Development of Sense and Avoid system based on multi sensor integration for unmanned vehicle system

Ari Legowo¹, M. Faiz Bin Ramli²a, Syariful Syafiq Shamsudin²b
¹ Department of Mechanical Engineering, Kulliyyah of Engineering, International Islamic University, Malaysia, P.O.Box 10, 50728 Kuala Lumpur, Malaysia.
² Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia.

E-mail: ¹legowo@iium.edu.my

Abstract. Unmanned Aerial Vehicles (UAV) have a great potential to replace manned aircraft in many tasks or missions. However, in order to allow these UAVs to execute their mission appropriately and especially to deploy them in national or civil airspace, UAVs must have a proper and reliable collision avoidance system. This avoidance system is known as a Sense and avoidance (SAA) system. The purpose of the system is to detect any obstacles either in static or moving condition and respond with proper avoidance maneuvers in order to maintain minimum separation distances. Therefore the research project deals with the development of a unique SAA system which is based on multisensory integration. In particular, it focuses on sensors, processing logic and hardware required on the UAVs to acquire situational awareness. Dissimilar kind of sensors which is optical and laser type is proposed to be employed, so that weaknesses from each individual sensor can be tolerated. Proper logics or algorithm related to the fusion of output from each sensor will also be studied. The combination of Extended Kalman Filter (EKF) and Differential Evolution (DE) method is used for the purpose of development of detection and tracking system which considered to be the main challenges in SAA system development. Subsequently, once the algorithms are put together, including maneuvers avoidance technique algorithm, the developed SAA system will be experimentally tested in order to validate and evaluate the overall capability of the system.

1. Introduction

Unmanned Aerial Vehicle (UAV) as the name implies, it is an aircraft without a pilot on-board or attached to it. Hypothetically, UAVs have a great potential to replace manned aircraft in many tasks or missions (e.g. surveillance, rescue mission, attack mission, collecting data, and etc.). In order to let
these UAVs execute their mission appropriately and especially to deploy them in national or civil airspace, UAVs need to have a proper and reliable collision avoidance system. In the field of UAVs, the term Sense and Avoid (SAA) is used for collision avoidance system. SAA system is an ability of the UAVs to detect traffic or obstacles (Static/moving) and respond with proper avoidance maneuvers in order to maintain minimum separation distances. Under requirement of Part 91 General operating and flight rules (Federal Aviation administration FAA), the key requirement for any vehicle to enter an airspace, that they must have ‘See and avoid’ technique incorporated in their vehicle [1].

In general, any SAA system must consists of five key stages or processes which are Surveillance, identification of risk, determination of appropriate maneuvers, maneuvers execution, and return to course [2]. Surveillance or close observation of the SAA system highly depends on the type of the sensors being used. There are two types of sensors which are cooperative and non-cooperative sensor (see table 1). Cooperative surveillance uses intruders information (e.g position, velocity, trajectory, and etc) constantly by employ a transponding method by which the intruders transmit its information. On the other hand, Non-cooperative sensor obtains intruders information via indirect method either by passive or active technique [3]. The ability to deploy UAVs across a multitude of operating environments and mission scenarios has rendered them exceedingly useful for both defense and commercial applications and this has fuelled their rapid development in the last decade.

In Korea, Chungnam National University has developed SAA system for the agriculture purposes using only Light Detection and Range (LIDAR) sensor system. The sensor is selected because this agriculture UAVs only hover or fly near the ground and do not require any communication between other aircraft [4]. Other sensing methods that are available for SAA system is vision sensing typesystem. Pazmany Peter Catholic University used five camera vision system in order to develop collision warning system and they have selected five pieces of WVGA (752x480) cameras (MBSV034M-FFC) to cover the required resolution [5]. Northrop Grumman Global Hawk the United States surveillance UAVs also utilizes a vision system which by adopting three camera system to detect intruder aircraft [6]. There is also research and studies of SAA system using unique sensor which is Doppler radar. These sensor radars require relative motion between the vehicle and target to detect obstacles. Pulsed Doppler radar can be used to give intruders velocity, range and in some cases angular location with respect to observer. By measuring the airspeed of the UAVs, it is possible to acquire the relative speed between the UAVs and target [7].

