Collision Avoidance Radar for UAV

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***Abstract*—A critical sensor characteristic for obstacle awareness and avoidance for UAV is assessed with the compliance of the equivalent level of safety regulation. Based on the assessment of the obstacle awareness and collision avoidance sensor, the small-sized, light-weighted radar sensor is proposed for the suitable candidate in meeting with the system requirement as well as operational requirement of smart unmanned vehicle. The conceptual radar design result is also presented with the design parameters and the radar detection and avoidance procedure are simulated with the probability of obstacle detection and the avoidance scenarios. As a result of performance assessment for obstacle detection performance, probability of detection is more than 90% at the given required detection range. The performance of collision avoidance mode is also simulated based on the various radar range and range-rate data in the four different flight scenarios.**

Key words: UAV, Radar Detection, Collision Avoidance, Obstacle Awareness, Sensor System Requirement

I. INTRODUCTION

Recently, UAV (Unmanned Aerial Vehicle) has been drawing a great attraction for the applications to both civil and military mission without risk in air safety for the pilot flying in low-altitude and/or in dangerous battlefield environment. Due to the inherent nature of the low flying vehicle, obstacle awareness is a fundamental requirement to avoid the collision against stationary and/or moving target obstacles along the flight path. Also it is noted that UAV should secure the equivalent level of safety comparable with manned aircraft in order to fly in civil and military airspace. Thus the collision avoidance system should be considered as a part of the navigation system in an unmanned vehicle. The obstacle awareness and collision avoidance are being acknowledged as the most important issues in the field of unmanned vehicle. An international standard regulation for the "sense-and-avoid" of UAV is being studied in Europe and USA, and the related technology has not been matured yet for the unmanned system application. Recent technology advances in obstacle detection using optical imaging sensor for aircraft [1] and laser radar for helicopter [2] have been addressed in the articles, but the radar sensor technology for obstacle awareness and collision avoidance is being under development [3] and has recently been demonstrated for the manned helicopter and unmanned vehicle [4]. The collision awareness and avoidance system is under feasibility study for the Korea Smart UAV project, whose objective is to develop a smart UAV capable of high speed cruise and vertical take off/landing (VTOL) by integrating "smart" technologies over the years. In this paper, the characteristics of candidate sensor for collision avoidance are compared and the requirement for the radar sensor is assessed in terms of the system requirement and air safety regulation. Radar sensor based obstacle awareness and collision avoidance criteria. Finally, the millimeter radar detection performance and the collision avoidance mode are presented for the application to the unmanned vehicles in the typical flight environments.

This work was partially supported by the Smart UAV Development Center the Ministry of Commerce, Industry and Energy, Korea.

II. COLLISION AVOIDANCE RADAR SENSOR

The smart UAV program requires the collision avoidance capability to automatically sense and avoid the stationary obstacles and/or non-stationary moving objects along the flight path in the relatively low-altitude flying and rapid maneuvering environment. It is essential to consider how the on-board sensor is able to providing the real-time position data measurement as well as accommodating the given payload avionics constraints such as weight, volume and power. Based on the system requirement, the key design parameters can be extended as follows.

A. Sensor System Requirement

Maximum speed of UAV is 500km/h without payload and 440km/h with payload. The surveillance mission payload is limited to less than 40kg and the separated collision avoidance payload is reserved for less than 25kg. The collision avoidance sensor selection should be considered in several important points of view: real-time measurement capability, operational environment, payload constraints and the air safety regulation. The most important

0-7803-9582-4/06/$20.00 ©2006 IEEE

requirement of the obstacle detection sensor for collision avoidance is the capabilities of real-time measurement of relative range, range-rate and bearing in azimuth and/or elevation. The operational environment of the vehicles is to be considered as the sensor selection criteria, which include the search and scan capability, vehicle maneuverability, endurance time in air and ECCM capability. The most critical constraints for small unmanned vehicles are the payload requirements. The payload weight requires less than 25kg and the volume limit requires 620mm(width) X420mm(height) X300mm(depth) for the space of the collision avoidance equipment in the vehicle. A low power and long life time reliability are to be requirements as well. Final consideration is to meet the air safety requirement flying in airspace as directed by FAA or international standard for "sense-and-avoid" requirement for UAV air safety, but at moment, as an upper bound of the regulation, the minimum requirement is to comply with the equivalent level of safety (ELOS) for "see-and-avoid" for manned aircraft pilot by the FAA regulation. Table 1 summarizes the key regulation for collision avoidance of the manned pilot.

