Current development of UAV sense and avoid system

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Abstract. As unmanned aerial vehicles (UAVs) are now gaining high interests from civil and commercialised market, the automatic sense and avoid (SAA) system is currently one of the essential features in research spotlight of UAV. Several sensor types employed in current SAA research and technology of sensor fusion that offers a great opportunity in improving detection and tracking system are presented here. The purpose of this paper is to provide an overview of SAA system development in general, as well as the current challenges facing UAV researchers and designers.

1. Introduction

Unmanned aerial vehicles (UAVs) are now used in various military fields including reconnaissance, environmental monitoring, border patrol, search and rescue operations, disaster relief, tracking and monitoring. In the next decade, UAVs’ market is expected to be rapidly growing in handful of civilian and commercial industries such as agriculture, energy, utilities, mining, construction, real estate, news media, and film production [1, 2]. These applications require the small and agile UAVs to fly at lower altitude or operating inside buildings, which are exposed to many hazards and obstacles. However, current UAVs technology in automatically sensing, detecting and avoiding fixed obstacles such as power line, building, tower, tree, and moving obstacles of birds and other aircraft is still immature compared to manned aerial vehicle [3]. As UAVs’ market is predicted to provide billions of dollars in economic growth especially in commercial market, researchers around the world are now in rush to develop an efficient automatic SAA system to satisfy the demands and requirements of the UAVs. Moreover, another factor to expedite this research field is due to the new regulation from aviation authorities, which will be implemented soon. The regulation requires each UAV to have this automatic SAA system to reduce collision risk and thus improve the safety flying environment in non-segregated airspace [4].

Figure 1 shows a basic diagram of how SAA system should automatically function. Several sensors are employed in the UAV to collect and record data along the flying path. During the operation, the sensors are responsible to detect and identify any obstacles or threats to the UAV depending on their specification. The sensors provide information of environmental mapping based on the implemented tracking model. The information from several sensors are gathered and processed using the collision avoidance program embedded in the main processor. There are many types of collision avoidance programs used such as nonlinear model predictive control, graph search algorithm, potentially field...
method and vision based neural network. Finally, the UAV executes the avoidance action depends on the processed obstacles’ information.

During the avoidance action, several parameters of interest such as position, speed, size and bearing angle of UAV may change. This cycle is continuously repeating to capture next mapping environment while at the same time UAV must look ahead to pursue its operational goal without fail. The capability of the sense function is not only to detect the presence and position of intruders but also to predict the speed and trajectory of the moving intruders. On the other hand, the avoid function should provide manoeuvre path to prevent the identified collision with consideration of kinematic and dynamic aspect [2, 3, 4].

![Figure 1. Diagram of SAA system](image)

Primary challenges in implementing collision avoidance technology in UAVs are their size, weight and electrical power consumption. The limitation of payloads, especially in small UAVs, has hindered current collision avoidance technology to be integrated as the employed sensors must be lightweight, small in size and consume low power. The driving algorithm also needs to be computationally efficient and less complex as the size of main board memory is small and the processor has less speed with limited power supply. Even though UAVs’ speed is slower than manned aircraft, the SAA system is expected to process the data fast enough to avoid collision with the faster manned aircraft. In addition, as UAVs’ applications are widely increased, the SAA system should be capable to operate in various environment, weather and condition. Therefore, a less complex algorithm with compatible sensors at relevant cost is an important consideration in developing an efficient SAA system.

2. Sensor

Although Traffic Collision Avoidance System (TCAS) and also Automatic Dependent Surveillance–Broadcast (ADS-B) technology have already matured for collision avoidance technique in manned aerial vehicle, the system is currently satisfied only for cooperative intruders. Technology of ADS-B in terms of transmitter and receiver system is not just capable to provide data about other aircraft, but also provides information of the host aircraft’s altitude and velocity. Furthermore, the system is able to deliver information of weather and terrains signal [5]. With these advantages, the requirement to integrate ADS-B to all size UAV is expected soon with current research focusing on miniaturisation of the equipment that will be beneficial to SAA system. Research on electronic sensors for ground based SAA system is also conducted for the near term solution in limited operational areas.

