Physical Approach to the Application of Numerical Methods in Analysing Race Car Dynamics and Performance on a Racetrack Using GPS Data

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OUTLINE

The dynamics of racing cars and their modifications play an important role in motorsport performance. The ability to analyse and optimise the behaviour of the vehicle and driver on the race track is crucial for improving lap times and overall efficiency. In this project, numerical methods are used to analyse and improve the dynamics of the race car and the driver's performance using GPS data collected with the Race Chrono app. The main objectives were to gain insights into cornering behaviour, acceleration and braking. The main objective of this research was to develop a systematic approach to process real-world data collected after a racing event to extract critical parameters that affect vehicle performance. By integrating computational tools with experimental measurements, the study aimed to provide actionable insights to improve performance.

Figure 1: Vauxhall corsa VXR on a racetrack (Photo: R. Jošt).

In this investigation, we imported GPS data from the application (Figure 3), which contained key information such as latitude, longitude, altitude, vehicle speed and timestamp. This data provided an important starting point for our analysis as it contained real measurements that could be processed using numerical methods. Using this data, we were able to examine the driver's behaviour and identify areas where performance could be improved. Optimization strategies investigated in the study included braking earlier, refining the racing line and evaluating the impact of improved vehicle acceleration. These optimizations are crucial to improving vehicle and driver performance, ultimately leading to better lap times and more efficient use of the track.

Race cars (**Figure 1**) are modified vehicles specially designed to operate under extreme conditions on the race track, e.g. high temperatures, G-forces and abnormal material consumption. A high performance racing car is complemented by an experienced racing driver. Professional drivers seek to maximize performance by utilizing both the vehicle's capabilities and strategic driving techniques. Analytical studies such as this provide valuable insight into areas where lap times can be improved to increase the overall synergy between the vehicle and the driver.

Figure 2: Experimental setup in a Porsche GT3RS with Race Chrono lap time (Photo: https://racechrono.com/#about).

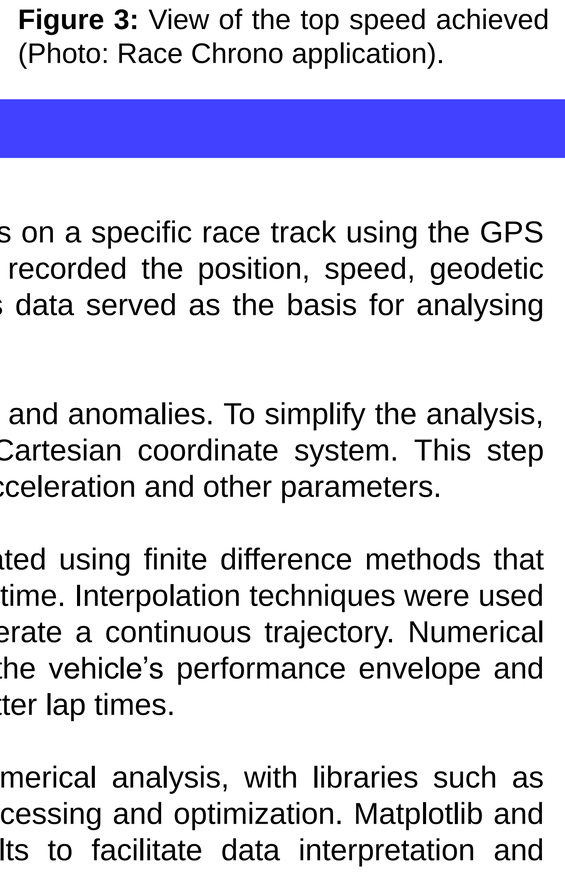

Figure 3: View of the top speed achieved (Photo: Race Chrono application).