TABLE I. "SEE-AND-AVOID" ELOS

Performance Parameter	ELOS for See & Avoid
Missed Distance	500 feet
Field of Regard Azimuth/Elevation	Search Volume +/- 60 deg, +/- 10 deg
VFR Detection Range Time to Collision (11 sec avoidance maneuver)	1.84 miles 21 sec (10 sec PRT) 23.5 sec (12.5 sec PRT)

PRT: Pilot Reaction Time

B. *Collision Avoidance Mode*

Three critical modes of operation are required to decide the status of the collision risk: search, awareness and avoidance modes. In a search mode, the system searches and monitors the obstacles within a certain scan volume along the flight path. Once the obstacles are detected from the sensor in a 23 sec of time-to-collision, the awareness mode is activated by tracking the position of the designated object. When time-to-collision is 11 sec, awareness mode is changed to the avoidance mode and the system initiates to maneuver and autonomously turn the vehicle in order to avoid the dangerous obstacles.

C. *OACAS Radar Design Model*

The CAS system consists of radar sensor (CAR) and Obstacle Collision Avoidance System (OCAS) processor. Utilizing the radar sensor data of range, azimuth or elevation and velocity of the obstacles, the OCAS should decide the collision criteria and send the avoidance command to the DFCC(Digital Flight Control Computer) based on the time-to-collision criteria. Depending on the closing or opening speed of moving obstacles from the radar, the minimum required time-to-collision required on the situation. In this case the UAV speed is assumed to be 440km/h with payload. The radar system model consists of antenna, transmitter, receiver, signal processor and system control computer. In addition the OCAS processor and the obstacle clutter map(C-map) may be included for the OACAS mission. The typical radar design parameters are listed in Table 2.

TABLE II. TYPICAL RADAR SENSOR MODEL

Frequency	35 GHz
Detection	6.4 km
PRF	5 KHz
Range Resolution	5 m
Pulse Width	33 ns
Peak Power	3 kW
Scan Coverage	180 deg (+90 ~ -90) in Az. 100 deg (+20 ~ -80) in El.
Scan Rate	150 deg/s
Antenna Beamwidth	2.5 deg
Antenna Gain	38 dB
Receiver Noise Figure	3.5 dB
RCS	2~30 dBsm
Probability of False Alarm	10e-6
Probability of Detection	90 % (SW 2 & RCS 2 dBsm)

III. RADAR DETECTION AND COLLISION AVOIDANCE MODE PERFORMANCE

The collision avoidance problem using radar sensor may be separately considered in two cases. One is the awareness problem, which can be represented by the probability of detecting the obstacles which are statistically different RCS model in the unmanned vehicle environments. The other is the avoidance problem which can be represented by the performance of the collision avoidance mode based on the given radar range, range-rate, and bearing information in the various flight scenarios.

A. *Obstacle Detection Performance*

Radar detection probability varies depending on SNR and/or false alarm rate. Also, SNR varies depending on RCS which may be fluctuated in amplitude(scintillation) and/or in phase (glint). For most cases, the glint can not be of major concern, but the cases where high precision and accuracy required, glint can be a detrimental. Scintillation can vary slowly or rapidly depending on the obstacle size, shape, dynamics and its relative motion with respect to radar. Due to the RCS change as random process, the RCS scintillation model is used as a statistical model.

For given radar model parameter and the probability of false alarm, the SNR is compared with target RCS, and then the probability of detection is compared with range using SNR. Since the atmospheric attenuation is the main reason for decreasing SNR in millimeter wave bands, the attenuation according to range should be considered in radar equation. The probability of detection versus range according to Swerling model in dual mode PRF is shown in Fig. 1.

