

The influence of road grade and GPS signal reconstruction on real driving behaviour and emissions

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Abstract— In recent years in Italy the progress of the automobile industry, in the field of reduction of emissions values, is very remarkable. Nevertheless their evaluation and reduction is a key problem, especially in the cities, that account for more than 50% of world population. The aim of this study is to investigate the parameters influencing the real driving emission monitoring with particular attention towards the influence of road gradient. Several experimental campaigns are carried out with some cars instrumented for both the acquisition of kinematic data, polluting emissions in continuous, and GPS latitude, longitude and altitude data to obtain precise geolocalization and slope variation during a path. Moreover this paper deals with the definition of a quantitatively approach for the reconstruction of GPS coordinates and altitude, in the context of correlation study between driving cycles / emission / geographical location. Also cluster analysis of kinematic data is realized, keeping in mind new corrected GPS data, and a basic statistical analysis of exhaust emissions of CO, THC, NOx, CO2 acquired on road..

Keywords— Driving cycle, Emissions, GPS Signal reconstruction, Slope variation.

I. INTRODUCTION

VEHICLE pollutant emissions and fuel consumption evaluation remain until now a major challenge for Italy. Positive results were obtained but in the case of Italy, some actors contributing negatively to this situation are present. So different aspects related to evaluation of vehicles pollutant emissions is still the subject of research studies. The dependence of emission not only from the average speed but also by many other parameters characterizing the kinematics of the vehicle is fully established [1], [2].

Furthermore, interaction with path road not only in terms of traffic experienced by the vehicle, but also in terms of orographic characteristics of the path has an overt acclaimed effect on the emission and consumption.

Various studies have been conducted to evaluate the effect of the traffic in terms of time of day and day of the week, to characterize the driving behavior.

The equally important feature that could be not neglect concerns the correlation between kinematic sequences / emissions / topography of the route runs from the vehicle in

real use [3], [4], [5]. In fact kinematic sequences and their features represent driving behavior in its totally, so it could be important defining in the best way every factor. In particular, it could be interesting to suggest paths based not only on the minimum distance, but also on the minimization of fuel consumption as a function of the geomorphologic features of the territory. In our integrated approach, kinematic, emissions and geomorphologic data are statistically analyzed, aiming to locate precisely where a specific situation may occur more frequently. For this purpose, the activities will be aimed at integrating automatically, the commercial digital maps with geomorphological data relating to the real three-dimensional pattern of the road network. But to do in a correct manner this activity, data must be pre-treated and corrected by any form of error that can be amplified in subsequent statistical analysis.

The aim of this paper is to give a primarily answer to the problem of signal reconstruction of GPS signal especially for altimetry [6], [7], to better analyze and to outline the behavior of low environmental impact vehicles in city traffic situations and in a precise location [8], [9]. Also it could be desirable to perform a quantitative analysis of altimetry to evaluate the slope variability during a path, so this variable can contribute to correlate kinematic behavior with emissions [10].

II. GLOBAL APPROACH FOR GPS DATA

In this paper, experimental data coming from four repetitions of a specific path, with different gradient situations, are analyzed. The experimental path, with a length of about 8 km, is shown in Fig. 1. It is chosen taking into account a roads with numerous elevation changes. In particular the identified experimental path is well balanced in terms of slope with an average uphill of 6.9%, while downhill has an average gradient of 6.5%. In the fig. 1 the range of the elevation profile is about between 50m and 190m.

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variables discriminate between clusters (groups) of multivariate observations.

Variable	Description
mv (km/h)	Mean of running speed($v>0$)
mv2(km ² /h ²)	Mean of square speed ($v>0$)
mv3(km ³ /h ³)	Mean of cube speed ($v>0$)
Tral (s)	idling time $v=0$ in second
Trunning (s)	total running time ($v>0$) in second
Dist (m)	distance covered
DS1 (%)	%time with delta slope <-0.70 meters (m)
DS2 (%)	%time $-0.70 \leq \text{delta slope} <-0.20$ meters (m)
DS3 (%)	%time $-0.20 \leq \text{delta slope} <0$ meters (m)
DS4 (%)	%time $0 \leq \text{delta slope} <0.20$ meters (m)
DS5 (%)	%time speed >60
DS6 (%)	%time with delta slope ≥ 0.70 meters (m)
Time(s)	Total duration of the sequence (s)
m_vapos (m ² /s ³)	Mean of instantaneous values of product ($a(t) \bullet v(t)$) when $v(t)>0$ and $a(t)>0$

Table I Acronyms of variables characterizing kinematic sequence.

