17.Nov 2024 Junlin Xiong

REAL-TIME CAT PREDICTION VIA CABIN SENSOR AND GROUND SYSTEM

1. ABSTRACT

Turbulence poses a significant challenge to flight safety and passenger comfort, especially the unseen and unpredictable clear air turbulence (CAT). Traditional prediction methods, such as radar echo analysis and expert judgement, have limited accuracy and subjective bias, and therefore there is currently no real-time and accurate method for predicting CAT. This paper proposes an innovative CAT early warning system that uses portable on-board devices, such as PADs, used by flight attendants or pilots to conduct flights. The system collects real-time data from accelerometer sensors embedded in the PADs and transmits the data to a ground platform via existing communication methods, including satellite communications (Satcom) and air-to-ground communications (ATG). The data is also processed on the ground using advanced data fusion techniques and models are trained to provide multiple levels of support through real-time CAT alerts. The proposed solution does not require additional hardware, thus ensuring technical and cost feasibility. The method achieves predictive power and accuracy for CAT.

2. INTRODUCTION

Turbulence is primarily caused by atmospheric instability, where changes in the direction and speed of airflow can upset the aerodynamic balance of an aircraft. When an aircraft encounters turbulent eddies of similar magnitude to its structure, irregular motion and vibration can occur. If the aircraft's natural oscillation frequency coincides with the turbulence's oscillations, violent shaking can occur.

Currently, turbulence prediction is based on two methods: radar echo analysis and empirical judgement. Radar echoes can detect severe weather, such as storms and typhoons, and provide turbulence forecasts with limited accuracy. Empirical judgement is mainly a manual analysis by intelligence officers and pilots, based on meteorological material, to determine the areas where turbulence is likely to occur. These two types of judgement can basically be made five minutes in advance, with an accuracy rate of about 50 per cent. The captain usually makes a plan together with the flight crew, using the weather charts and the turbulence predicted by the

ground services. However, these tools are difficult to apply to monitoring and forecasting clear air turbulence (CAT) [1]. This is because meteorological radar relies on the detection of scatterers in the atmosphere to study atmospheric motion, but CAT is difficult for meteorological radar to accurately detect due to the relatively large air permeability, and expert empirical judgement can only be roughly estimated to ensure reliability. This paper aims to address these issues by using sensor data from mobile electronic devices in the passenger cabin and cockpit, and data fusion techniques to improve the accuracy of real-time CAT detection and prediction.

3. PROPOSED SOLUTION

To address the difficulty of accurately predicting CAT in flight, this paper proposes a new CAT warning system. The method captures bump data through embedded sensors such as accelerometers and gyroscopes in mobile electronic devices used by the flight crew, including electronic flight bags (EFBs) and other on-board mobile devices [2]. With the real-time vertical acceleration data collected, the system can assess the intensity of cabin and cockpit bumps in real time. This approach enables accurate CAT detection and live alerts without the need for additional on-board equipment or sensors. This approach is real-time, highly reliable and easy to implement.

4. DATA TRANSMISSION

After the data has been collected, there are two widely used ground and airborne communications methods for transmitting the data to the ground platform for analysis: Satcom and ATG. Satcom uses a high-throughput satellite communications network to transmit data between the aircraft and the ground, and the transmission range can cover the entire world, which is very suitable for trans-oceanic and mountainous flight areas or routes that cannot be covered by ground stations. Satcom has the advantage of stable high-bandwidth communication capability and wide area coverage, ensuring uninterrupted data transmission even in remote areas or vast sea areas, but it is relatively costly to deploy [3].ATG relies on ground base stations to achieve network interoperability with aircraft and provides lower latency and faster data transmission speeds than satellite systems. faster data transmission speeds than satellite systems, and its construction and maintenance costs are much lower than those of satellites. Therefore, ATG is a more efficient and cost-effective option in areas with good ground base station coverage (e.g. inland or coastal routes) [4].

In practice, a combination of Satcom and ATG can be used. For example, if the current flight area is within the coverage area of an ATG base station, ATG is used, and when the flight area enters the ocean or no man's land, which cannot be covered by ATG, Satcom is switched to Satcom. switching between the two technologies can reduce network costs while maintaining network efficiency and stability.

5. DATA FUSION

The sensor data returned to the ground is stored in the ground analysis system and fused with the radar detection data using the extended Kalman filter [5]. CAT panoramic data images were visualised from the fused data to assess the severity, extent and expected duration of turbulence.

6. REAL-TIME DETECTION AND PREDICTION

The fused data feeds into a real-time analysis system that provides multiple levels of support from detection to prediction, as required. At the detection level, the system identifies the intensity and extent of the CAT in real time and issues immediate safety alerts and contingency plans to the flight crew and ground personnel. At the prediction level, the system uses deep machine learning to train predictive models that provide early warning before a flight enters the CAT area, giving flights time to adjust their routes and avoid the CAT impact area.

7. CONCLUSION

This paper proposes a new real-time CAT warning system that uses existing portable airborne equipment to collect real-time turbulence data and make CAT predictions, effectively overcoming the limitations of traditional radar systems and human judgement methods. More importantly, the system requires no additional airborne equipment, significantly reducing operational costs.

In addition, this methodology demonstrates the great potential of combining existing airborne systems with advanced computational models. In a broader sense, this prediction principle and architecture can be applied to other types of hazardous weather, such as typhoons, thunderstorms, heavy rain, squall lines, hail, tornadoes, etc. And further research on fusion algorithms can be carried out to extract more forecast information and solve the warning and prediction problems of various special transport situations at sea, on land and in the air.

REFERENCES

[1]D. B. Lee, H. Y. Chun, and J. H. Kim, “Evaluation of multimodel-based ensemble forecasts for clear-air turbulence,” *Weather and Forecasting*, vol. 35, no. 2, 2020, doi: 10.1175/WAF-D-19-0155.1.

[2]D. C. Chandra and M. Yeh, “Human Factors Considerations in the Design and Evaluation of Electronic Flight Bags (EFBs) Version 2,” *Security*, no. September 2003, 2003.

[3]O. Kodheli *et al.*, “Satellite Communications in the New Space Era: A Survey and Future Challenges,” *IEEE Communications Surveys and Tutorials*, vol. 23, no. 1. 2021. doi: 10.1109/COMST.2020.3028247.

[4]L. Liu, C. Li, and Y. Zhao, “ATG spectrum analysis and interference mitigation for intelligent UAV IoT,” *Eurasip Journal on Wireless Communications and Networking*, vol. 2022, no. 1, 2022, doi: 10.1186/s13638-022-02197-1.

[5]W. Elmenreich, “A review on system architectures for sensor fusion applications,” in *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 2007. doi: 10.1007/978-3-540-75664-4_57.