ACCURACY REQUIREMENTS VALIDATION METHOD BASED ON GPS REFERENCED FLIGHTS

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ABSTRACT

Tracker homologation in airspace is a requirement for the generation of reliable traffic control information. In Brazil, the GEIV flight is one of the elements involved in the SAGITARIO control software homologation. The goal of this article is to present a method for homologation of accuracy requirements through calculation of error position (RMS) in the system tracker, using the GPS data from the GEIV aircraft flight in comparison to the synthesis of SAGITARIO tracker. Application of the method as tool allowed us to validate the RMS error requirements.

Keywords: homologation, control software, GPS data, RMS error, tracker.

1. INTRODUCTION

In the recent years, there has been an intensification in air traffic worldwide. Figure 1 shows the growth in the international scheduled passenger traffic in 2016. General predictions show that shortly the traditional traffic management manner will cause a saturation of airspace. This demands an evolution of air traffic control (ATC) systems.

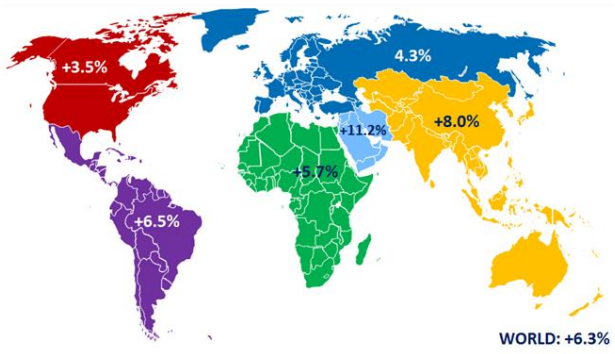


Figure 1: International scheduled passenger traffic growth in 2016 (by ICAO, 2017)

Bearing in mind the ATC system evolution, greater aircraft autonomy may help to solve the problems caused by the increased demand. A way of managing air traffic growth and thus improving safety is the automatic transmission of location and intent from commercial aircrafts. The boarded GPS equipment pinpoints location and the Automatic Transmission and Auxiliary Vigilance System (ADS-B) transmits this data (Strohmeier, Schafer, Lenders, & Martinovic, 2014).

Traditional radar equipment has relatively low precision and accuracy in its detections (Strohmeier, Schafer, Lenders, & Martinovic, 2014). Hence, a way to valid whether current radar equipment is sufficiently accurate is by comparison to the data from a more precise equipment: the aircraft's GPS.

Air traffic control can be divided in three distinct moments: Control Tower (TWR), Approach Control (APP) and Area Control Center (ACC). The TWR is responsible for controlling the airport traffic, including landings, takeoffs and aircraft taxi. The APP is responsible for controlling the approach area surrounding airports, including the separation of aircrafts that come in and out of airports towards the corresponding airways. The ACC is responsible for the traffic route in between APPs (Carlijn, 2016).

This division matters since the response time for any needed action differs, which also affects the requirements that must be observed.

2. GREAT-CIRCLE DISTANCES

The Earth globe is a geoid and hence it is necessary to consider its curvature when calculating the distance between two points with accuracy. This calculation is called great-circle distance. For this paper, we consider two spherical distance calculation methods: haversine and Vincenty.

The haversine is a geometric measure that dates back to ancient Greece, and sailors have widely used it in open seas throughout time (Sinnott, 1984). Distance calculation with the haversine method is more accurate for small angles, which is the case when calculating the distance between two approximated points in Earth.

Vincenty's calculation for geodesic solutions is more complex than haversine and gives solutions to distances with good accuracy, varying from some centimeters up to 20 000 km (Vincenty, 1975).

The horizontal RMS error is the square root of the quadratic measure between the position differences (along and across) between two different measurement systems regarding an aircraft.

The support tool that we propose on this paper can calculate RMS error in horizontal position using either methods. Through empirical tests, however, we could not notice any substantial difference between both methods.

3. METODOLOGY

The European Organization for the Safety of Air Navigation (Eurocontrol) is an international organization working to achieve safe and seamless air traffic management across Europe (EUROCONTROL, 2018). The United States's Federal Aviation Administration (FAA) is a national authority with powers to regulate all aspects of civil aviation (FAA, 2018). Both

organizations issue policies for controlling airspace with local and global application.