Some optimal combinations (functions) of variables are automatically determined so that the first function provides the overall discrimination between groups; the second provides the second most, and so on. Functions are denoted as canonical variables (called in the paper CAN1, CAN2,...). Each canonical variable is characterized by the percent amount of explained variance respect to the total variance. Plots of the first two canonical variables, generally explaining a consistent percent of variance, give a good two-dimensional representation of observations. Results are illustrated by cluster representation in the Can 1 sequence, Can 2 sequence scatter plot (Fig. 11) [18].

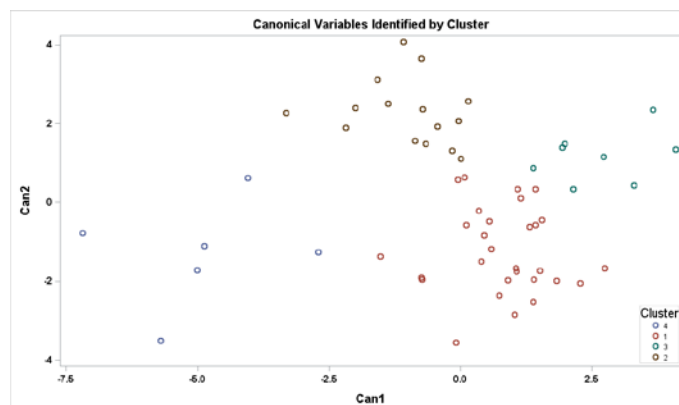


Fig. 11. Cluster representation of sequences.

The following Table II presents the results of Cluster Analysis. The four road tests are subdivided in 58 sequences, which are grouped in four clusters. For each cluster the table presents mean values of variables most representative, so it is possible to point out fundamental differences in the kinematic features.

CLUSTER	1	2	3	4
N	29	15	8	6
Tral (s)	10.93	3.73	7.38	41.33
Dist (m)	101.59	679.09	813.81	463.64
mv (km/h)	10.52	20.71	20.79	15.91
mv2 (km ² /h ²)	168.18	490.77	498.23	339.40
mv3 (km ³ /h ³)	3396.59	12650.96	12956.17	8050.23
m_vapos (m ² /s ³)	0.80	0.59	0.56	0.47
Time(s)	37.31	123.67	154.25	127.50
DS1 (%)	0.49	9.71	0.53	76.90
DS2(%)	6.19	37.70	6.24	5.31
DS3(%)	14.90	26.53	5.64	2.73
DS4(%)	57.46	17.52	25.29	12.02
DS5(%)	20.21	8.39	51.36	3.05
DS6(%)	0.14	0.27	15.25	0.00

Table II. Cluster mean values of sequences kinematic variables.

Cluster mean values of some original variables (mean velocity, sequence duration, idling time and distance covered) are reported. Cluster 1 represent sequences along the road path with a short distance realized and with 57% of the time in flat road part. Clusters 2 and 3 have about the same mean speed. They are essentially different because the cluster 2 is mostly downhill (only 20% uphill) while Cluster 3 has about 70% uphill. Cluster 4 are formed essentially by downhill sequences (15% uphill).

In fig. 12 an overlay of representative sequences profile of each cluster is shown. The kinematic characteristics are consistent with the values of the Table II.

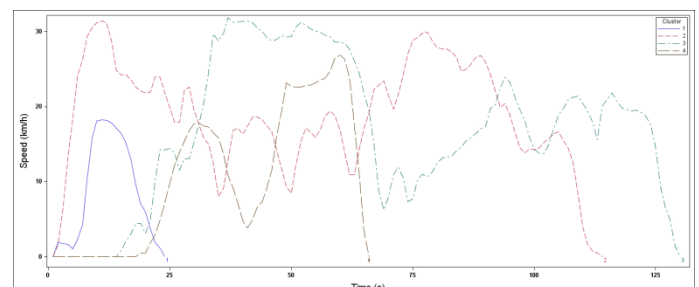


Fig. 12. Speed profile overlay of representative sequence for each cluster.