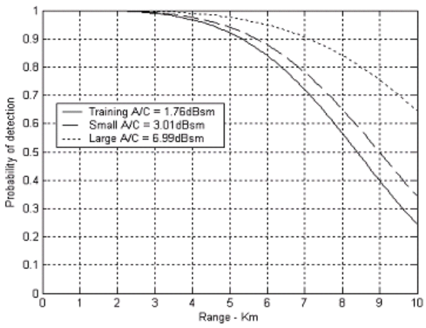

Figure 1. Detection Probability vs. Range (Swerling I, LPRF)

When it is the time-to-collision of 23sec for awareness mode in the closing speed of 1000km/h between UAV and moving obstacle, the distance between them becomes the minimum detection range of 6.4km for collision avoidance radar. In case of stationary obstacle, considering UAV maximum speed of 440km/h, the minimum detection range becomes 2.8km based on time-to-collision of 23sec. In the high PRF mode, due to the number of integration pulses is increased in the constant dwell time, which also increases the SNR, power line and small-sized aircraft which were not detected in low PRF mode are capable of detection more than 90%. Since that if high PRF more than 15KHz is used for increasing SNR, unambiguous range will be shorter than 10km, high PRF mode of 15KHz is designed to escape range ambiguity.

B. Collision Avoidance Mode Performance

Collision avoidance problem is to determine the possibility of collision, and to provide the maneuvering command to the vehicle in the complicated obstacle environments. There are three modes of operation to be conceived: search mode (detect), awareness mode (detect and track) and avoidance mode (maneuvering). The procedure of the collision avoidance is shown in Fig. 2.

In search mode from the normal navigation state, the UAV flies to the pre-programmed destination by navigation system and CAS radar searches the obstacle coming close to own vehicle. Once any objects come close within the time - to-collision of 23 sec, the search mode is transferred to the awareness mode, which can now react the obstacle by tracking the moving obstacle by updating the vector of the object every scan rate. If the time-to-collision of any closing objects is less than 11sec during the track, the avoidance mode is initiated to maneuver the vehicle. In this case, the potential collision point and safety circle (500ft) are computed and waypoint is set on the safety circle for avoidance maneuvering. UAV maneuvers depending on the avoidance angle, which is computed based on the waypoint and potential collision point.

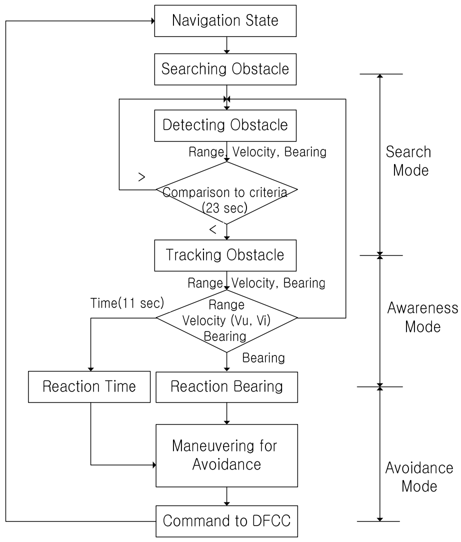

Figure 2. Concept of Collision Avoidance

Flight Scenario 1: The first scenario is the case where the moving obstacle is closing in the radial direction with the speed of 560km/h whose aspect angle is 0 degree. In this case, since the speed of UAV is 440km/h, the closing speed becomes 1000km/h. When the awareness mode is initiated (time -to-collision of 23sec), the distance between UAV and moving obstacle could be 3.1km. In avoidance mode (time-to-collision of 11sec), the time that moving obstacle comes to potential collision point is 10.5sec and the distance between UAV and waypoint is 1.47km, which is sufficient time for UAV to avoid from the collision risk. As shown in Fig. 3, UAV avoids safely the moving intruder obstacle in the closing direction without collision approach into the safety circle.

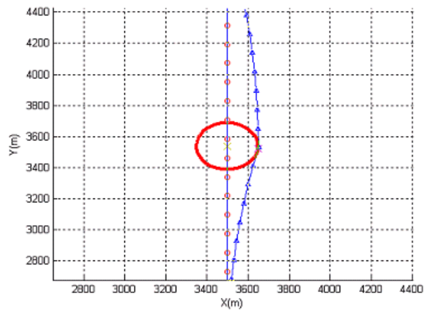

Figure 3. Trajectory of UAV and Obstacle in the Radial Direction

It is assumed that the collision avoidance radar information such as range, azimuth or range-rate is accurate. However if there is an error in the radar information, it has an effect on the collision avoidance performance. It is assumed that the range of azimuth error is equal to radar beam width of 2.5 degree, which is +/- 1.25 degree centered 0 degree in the avoidance mode. As the simulation result is shown in Fig. 4, in the given azimuth error information of

+1.25 degree, UAV approaches to the potential collision point about 99.327m, which means that UAV approaches into the safety circle about 50.673m and collision risk is very high. On the other hand, in case of given azimuth error of -1.25 degree, the minimum distance between UAV and safety circle during the avoidance mode becomes 204.586m, which means that UAV maneuvered more safely than no-error condition.