Many researchers have focused more on non-cooperative sensors of active and passive type as they can provide better detection for the non-cooperative obstacles especially when problem of data link loss occurs. Non-cooperative sensors are really important, particularly for the UAVs that fly inside buildings since the obstacles are mostly wall, machine, office equipment and humans. Active sensors in application include laser ranging, radar and sonar submit signal in detecting obstacles. They usually provide a very good information of the obstacles distance and it is very essential criteria in tracking operation. On the other hand, passive sensors such as electro optical, infrared, thermal imaging and motion detector depend on the signal detection emitted from the obstacle [6].

Application of electro optical sensors, combined with radar/infrared sensor/thermal imaging/motion detector, is a very popular approach in SAA system. Electro optical sensor, which is small in size and weight, has very fast scan rate and high resolution of image. They are also low in cost and consume
low electric power. However, they are not capable to estimate obstacle range and sometimes generate high false alarm rate [7]. Since they need light in their operation, bad weather or cloudy condition can really affect their performance in object detection. Hence they cannot function well in low illumination [8]. The infrared sensor, which aids the electro optical sensor detection at night, is not affected by the electromagnetic interference and can measure obstacle range by calculating the infrared light radiated from objects. Thermal imaging sensor detects heat and is capable to operate in all-weather operation whereas motion detector function by sensing direction and velocity of objects [6].

Milimiter wave radar that has narrow beam width is capable to detect low altitude target without multi-path effects. The advantage of this radar is that it can work well in all-weather conditions, hence dust and lightning are less affected. However, it can be easily interfered by electromagnetic and has a bad tracking accuracy when the target is cloaked [9]. Light detection and ranging (LIDAR), which has high precision and resolution in distances measurement, is able to detect objects of different sizes and shapes by calculating the time taken for light to travel forth and back. The high-speed acquisition feature of LIDAR makes it commonly used in contour mapping but it is a high cost equipment and consumes more power. While sonar sensor is widely used in maritime for it is cheap, light weight and compactness, it provides accurate distance only to flat and upright indoor environment. Detection of irregular shaped object such as inclined roofs, trees and fences using sonar sensor will produce error to the system [10].

3. Sensor fusion technique

Sensor fusion offers a great opportunity to overcome the physical limitations of the sensing systems. It combines information from a number of different sensors to provide a robust and complete description of the flying environment that is rapidly changing. Since each sensor has its strength and weakness, a technology to integrate multiple sensors in one UAV platform is necessary to improve detection and minimize error in tracking. An efficient tracker system will result in accurate and reliable tracking and can perform fast speed avoidance manoeuvring if risky collision is identified [9, 11, 12].

The research development in sensors fusion is however still far from maturity level. The integration of the sensors into main board requires real time operation of embedded system programming, which will involve high processing power in capturing and processing various signals data from multiple sensors. Fast response algorithm without much complexity is preferable to ensure that the sense and detection system functions properly. This fast process in real time operation will increase probability of successful avoidance action in the required time frame. Another problem is the increasing UAV payload when the multiple sensors are employed. There are only few efficient lightweight sensors available in the market. As a result, some sensors with many advantages have to be neglected due to increasing payload problem since the stability and the speed of UAV also need to be considered.

Ramasamy and Sabatini (2015) have successfully shown a simulation study of sensor fusion, which combines several cooperative sensors, non-cooperative sensors and naturally-inspired sensor [11]. The integration and sequence of the sensors were made based on Boolean decision logic. The system used Kalman filter tracking at each sensor site and then communicated to a centre where a global track file was assimilated. The algorithm known as track to track fusion combines the estimation compared to observation where it can solve the robustness issues such as limited information of the environment and partial loss of information. On the other hand, Fasano et al. (2015) have recorded a significant improvement on the collision detection performance in multi sensor fusion of radar and electro optical sensors [12]. The effectiveness of sensor fusion in the flight experiment has successfully reduced false alarm rate, detection range sensitivity and computational burden problems. The similar result was detected in [8] for the fusion study of electro optical sensor and synthetic aperture radar, which showed the false alarm number per imaging area (in km) has significantly reduced down to 14-23%. Moreover, according to [13], the employment of infrared and ultrasonic sensors fusion has effectively reduced reading noises and errors that resulted in accurate range estimation in collision avoidance.
4. Conclusion

The overview of SAA development as well as the challenges faced by the researchers has successfully presented here. Advanced development in miniaturisation technology like MEMs and microcontroller is predicted to promote high research in the integrated sensor architecture of the SAA system. Finally, although several challenges are still unresolved for now, the industry is still young and the increased market demands for civil/commercial applications will surely attract big companies and industries to fund SAA research and thus expedites the technology growth.

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