Correlation analysis between a kinematic sequences and the corresponding emission sequence is performed in the same traffic situation (determined by cluster) and same GPS location. A trend analysis is performed via the visualization of instantaneous emission profiles and kinematic sequences for each cluster. Figures 13 and 14 report a GPS profile, while figures 15 and 16 report the elevation profile of the GPS instrument and those calculated through the numerical model (Dev). In particular, the road path characteristics are well related to cluster characteristics reported in previous table, which are an expression of uphill road, flat road and downhill road.

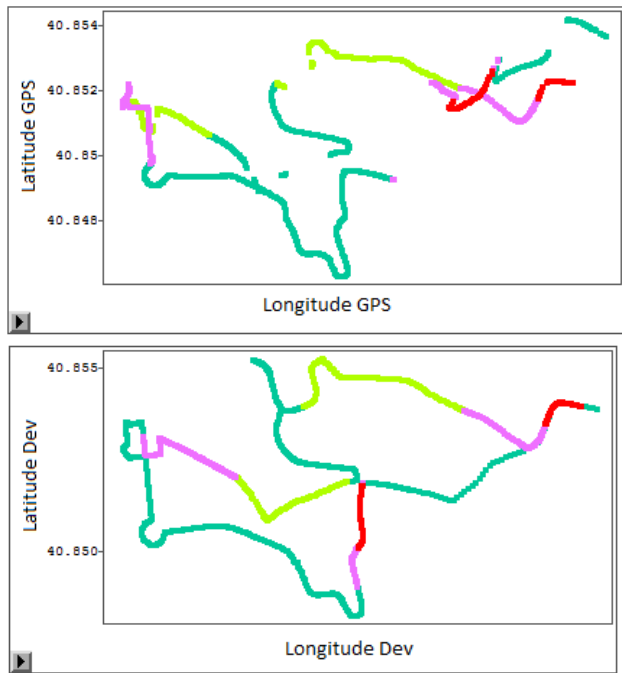


Fig. 13. GPS profile of day trip 12/06 coloured according to cluster.

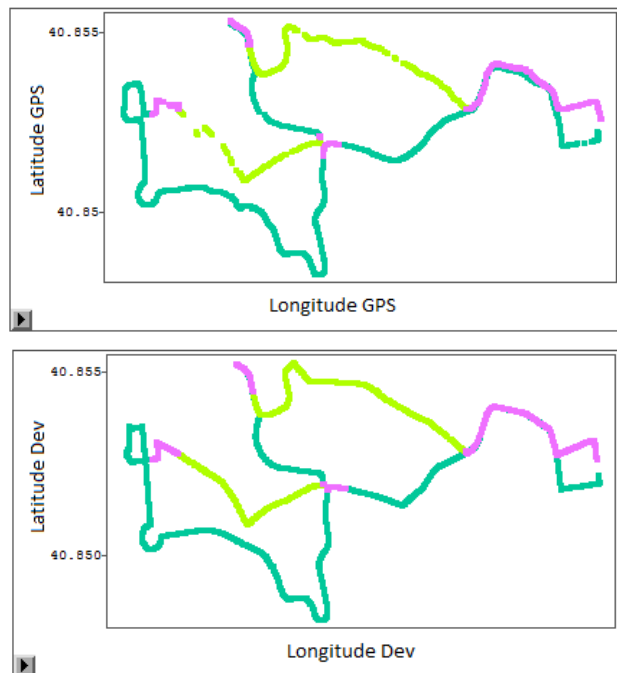


Fig. 14. GPS profile of day trip 29/06 coloured according to cluster.

With particular regard to figures 8 and 9, it is possible to note how the cluster distribution is well identified in both the uphill and the downhill faces. Moreover, comparing the figures 8a vs. 8b, and 9a vs. 9b, it is possible to note as the reconstruction process has properly filled the missing parts. Furthermore in the reconstruction phases we must consider that the recorded distance is different from the real one, due to the error of the recorded velocity signal especially in the speed range close to zero. In the data processing, we have to keep in mind that gap.