EXPERIMENTAL METHODS

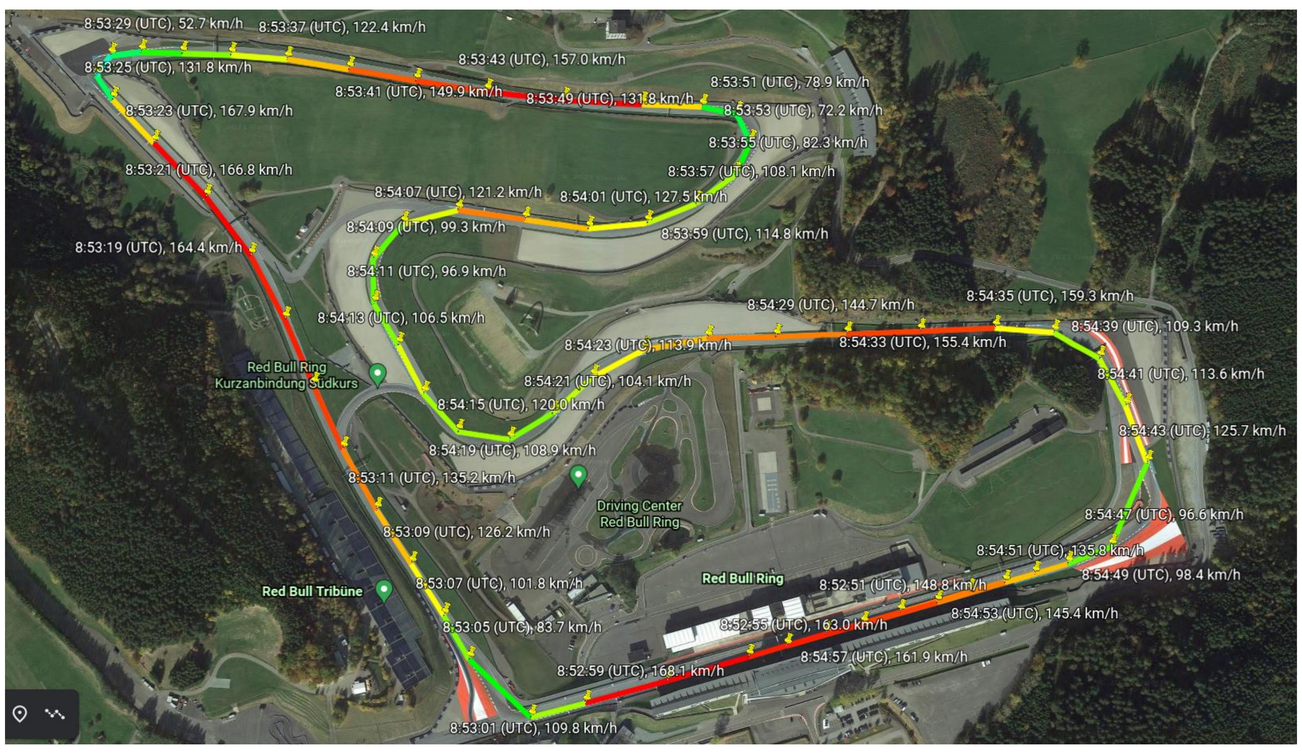

Figure 4: View of the merged data with timestamps and speed information (Photo: V. Nemec).

Data collection:
The GPS data was recorded during several laps on a specific race track using the GPS module built into the smartphone. The phone recorded the position, speed, geodetic coordinates and timestamp of the vehicle. This data served as the basis for analysing the vehicle's performance and trajectory.

Preprocessing of the data:
The raw GPS data was filtered to remove noise and anomalies. To simplify the analysis, the GPS coordinates were converted into a Cartesian coordinate system. This step enabled a more efficient calculation of speed, acceleration and other parameters.

Numerical methods:
The speed and distance travelled were calculated using finite difference methods that approximate the rate of change of position over time. Interpolation techniques were used to reconstruct the optimal racing line and generate a continuous trajectory. Numerical optimization algorithms were used to analyse the vehicle's performance envelope and optimise speed, acceleration and braking for better lap times.

Software tools:
Python was used for data processing and numerical analysis, with libraries such as NumPy, Pandas and SciPy supporting data processing and optimization. Matplotlib and Seaborn were used for visualisation of results to facilitate data interpretation and decision making.

RESULTS

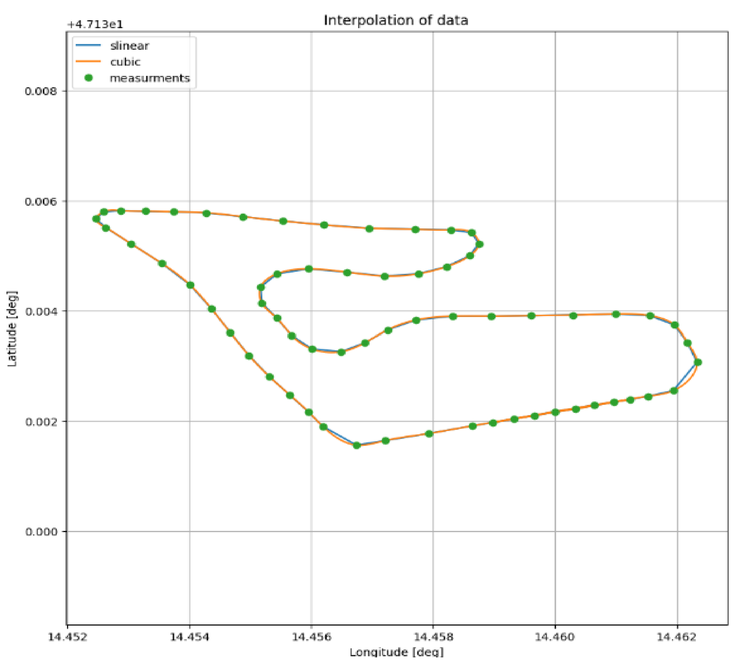

Figure 5: Interpolation of GPS coordinates.