This paper focused on proposing a unique enhancement solution to develop UAVs SAA system by using the integration of dissimilar type of sensors that capable to efficiently and accurately detect intruders or obstacles and ultimately evade the collision.

2. Challenges

A lot of research and investigation pertaining to SAA system are still undergoing. When it comes to development of SAA system for UAVs, every researcher must considers properly two important aspects related to system itself which is sensor characteristic and algorithm method for tracking and avoidance system. Field of Regard (FOR), Field of vision (FOV), and range of the sensors have to be properly considered, so that the SAA system being develops is accurate and reliable. Furthermore, weight and size of the sensors attached must be suitable with the physical size and power produced by the UAVs. Most of the sensors only sense their target within their own capabilities. For example, an UAVs equipped with optical sensors, will only detect their target by bearing attitude and not by range. Therefore, the detection reliability of the SAA system will certainly not favourable.

The complexity of the SAA system also lies on the development of the detection and tracking algorithm (filtering/estimation method) because it has several methods and each methods has its own
advantage and disadvantage. These two aspects are closely related to each other, because each selection of sensors can have a direct impact on the complexity of the algorithm. Thus, when the algorithm become too complex, the tracking system may not be accurate enough and might as well fail.

| Name            | Type      | Range       | Bearing Azimuth | Bearing Elevation |
|-----------------|-----------|-------------|-----------------|-------------------|
| A/C transponder | Cooperative | Accurate    | Calculated      | Calculated        |
| ADS-B           | Cooperative | Accurate    | Calculated      | Calculated        |
| Optical         | Non-Cooperative | Not sensed | Accurate        | Accurate          |
| Thermal         | Non-Cooperative | Not sensed | Accurate        | Accurate          |
| LIDAR           | Non-Cooperative | Accurate    | Narrow          | Narrow            |
| Radar           | Non-Cooperative | Accurate    | 360 Degrees     | 360 Degrees       |
| Acoustic        | Non-Cooperative | Accurate    | 360 Degrees     | 360 Degrees       |

3. Proposed solution
As stated above, the proposed solution of the research project to enhance the level of accuracy and reliability of the SAA system is by the employment of multiple sensors that have a different type of sensing capabilities into the system. Apart from that, we will also introduce a combination of Extended Kalman filter (EKF) and Differential Evolution (DE) as our state estimation or filtering algorithm.

3.1 Multi sensors integration.
There are several techniques to encounter the disadvantages of sensor types or single sensor. One could introduce multiple and similar type of sensors or multiple sensor types. In order to integrate multiple sensors into one system that produce a single output, one must properly combine all the data coming from all sensors (similar/dissimilar). This combination of data is called as a data fusion. Data fusion techniques combine data from multiple sensors, and related information from associated databases to achieve improve accuracies and more specific inferences that could be achieved by the use of single sensor alone [8]. In this project, dissimilar sensors will be employed which LIDAR and Optical sensors.
Combination of these sensors can wipe off the disadvantages from each individual sensor, because LIDAR can detect accurately the range and the distance of the obstacle while not for optical sensors. Conversely, Optical sensor have the capability to detect the bearing of the obstacles while this capability is not the case for LIDAR. Since data coming from these sensors are different, it is considered as a non-commensurate data, therefore, these data must be fused at decision level and cannot be used at raw level [9].

Figure 1. Fusion Architecture

3.2 Detection Method.

The project will uses EKF with combination the of DE to make the tracking system computationally efficient and capable of running real time on-board of the UAVs. Since computing all data (e.g. source image) or coefficients at every position is computationally expensive and consumes a lot of time, it is more efficient and cost-effective to predict the position of the interest obstacles and searching only a region around the predicted position. The position of the obstacles is estimated using the measurement from the obstacles detection and the process covariance matrix is updated and optimized by DE algorithm method[1,10,11]. These are the few of the governing equations:

predicted state

\[ X_k = f(X_{k-1}, U_{k-1}, W_{k-1}) \]  \hspace{1cm} (3.1)

Measurement input

\[ Z_k = f(X_k, V_k) \]  \hspace{1cm} (3.2)

Position and velocity

\[ X_k = \begin{bmatrix} \bar{X}_k \\ X_k \end{bmatrix} \]  \hspace{1cm} (3.3)

Process covariance matrix

\[ P_k = (I - KH)P_{k-1} \]  \hspace{1cm} (3.4)
These are general steps in implementing the technique:

i. **Initialization**
   In this stage the whole image is searched for the object due we do not know previously the obstacle position. Process covariance matrix is also initialized.

ii. **Prediction**
   The state of the obstacle is predicted using the motion model of the kalman filter for the next frame at next time step.

iii. **Correlation**
   In this stage, the obstacles is detected within the search window (measurement $Z_k$) and the State position and covariance matrix is updated with the measurement data.