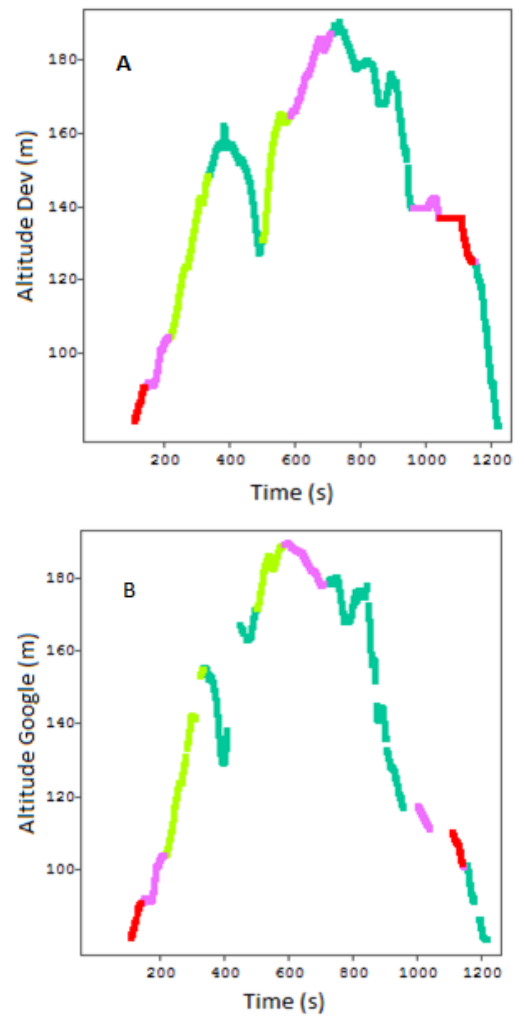


Fig. 15. Elevation profile of day trip 12/06 coloured according to cluster.

IV. EMISSION RESULTS AND DISCUSSION

The time series of each regulated emission acquired during each trip is split into sequences. CO₂ and fuel consumption (FC) are expressed in g/s, CO and NO in mg/s. Correlation analysis between a kinematic sequences and the corresponding emission sequence is performed in the same traffic situation (determined by cluster) and same GPS location. A trend analysis is performed via the visualization of emission instantaneous profile and kinematic sequences for each cluster.

Fig. 17 reports a GPS (a) and elevation profile (b) of a trip with color related to the identify cluster, that identifies uphill road, flat road and downhill road. In particular, the road path characteristics are well related to cluster characteristics reported in previous table.

Furthermore in Fig. 18 pollutant emissions (a, b, c) and FC (d) profiles relative to the same trip are shown. Time series of CO₂, NO, CO, and FC are colored according to cluster sequences road characteristics. We have to consider that this result is not a qualitative one but it is obtained by statistical cluster analysis of succession of sequences. Here it is possible to note that at similar kinematic conditions (i.e. mean speed) in all sections of road we have different emission profile. This confirms the importance of the variable slope in emission evaluation in real use analysis, such as in the case analyzed in which the identified experimental path is well-balanced in terms of slope, with an average uphill of 6.9%, and downhill with an average gradient of 6.5%.

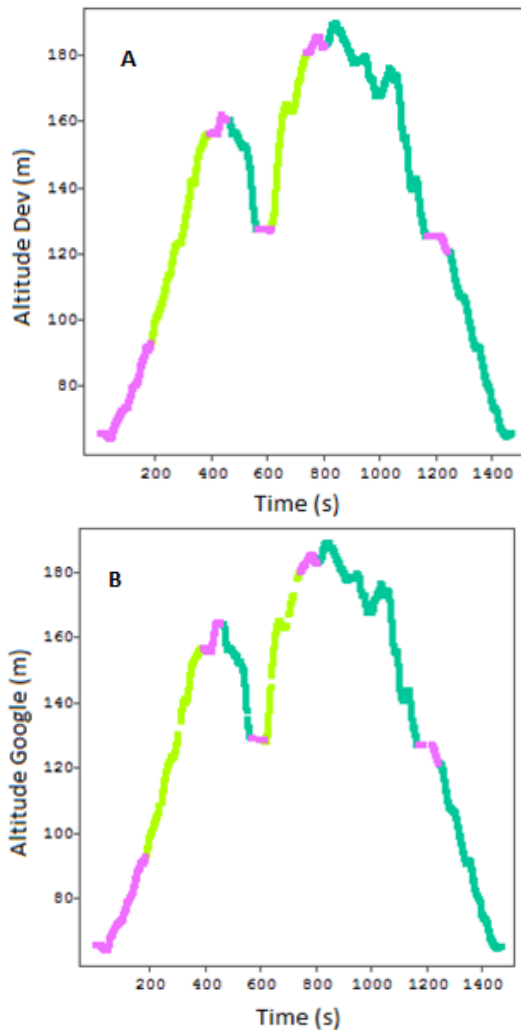


Fig. 16. Elevation profile of day trip 29/06 coloured according to cluster.

