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Exploiting high-resolution ADS-B data for flight operation reconstruction towards environmental impact assessment

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Abstract

The estimation of the detrimental impact of civil air traffic on the near-airport environment is conducted by means of dedicated assessment tools, usually based on best-practice methods. However, their application involves availability of information on the flight operations, and, although the use of flight tracking data is very helpful, their full inclusion into these tools is challenging. In this paper, following the authors' previous efforts and with the purpose of future implementation into assessment tools, highly time-resolved datasets from the OpenSky Network are used for the identification of daily flight operations. Then, the ground track reconstruction is carried out with a newly developed algorithm, which exploits the high time resolution to generate smooth trajectories using only segments and circular arcs while maintaining high accuracy, as shown in the results. This work lays the foundation for immediate future developments involving the reconstruction of aircraft performance and the estimation of airport noise levels.

Keywords: Civil air traffic; ADS-B data; flight operations; ground track; environmental impact.

Abbreviations: ADS-B: Automatic Dependent Surveillance - Broadcast, ECAC: European Civil Aviation Conference, OSN: (The) OpenSky Network, GT: Ground Track

1. Introduction

Assessing the environmental impact of civil air traffic is a complex task that is normally conducted by means of best-practice methods [1]. In this regard the standard European tool is EUROCONTROL's IMPACT platform [2], which enables environmental impact assessment near airports primarily by means of the ECAC Doc 29 method [1], but its accuracy is highly dependent on the available air traffic data. Nowadays for this purpose it is possible to make use of the rich information coming from flight tracking, but a key challenge remains in how to relate these data, not thought for environmental purposes, to the tool itself. This problem has been addressed by the present authors, who developed an airport noise modeling tool based on ADS-B datasets and a modified Doc 29 method [3, 4, 5], but limitations in the data quality led to restrictions in the devised modeling solutions.

In the present work, some of these restrictions are removed using highly time-resolved (one second) traffic datasets from the OpenSky Network (OSN) [6], Section 2 describes the easier identification of flight operations and the new ground track (GT) reconstruction algorithm, now fully compliant with the IMPACT/Doc 29 requirements. The validation of the proposed GT reconstruction method is conducted in Section 3, while the conclusions are drawn in Section 4.

2. Flight operation reconstruction methodology

2.1   Pre-processing: the identification of aircraft operations

OSN provides open access to historical air traffic datasets mainly based on ADS-B, which were re-trieved using the Python library *traffic* [7] and stored in single files hosting all daily data for a given airport. However, accurate identification required performing these pre-processing operations:

1. each separate flight at the selected airport was detected and assigned a unique identifier,
2. the operation type (arrival/departure) was extracted from the flight,
3. takeoff and landing runways were assigned to each departure and arrival, respectively.

A key feature of the OSN datasets is the good amount of on-ground data, which made the runway assignment trivial. The previous method [5] was used only for the few operations without such data.

2.2   The new ground track reconstruction algorithm

The authors' original ground track reconstruction algorithm [3] enabled drawing each operation's GT using only segments and circular arcs, but the smoothness condition (i.e. heading angle conti-nuity) was not met. This, however, is a requirement of the IMPACT/Doc 29 tool, and the availability of OSN data prompted a revision of the algorithm, whose main steps are listed below.

1. A low-pass filter is used for mitigating the data noise stemming from the highly time-resolved information. Latitude and longitude pairs are then converted to (x, y) Cartesian coordinates.
2. The N OSN points representing the flight operation are connected by vectors $\mathbf{v_i}$, $i = (1, \ldots, N-1)$ in sequence. Value and sign of the angles α_i between consecutive vectors are computed and a threshold angle $\alpha_{th} = 0.25°$ is used to distinguish the points belonging to straight segments from those inside turns. The i-th point is deemed to be part of a turn if the conditions below are met:

$$|\alpha_i| \geq \alpha_{th} \ \ \text{(a)}; \quad \alpha_{i-1} \cdot \alpha_i > 0 \ \ \text{(b)}. \tag{1}$$

   Finally, to increase the GT reconstruction accuracy turns longer than 90° are split into two or more sub-turns, each one having a maximum turn angle of 90°.
3. Tentative GT nodes (ends of a segment or a circular arc) are identified as the first and last point of each turn resulting from step 2, plus the first and last of the N OSN points.
4. The definitive GT nodes are identified by ensuring trajectory smoothness (heading angle conti-nuity), which is done by imposing three conditions:
   (a) tangency between circular turn and start-of-turn heading θ_S,
   (b) tangency between circular turn and end-of-turn heading θ_E,
   (c) circular turn passing through one of the nodes.
   The algorithm distinguishes two cases. In the first and most common one (Figure 1(a)) the turn lies between two segments, and the end node E is selected as the arc-belonging node. Point K is then found according to Equation 2 as the intersection between the extensions of the segments with headings θ_S and θ_E. This allows computing distance d_{EK}, which is used to identify the new start node S' along θ_S. Instead, the second case (Figure 1(b)) occurs when turn subdivision is necessary, but the only difference in the procedure is that S is fixed, while E is moved. The procedure is applied to all sub-turns after the first one, handled instead as in the first case.