Two documents are used as basis for evaluating performance requirements of surveillance systems, taking into account only equipment and disregarding human and operational elements. In summary, the evaluated scenarios are: 3NM horizontal separation combined with 1000 feet vertical separation for APP and 5 NM horizontal separation combined with 1000 or 2000 feet vertical separation for APP or ACC. Particularly regarding RMS, the document for the european territory (EUROCONTROL, 2015) establishes as a mandatory requirement an average error equal or less than 500 m global and less than 550 m for 100% of flights in the 5 NM separation scenario, as well as average error equal or less than 300 m global and less than 330 for 100% of flights in the 3 NM separation scenario. The document for the american territory (S.D. Thompson, 2006) is less restrictive: 0,20 NM (aprox. 370 m) for 3 NM and 1 NM for a 5 NM separation (aprox. 1800 m). This document suggests using data comparison of GPS data to trackers' data for error evaluation.

The Flight Inspection Group (GEIV) is a unit from the Airspace Control Department (DECEA), which is the organ responsible for controlling the brazilian airspace (DECEA, 2018). The GEIV periodically conducts flight tests to evaluate the tracking accuracy in the Advanced System of Air Traffic Information and Operational Interest Report (SAGITARIO in portuguese), which is the brazilian air trafic system, in comparison to GPS data provided by the aircraft. According to DECEA (2014), a GEIV flight requires an appropriate aircraft, with eletronic equipaments properly calibrated to secure accuracy in the GPS data measurement.

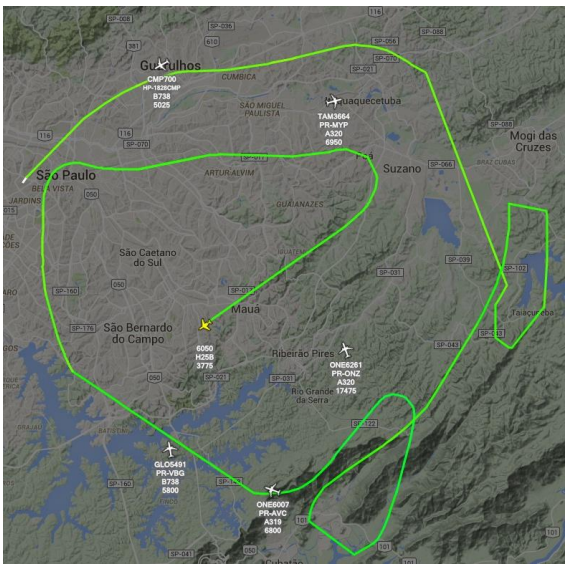


Figure 2: Example from GEIV test flight trajectory in Garulhos – SP – Brazil (by Nagg, 2016)

The algorithm developed in the present work can be applied for a GEIV flight and for any other flight that has GPS and ADS-B[1] transmission. As such, the GPS data is used as reference and the tracker data must be as close as possible in order to secure optimal accuracy. The farther apart both data results fall, the least accurate the tracking is considered to be.

The algorithm's first step is to define a GPS reference point with good accuracy regarding positions in the system track. In Figure 3, this position is manually identified by a comparison between the GPS data trajectory (represented by the line) and the positions in the system track (represented as the circles). Each of these positions in the track contain latitude and longitude information to be compared with the GPS latitude and longitude data.

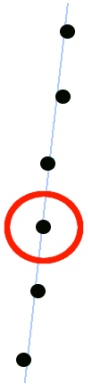


Figure 3: Reference point definition

[1] FlightAware (https://flightaware.com/) publicly distributes ADS-B aircraft data from all over the world.

[INFO] Function: Sync between system Track and GEIV

[INFO] Add track id 1

[INFO] GEIV sync lat=-16.087600

[INFO] GEIV sync lon=-47.953000

[INFO] GEIV sync rad=1000.000000m

GEIV Point: coordinate lat=-16.087600 lon=-47.953000; timestamp=62765.000000s; distance=**0.000000m** from reference point

System Track Point: coordinate lat=-16.089333 lon=-47.950623; timestamp=51778.148438s; distance=**318.488703m** from reference point

System Track Point: coordinate lat=-16.080723 lon=-47.948354; timestamp=51782.148438s; distance=**908.986064m** from reference point

Listing 1: Reference point definition

Afterwards, the tool calculates the distance between the GPS position and the system track positions in a given radius. It also shows the *timestamp* for each position of the system tracks. Next, we manually calculate a time correction factor (*offset*) to adjust position. This calculation takes into account that the GPS data corresponds to the system position data and this correction assists in adjusting the full trajectory. The algorithm's ideal point is the one with the smallest difference between the chosen GPS position and the system track position – the ideal difference is 0.