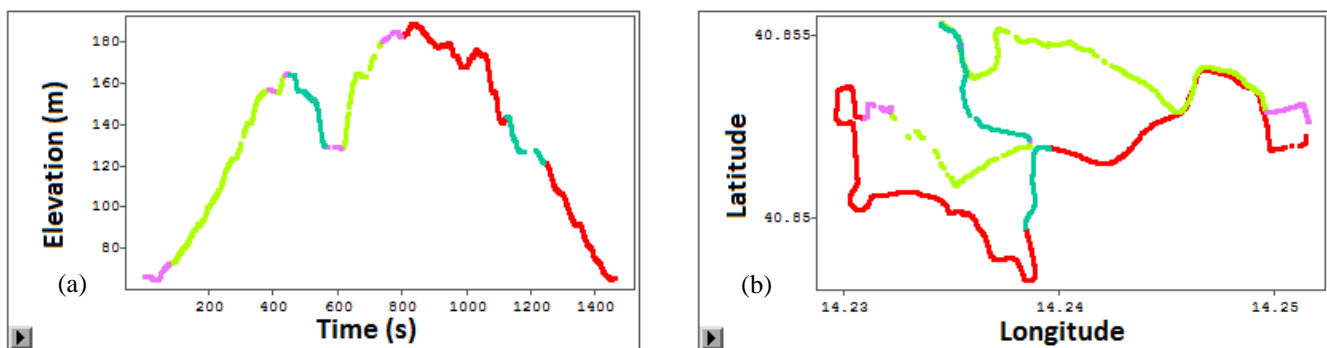


Fig. 17 (a) GPS profile of a trip colored according to cluster; (b) Elevation profile of the same trip