$$\begin{cases} x_K = \dfrac{(y_E - y_S) \cdot \tan(\theta_S) \cdot \tan(\theta_E) + x_S \cdot \tan(\theta_E) - x_E \cdot \tan(\theta_S)}{\tan(\theta_E) - \tan(\theta_S)} \\ y_K = y_S + \dfrac{x_K - x_S}{\tan(\theta_S)} \end{cases} \tag{2}$$

5. All turns are drawn as circular arcs and their ends are joined with segments, completing the GT.

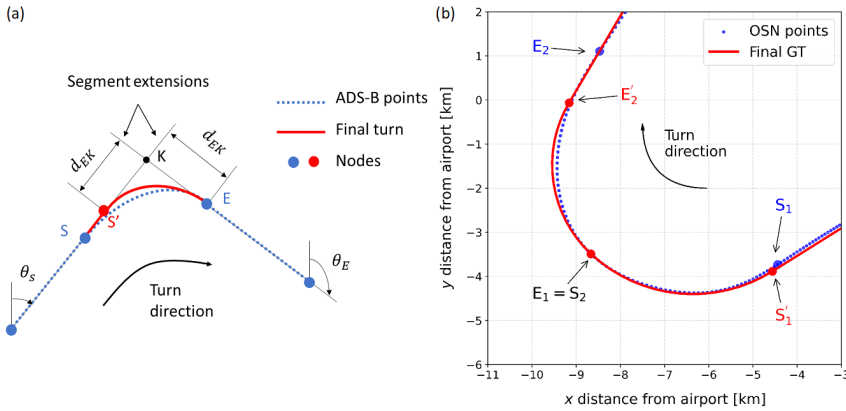The algorithm was applied to all flight operations identified as per Subsection 2.1.

Figure 1. GT reconstruction algorithm applied to a single turn (a) and to an OSN operation with two sub-turns (b).

3. Results

Effective validation of the GT reconstruction algorithm can be conducted by examining the projection errors between GTs and OSN positions, with each error defined as the distance between the unfiltered OSN point and the corresponding reconstructed GT. In the present work, this is done referring to the air traffic at Schiphol Airport on 15 March 2023, for which a total of 1077 operations (550 arrivals and 527 departures) were processed, with Figure 2(a) depicting the reconstructed GT map. The errors, computed for the OSN points of all operations, are instead illustrated in Figure 2(b) as a frequency distribution bar chart alongside its cumulative counterpart. This figure reports a median error of 17.2 m, a very good result considering the presence of data noise. Moreover, the median error of turns is only moderately higher than that of segments (22.8 m vs 15.8 m), indicating that circular arcs can be confidently used for modeling aircraft turns. The only limitation seems to lie in the higher mean errors, particularly for straight portions (98.5 m). However, these values are partially misleading, because their root cause is the geographic-Cartesian coordinate conversion, which is inherently flawed especially far away from the airport. This conversion leads to unrealistic large-radius turns that the algorithm cannot capture due to the use of a threshold angle $\alpha_{th} > 0°$.
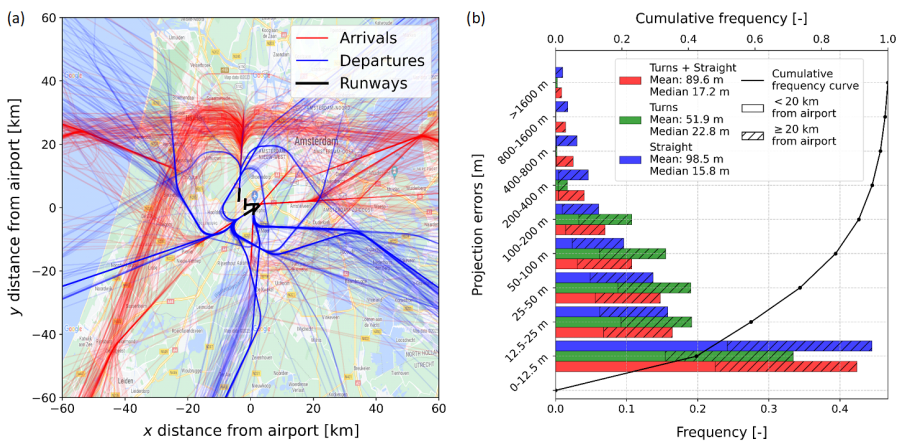

Figure 2. Schiphol Airport on 15 March 2023: ground track map (a) and ground track errors (b).

4. Conclusions

The methodology presented in this paper is an evolution of the authors' original solution for aircraft operation identification and ground track (GT) reconstruction. In particular, use of high-resolution OSN traffic data enabled i) much easier runway assignment and ii) development a new GT reconstruction algorithm that produces smooth GTs using only segments and circular arcs, as prescribed by the IMPACT/Doc 29 tool. The results obtained for air traffic at Schiphol Airport on 15 March 2023 are very good, with a median projection error of only 17.2 m. This constitutes a solid basis for future developments on the estimation of aircraft performance and near-airport detrimental emissions.

Author contributions

- M.P.: Conceptualization, formal analysis, investigation, methodology, software, writing.
- L.D.: Data curation, formal analysis, investigation, software, validation, visualization, writing.
- P.G.: Conceptualization, methodology, funding acquisition, resources, supervision.

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Reproducibility statement

All the methodological information is provided here or in the authors' previous papers [3, 4, 5].

Both data and source code are available at: https://doi.org/10.5281/zenodo.10074634.

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