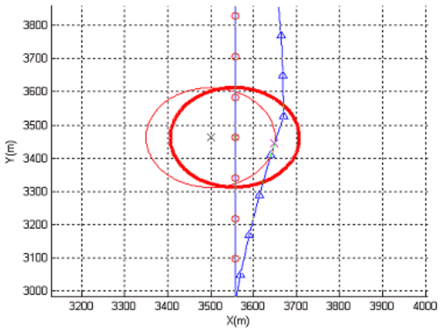

Figure 4. Trajectory in Azimuth Error: +1.25 deg

Flight Scenario 2: The second flight scenario is the more general case where the moving obstacle is closing in the off-angular direction from 0 to 90 degree. In this simulation, it is assumed that moving obstacle comes close to UAV with aspect angle of 30 degree and speed of 500km/h. Since the time-to-collision is calculated depending on the closing speed, and there is a difference between direction of moving obstacle and closing velocity vector, the potential collision point becomes different from the trajectory of obstacle about 40m.

Flight Scenario 3: The third scenario is the case where the obstacle vehicle flies to the opening direction, but own vehicle moves faster than the obstacle speed. In this case, there is a collision possibility in only case where the speed of own vehicle is faster than that of the opening obstacle. In this simulation, it is assumed that the UAV speed is 440km/h and the speed of moving obstacle with opening direction is 270km/h.

Flight Scenario 4: The fourth scenario is the case where the stationary obstacles such as tower or hill are within the threat distance. In case of stationary obstacle, due to the zero speed of obstacle, collision can be avoided if the range and azimuth information of the obstacle is available. The distance from UAV to obstacle becomes to 2.8km with the UAV speed of 440km/h at the awareness mode, which means that once the collision avoidance radar secures the detection range of 2.8km, collision avoidance will be feasible. Avoidance maneuvering initiates at the distance of 1.3km from obstacle.

C. *Performance Evaluation and Discussion*

From the simulation results described in case of erroneous radar information of azimuth and range-rate, UAV could move into safety zone about 50m, which means that collision risk between UAV and obstacle is very high. Margin boundary circle which is extended from the safety circle is desirable, and new waypoint is set on this margin boundary circle to secure the safety for given erroneous information.

Collision avoidance performance according to size of margin boundary circle is evaluated in case of azimuth error corresponding to radar beam width. In this case, the range-rate error is randomly generated from 0m/s to 8m/s. In case that waypoint is set on the margin boundary circle which is extended about 50m from the safety circle, the probability of collision avoidance is over 85% for the given erroneous radar information in Fig. 5.

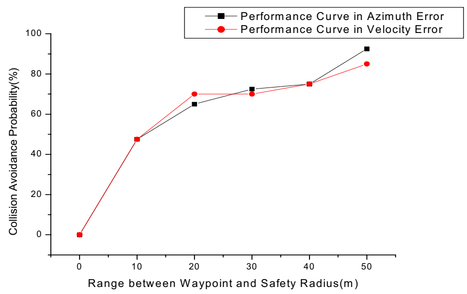

Figure 5. Collision Avoidance Perfromance – scenario 1.

IV. CONCLUSION

Due to the inherent nature of the low flying vehicle, obstacle awareness for UAV is a fundamental requirement to avoid the collision against stationary and/or moving target obstacles along the flight path. As a result of performance assessment for obstacle detection performance, probability of detection is more than 90% at the given required detection range. The performance of collision avoidance mode is also simulated based on the various radar range and range-rate data in the four different flight scenarios. The simulation results show that in case of radar error data, the safety margin boundary is well designed for securing the safety of UAV, and the more than 85% of probability of collision avoidance can be achieved within the requirements.

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