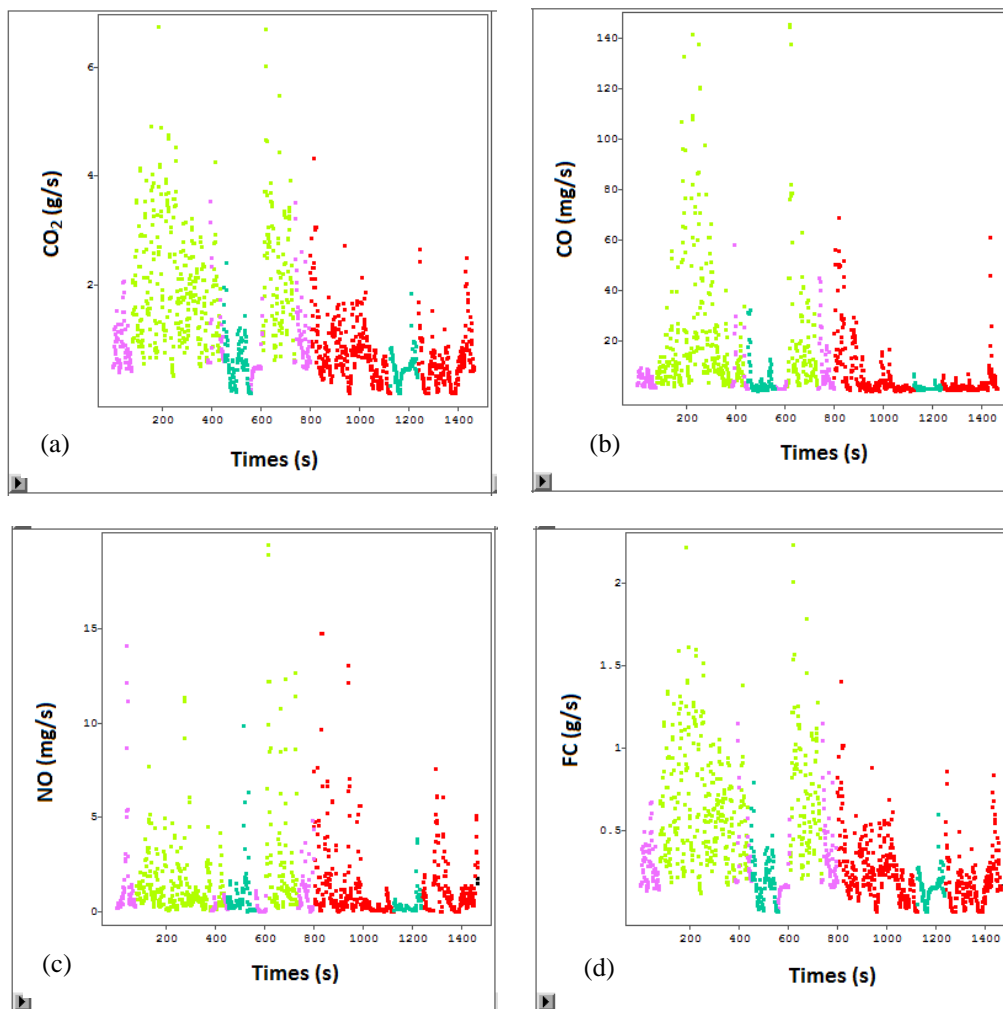


Fig. 18 (a), (b), (c) Emissions and (d) fuel consumption profile of a trip colored according to cluster.

In Table III, to better underline and quantify difference due to cluster of sequences and their characteristics, mean velocity (mv), mean of each emission and FC (fuel consumption) are summarized for each cluster. In addition, the maximum emission values are recognized in cluster 3, probably due to kinematics sequences high percentage of uphill phase. Although it shows the same mean velocity, a strong reduction effect for each emission could be evidenced in cluster 4, formed essentially by downhill sequences. Emission reduction are stronger for NO emission, but also clearly stated for CO₂.

Cluster	mv (km/h)	CO ₂ (g/s)	CO (mg/s)	NO (mg/s)	FC (g/s)
1	10.52	1.2344	5.3239	0.9886	0.4004
2	20.71	0.8312	4.5342	1.0751	0.2701
3	20.79	2.1820	11.0590	1.5558	0.7085
4	15.91	1.7839	6.5573	0.8382	0.5780

Table III. Cluster mean values of speed, emissions and fuels consumption.

Regarding cluster 2 emission mean values are the lowest, especially for CO₂ and FC, due to sequences with high average speed especially in downhill part. The same consideration could be made for fuel consumption.

Cluster 1 represents sequences along the road path mostly in uphill with a short distance and it shows medium values for each emission and for fuel consumption.

V. CONCLUSION

An experimental campaign is carried out in the city of Naples, in two areas different for the topography of the streets, but that present very similar vehicular traffic, typical of busy streets. The aim of this activity is to compare fuel consumption and emissions on road during real world experimental tests, in order to identify some characteristics of road that strongly influence emission production. Moreover, this paper seeks to give a contribution to on-board measurements, in different geographical areas, with PEMS using a statistical methodology. A procedure to implement the reconstruction of the GPS signal during a real experimental campaign is completely formalized. A more precise GPS signal and altimetry value help to better perform a quantitative analysis of driving behaviour. These signals, in particular altimetry value, may be statistically evaluate to produce variables that describe the variation of the slope and the distance travelled during a trip with greater precision.

Experimental data are subdivided in sequences, which are grouped in cluster, so it is possible to point out fundamental differences in the kinematic features. Particularly attention is given to the construction of appropriate variables to characterize the slope variation along the road path after the reconstruction of the GPS signal. These variables are among the most significant in kinematic sequences classification above all on a journey in path with many uphill and downhill phases. In fact the introduction of these variables in discriminant and cluster analysis of sequences produce different group with different kinematic characteristics.

The approach followed in this paper allowed us to evaluate the emissions trend with two cars gasoline fuelled on a particular path road characterized by uphill and downhill gradient variability. Results show an influence of this street feature on emissions and fuel consumption.

In the future, we will aim to conduct a comparative emissions analysis on mean emission values with and without these slope variables.

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