-power operation, high speed, and ease of integration. Small UAVs' limited payload capability, size, dimension, weight and power consumption make CMOS-based sensors a good choice for DSA system if resolution requirement can be fulfilled.

The number of sensors is flexible, technically one optical sensor is fine, but to detect as wide range of view as possible, three is the minimum possible number of optical sensors.

2.3.2 DSA Configuration

If CCD is used as sensors, the DSA system must have separate sensors and processors. Figure 5 shows a typical DSA system configuration. (Utt, McCalmont and Deschenes, 2005). This system consists of three CCD optical sensors, FPGA based image processors that compute the optical flow of the sensor scenes, and a track filter that merges and declares tracks of detected aircraft.

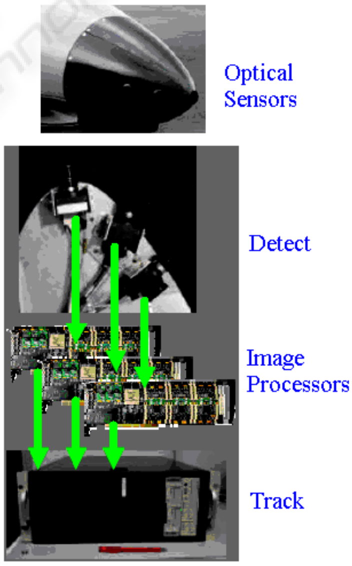

Figure 5: DSA configuration.

If CMOS is used as sensors, then readout circuitry and processing circuitry can be embedded on-chip together with the sensing circuitry. Such embedding can happen either pixel-by-pixel (in-pixel circuitry), or at chip level (off-pixel circuitry), or as a combination of both. In-pixel processing circuitry can be used to obtain high-speed through parallel processing in tasks where many data are involved such as image feature extraction, motion estimation. Then, off-pixel embedded digital processors can be used for control and high-level processing tasks. The combination of in-pixel and off-pixel processing can be used to speed up the computations needed to adapt the sensor response to changing conditions in the environment, this makes the sensor capable of acquiring images with high dynamic range, which is an important parameter for optical sensors.

3 BIOLOGICAL MODELS FOR DSA

This DSA system should be able to provide the relative position of the traffic and a velocity indication. This allows the system to predict the traffic's flight path and determine whether there will be a conflict. If a conflict is predicted, the system can act to avoid it in time. So not only should a DSA system be able to determine the position and velocity of another approaching aircraft, but also can "see" the aircraft early enough to avoid the collision.

Due to the large amount of data contained in images, rapidly changing image flows in real-time could be a big challenge. To get DSA systems work efficiently, a new solution, bio-inspired vision system can be used here. Since visual detection of motion is essential to survival, many animal species, like insects, have evolved to have large neurons in the brain to be good at detecting and reacting to the motion of an approaching object. The knowledge of the neural circuitry can be used here to construct artificial vision systems for DSA. (Cembrano, et al., 2008)

Natural vision systems have been improved through millennia of evolution and are more robust and efficient than artificial counterparts. Many insects rely on vision to control its own movements and observe that of others around it. They are also able to perform these tasks within a wide range of lighting conditions. This is a perfect biological example of natural DSA system. The correct operation of the DSA system requires proper image acquisition at the optical sensor layer. So the sensors and image processing module should have the ability to handle wide illumination ranges.

4 CONCLUSIONS

Due to the advantages of UAVs over manned aircraft for many applicable situations, the permission of UAV flying in commercial airspace could be an amazing start of many potential applications. To open this door, a mature see and avoid system on board is a necessity. There are several kinds of detect, sense and avoid solutions for UAV DSA, among which optical based DSA system is applicable for small UAVs because its size, dimension, weight and power consumption can be minimized. And a new efficient bio-inspired vision system can be introduced into DSA system to handle the huge amount of image data flows in real-time.

There are still many details to work on for DSA system, such as system minimization, mature image processing module development, etc., with all these works ongoing, hopefully it won't take long for UAVs to get access to civil space.

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