Listing 1 shows the tool's output for an example showing a track with ID. 1 and a GPS point identified in latitude -16.0876 and longitude -47.953. The closest point to the reference is 173.398655 m away. The time *offset* can be calculated by subtracting the GEIV *timestamp* from the radar detection *timestamp*, i.e. 62765-51778,148438 = 11714,883s.

The next step is to do a point-to-point comparison and to calculate the RMS error between the GPS positions and the system track positions. The algorithm considers all track system positions and, as usually the amount of track data is greater than the amount of GPS data, the algorithm makes data extrapolation and calculates error in the intermediate positions between the GPS values. With these values, it is possible to plot the "error x time" graphs and to estimate the mean error value.

The tool allows selecting the most appropriate algorithm to calculate the great-circle distance calculation, i.e., haversine or Vincenty method.

4. CASE STUDY

We used a flight from São Paulo to São Luís as case study. The GPS trajectory is shown in blue in Figure 4.

A simulation tool generates the system track data. A clipping was made in the corresponding data by regions and two approximations were made for the trajectory: in the first case study (CS1), the trajectory was divided in two straight sections with average speed calculated by each part; in the second case study (CS2), the trajectory was divided in three straight section with two average speed. The clipping is shown in the red circle in Figure 4. The RMS error was calculated with the tool, by using as reference the simulated track data.



Figure 4: SP-SL flight used as case study

The division in two sections for CS1 data is shown in Figure 5, in which the blue line represents GPS data and the red line represents the data from the simulated track. We based CS1 on a point located in the second part as basis.



Figure 5: Section division for CS1

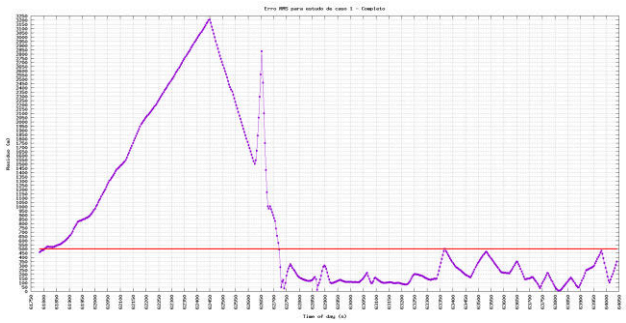


Figure 6: RMS error x Time (CS1 - Full)

Table 1: Estimated RMS error (CS1 - Full)

Parameter	*Value*	*Ref.*
Across track position error (RMS)	1206,06 m	N/D
Along track position error (RMS)	383,96 m	N/D
Combined position error (RMS)	1265,64 m	< 550 m

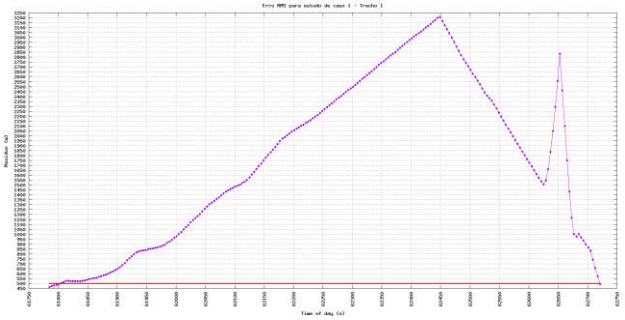


Figure 7: RMS Error x Time (CS1 – Section 1)

Table 2: Estimated RMS error (CS1 – Section 1)

Parameter	*Value*	*Ref.*
Across track position error (RMS)	1867,31 m	N/D
Along track position error (RMS)	544,37 m	N/D
Combined position error (RMS)	1944,94 m	< 550 m

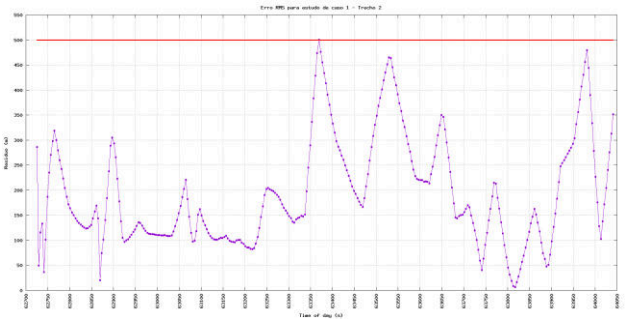


Figure 8: RMS Error x Time (CS1 – Section 2)

Table 3: Estimated RMS error (CS1 – Section 2)

Parameter	*Value*	*Ref.*
Across track position error (RMS)	85,91 m	N/D
Along track position error (RMS)	203,41 m	N/D
Combined position error (RMS)	220,80 m	< 550 m

We calculate the RMS position error by point-to-point comparison of each GPS and system track positions though time. For calculating the great-cricle distance, we used Vincenty's method. The red horizontal line marks the reference average value (threshold 550 m for ACC).