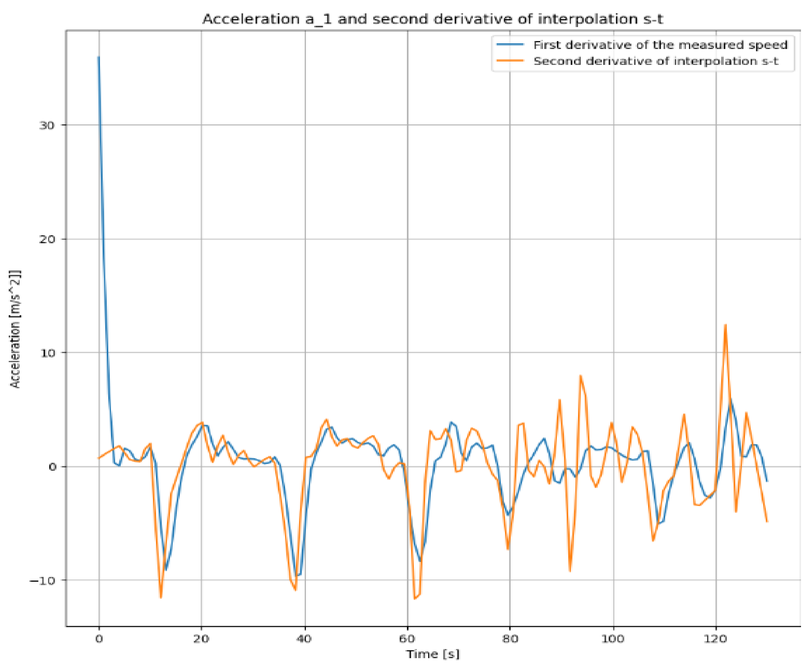

Figure 6: Derivation of measured speed and measured travelled data.

Figure 6 illustrates the comparison between the acceleration obtained by differentiating the measured speed and the acceleration calculated by differentiating twice the distance travelled. It is important to note that the time stamps for both data sets must match to allow an accurate comparison. The measured speed was determined using the phone's GPS data and the Race Chrono app, while the acceleration derived from the distance travelled was calculated by double differencing using the time and distance data from the car's movement. When comparing the two accelerations, we found that they were broadly similar, although there were some noticeable anomalies. The anomaly at 100 seconds could be attributed to the nature of the differentiation process, which can amplify errors. In addition, the GPS signal may have been weak or disturbed by nearby objects, which could have contributed to these deviations. The significant drop at the beginning of the first derivative of the measured speed is due to the fact that we were at the end of a long straight line before we started the measurement.

In this part of the task (**Figure 5**), the shape of the racetrack is interpolated using a parametric approach. Unlike conventional *2D* curves, which are represented by polynomials, parametric curves allow multiple values of y to correspond to a single value of ***x***. Therefore, to accurately model the shape of the racetrack, a parametric function defined by the new relation (***x***, ***y***) = *f*(**d**) is introduced, where d is the cumulative distance between consecutive points along the curve. This allows the interpolation to be performed relative to the distance ***d***, providing greater flexibility in accounting for the nonlinear characteristics of the shape of the track.

CONCLUSION

This study successfully demonstrates the application of numerical methods in analysing the dynamics of racing cars using GPS data. By importing data from the Race Chrono app, which contains detailed information about speed, time and position, we were able to accurately reconstruct the tracks and analyse the movement of the car on the track. This allowed us to identify the key acceleration and braking points that are crucial for optimising the car's performance. Through the driver's feedback, we realised that our ideal line was quite optimal and therefore did not need to be improved. We uncovered specific performance limitations, particularly in cornering and braking, which highlighted areas where the car's dynamics could be refined for better lap times. The methodology developed in this research not only provides actionable insights to optimise vehicle and driver performance, but also provides a solid framework for future studies in the field of motorsport engineering. This work contributes to the growing field of motorsport analytics and provides practical tools to improve competitive performance and achieve faster lap times.

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