4. **Result and Discussion**

Research project methodology starts with analysing related literature reviews on SAA systems including regulations or requirement, sensors characteristics, sensor detection algorithms, maneuver avoidance method and others. After extensive reviews have been done, type of sensors will be chosed (e.g size, weight, range, bearing angle and etc).

Each sensor chosed will be tested or simulated to determine what kind of data can be captured. After the sensors simulation, proper detection and tracking algorithm including data fusion algorithm will be developed. The combination of EKF and DE method is used for the purpose of filtering the data (Optimized) to develop the detection and tracking system. Subsequently, once the algorithms are put together, the system will be experimentally tested.

When detection and tracking system is accomplished, maneuver avoidance method for the SAA system will be developed. Finally, this SAA system will going through several experiment in order to validate and evaluate the overall capability of the system.

5. **Conclusion**

By using a unique UAVs SAA system based on multisensory will be developed. The system is expected to succeed in detecting and tracking the obstacles either in static or moving condition. Ultimately, the UAVs must be able to perform safe maneuver when risk of collision detected. The SAA system will give a contribution (e.g multisensory technique, sense and detection method, sensor fusion method and manoeuvre avoidance technique) on the matters regarding the operational possibilities of UAVs in the national or civil airspace.

**References**

[1] United States Department of Defense (2004), “Airspace Integration Plan for Unmanned Aviation”

[2] Andrew R. Lancher, David R Maroney, Dr Andrew D. Zeitlin (2007) “Unmanned Aircraft Collision Avoidance Technology Assessment and Evaluation Methods”, The MITRE Corporation, McLean, VA, USA.

[3] Hung Pham, Scott A. Smolka, Scott D. Stoller, Dung Phan, Junxing Yang (2015) “A survey on Unmanned Aerial vehicle Collision Avoidance Systems”. Department of Computer Science, Stony Brook University, Stony Brook, NY, USA.
[4] Jingu Kim, Sua Song, Seungkeun Kim, Jiyoung Souk (2014), "Collision Avoidance System for Agriculture Unmanned Helicopter Using LIDAR Sensor", Asia Pacific International Symposium on Aerospace Technology (APISAT).

[5] Akos Zarandy, Zoltan Nagy, Balint Vanek, Tamas Zsedrovits, Andra Kiss, Mate Nemeth, (2011), "A five camera vision system for UAV visual attitude calculation and collision warning", Springer-Verlag Berlin Heidelberg.

[6] J. Daniel Griffith, Mykel J. Kochenderfer, James K. Kuchar (2018), "Electro Optical System Analysis for Sense and Avoid", AIAA Guidance, Navigation and Control Conference and Exhibit.

[7] Andrew Viquerat, Lachlan Blackhall, Alistair Reid, Salah Sukarrieh, Graham Brooker, (2017), "Reactive Collision Avoidance For Unmanned Aerial Vehicles Using Doppler Radar", 6th International Conference on Field and Service Robotics.

[8] David L. Hall, James Llinas (1997), "An introduction to multisensor Data Fusion", Proceeding of the IEEE, Vol-85, No-1. Appl. Res. Lab., Pennsylvania State Univ., University Park, PA, USA

[9] David L. Hall, James Llinas (2001), “Introduction to multisensor Data Fusion”, CRC Press LLC.

[10] Ashraf Qadir, William Semke, Jeremiah Neubert, (2011), "Implementation of an onboard visual tracking system with Small unmanned Aerial Vehicle (UAV)", International Journal of Innovative Technology & Creative Engineering, Vol.1 No.10.

[11] Robert H. Chen, Arthur Gevorkian, Alex Fung, Won Zon Chen, (2011), "Multisensor Data Integration for Autonomous Sense and Avoid", AIAA 2011-1479.