Our results show that the values calculated by the tool are slightly higher than the reference values on the full CS1 flight (Table 1) and on the section 1 (Table 2), which means, in theory, that the simulated track is not accurate. The Figure 6 shows two distinct moments: one above the threshold and one below it. The RMS error of section 1 is shown in detail in Figure 7 and the error of the section 2 is shown in detail in Figure 8. The calculated value for the section 2 (Table 3) is lower than the reference value; this means that only section 2 value would be sufficient for this flight.

By observing closely the section 1 (Figure 9), we see that it is not exactly a straight line, but it has a small deviation. This could significantly influence the across error value, which is why we have divided the trajectory in three sections for CS2 (as shown on Figure 10).

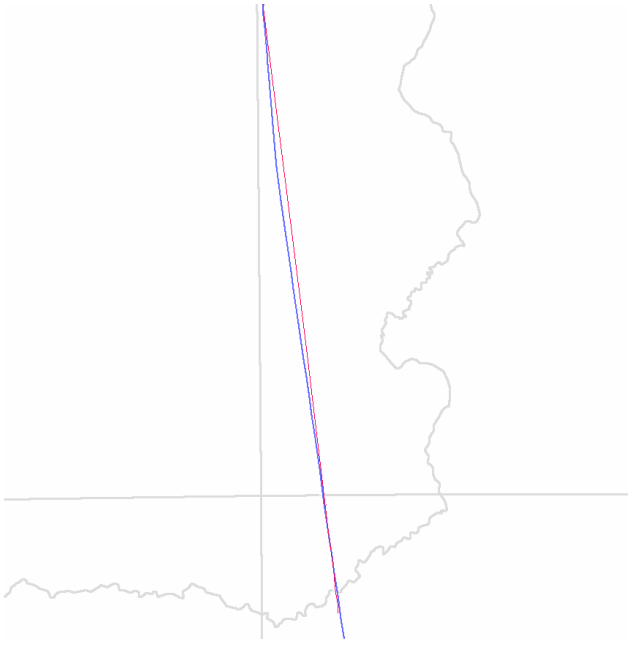


Figure 9: Section 1 (CS1)



Figure 10: Section division for CS2

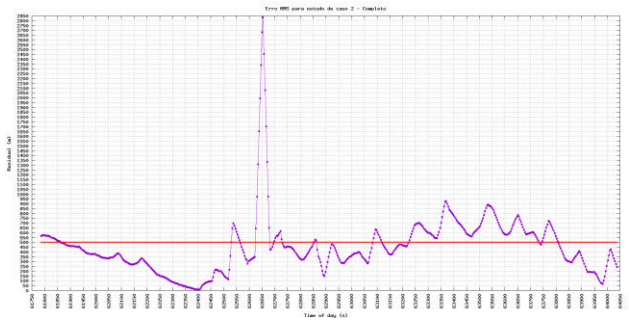


Figure 11: RMS error x Time (CS2 - Full)

Table 4: Estimate RMS error (CS2 - Full)

Parameter	*Value*	*Ref.*
Across track position error (RMS)	203,98 m	N/D
Along track position error (RMS)	504,42 m	N/D
Combined position error (RMS)	544,09 m	< 550 m

As we can see in Table 4, the values calculated by the tools are lower than the reference values for the full CS2 flight, which shows us that dividing the flight into three parts, thus bringing the simulated system track closer to the GPS data (actual values) was enough to comply with the requirement.

5. CONCLUSION

Air traffic systems evolution demands reliable aircraft tracking and an update in available equipment. One way to validate tracking accuracy is by comparing its data with GPS flight data.

We proposed a method for validating accuracy requirements through the RMS error calculation between the system track and GPS data. The calculation can be made by using one of these great-circle distance calculation methods: the haversine or the Vincenty.

We conducted a case study based on GPS data from a flight from São Paulo to São Luís and on simulated track data.

This study pointed the differences between a case in which the RMS accuracy error requirements are met and another one in which they are not met.

6. REFERENCES

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