

# Geospatial Characterization of Archaeological Sites in La Serena Region (Badajoz) by Direct Methods (DGPS): Capturing and Analyzing Data

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*In this paper we assess the capacity of survey-grade GPS equipments to provide high resolution DEMs for archaeological analysis. Strengths and weaknesses of these methods are pointed out, and the importance of careful planning of capture and further analysis of information is stressed. Several archaeological sites from La Serena Region (Badajoz, Spain) are taken as case studies. We show the workflow from the acquisition of data in the field to the validation of surface models with different interpolation methods. A key point is that the choice of one of the available options in GIS packages must be based on a rigorous estimation of error rather than on the search of a realistic or aesthetic appearance.*

*Keywords:* High precision survey, DGPS, Digital Elevation Models, Micro-topography.

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## 1. Introduction

In recent years, rapidly advancing technologies to perform high precision surveying have provided archaeologists powerful recording tools and vast amounts of data. Management of all this information in accessible work environments, such as GIS packages, has increased the opportunities for analysis. But at the same time, decision-making involving the use of many procedures leaves free way to the generation of results that are not always easy to interpret by non-specialist users.

This sometimes leads to use these tools guided by intuitive decisions or with the aim of obtaining visually appealing maps. However, it is obvious that what is behind digital surveying is a numerical model whose parameters have a decisive influence on the degree of fidelity to the original surface. Our aim in this contribution is to deepen the problem, analyzing constraints posed by data collection (terrain characteristics, precision of devices) and the effect of different interpolation procedures. This work focuses on chances provided by the use of dual-frequency GPS technology, specifically at site scale, where survey-grade precision of DEMs is needed in order to analyze micro-topographical features as potential traces of buried

structures, and to combine this information with data provided by an excavation or a geophysical survey.

## 2. High precision survey methods in archaeology: a very short review

During the last few years, survey-grade GPS has been widely implemented in engineering, territorial, and urban planning and many other fields. Nevertheless, the application in Cultural Resource Management, and more specifically in the research and preservation of archaeological heritage, has been much more limited. Budgetary restrictions, together with inadequate training in geomatics, have kept the use of GPS mostly in the domain of navigation-grade equipments for the location of archeological sites and basic mapping. Of course, on many occasions, professional survey specialists have been involved in archaeological projects, but as a whole we cannot find a significant number of case studies in which the use of this technology has been applied for the specific nature and requirements of the archaeological record. Perhaps this problem can be better understood exploring the development of research focused on micro-relief representation of landscapes and historical sites. Subtle topographic variation may be a meaningful sign of several kinds of earthworks (ditches, banks, ramparts) but also an indirect trace of the presence of

buried structures. Then topography is considered a valuable way of knowing the physiognomy of archaeological features that cannot be directly or globally perceived by other means.

Technical skills and equipments have evolved very quickly in last 20 years. Still at the end of the 90's, high precision GPS technology remained relatively underutilized in archaeological projects. Early experiences, like the one developed in 1999 in the English medieval village of Cottam (FITTS, 2005), concluded that traditional total station survey was a competitive alternative. It was clear nonetheless the great potential of RTK methods with dual-frequency devices. In this case GPS was just used to outline archaeological features, in order to be managed in a CAD environment, with no elaboration of digital models.

Almost in the same years, but with a more sophisticated design, we can mention other critical evaluations of GPS for obtaining highly detailed topographic surveys. A research project focused on two case studies in the British wetlands (CHAPMAN and NOORT, 2001) included fieldwork oriented to the identification of archaeological features at a landscape scale through subtle topographical variations. They take into account the need of a systematic sampling design for the arrangement and spacing of measured points, considering also resolution problems. More innovative is the attention paid to the process of DEM generation and the variable effect on accuracy of different interpolation algorithms. Nevertheless the search of "realistic" and "aesthetic" can still be perceived. Neither geostatistical nor other validation procedures are performed.

A similar experience has been described in the Roman town of Wroxeter (BARRATT *et al.*, 2000). Here a detailed topographic survey of the site was obtained using Real Time Kinematics (RTK) correction technique for the subsequent generation of a DEM. Work was developed in 1998. Care was taken to produce a systematic coverage using regular transects of variable width marked with ranging rods. Even spacing of measured points was also observed (about 2 m), reducing this interval to 0.1 m where higher resolution was required.

We think that these examples reflect the concerns of a long tradition in British field archaeology and landscape studies, leading to the incorporation of survey-grade GPS as a common practice. We can see it integrated as a usual procedure in English Heritage recording methods (see for example (AINSWORTH, 2003), with the explanation of a case study in Ring Chester hillfort). A good reference about the progress of this kind of works is the Wessex Hillforts project, published by English Heritage (PAYNE *et al.*, 2006: 36-38). In this case the strategy stressed the importance of regular grids for an even distribution of point measurements. The large surface of some of these archaeological sites posed the

problem of its coverage with a dense cloud of points with a reasonable investment of time. The adopted solution was the use of a backpack-mounted antenna system, replacing the hand-held pole.

We can see another good example of massive data capture for great areas in the survey conducted at Double Ditch State Historic Site (USA) (KVAMME *et al.*, 2006). In this case advantage was taken on the availability of a robotic total station. Its ability for the automatic tracking of the reflector rod, together with its attachment to a wheel, increased noticeably the capacity for producing thousands of measurements without a loss of quality. There is a valuable detailed explanation of the sampling strategy followed to obtain the point cloud, but further analysis of interpolation procedures for DEM generation is not well developed.

If we look to Peninsular studies now, we will find even less published examples. As in many other countries, GPS technology has been extensively adopted in archaeological works. We can see pioneer contributions, like the study of several prehistoric mounds in the province of Seville by (GARCIA SANJUÁN and WHEATLEY, 2003).

Geospatial technologies develop very quickly and, as we have seen before, what seemed too expensive or awfully time-consuming just a few years ago, can be now efficiently implemented at a reasonable cost. LIDAR technology is beginning to be available for extensive areas and from government, public sources. Terrestrial laser scanner is up to now synonym of high precision survey. At the same time there has been an extraordinary boom of applications of digital photogrammetry. In the last technological frontier, devices combining laser scanning with GPS and robotized total station provide integrated solutions.

Therefore, survey-grade GPS should be considered a complementary approach for high resolution terrain analysis, with its particular drawbacks and advantages.

Regarding to the first ones, perhaps the more persistent is economical cost, since they are still quite expensive for small research teams and organizations. Nevertheless, hiring is a good choice, and when it is well justified the purchase will be easily recouped. Another problem is the demand of time invested in data capturing. Here an equilibrium must be considered, between the desired degree of accuracy and the scale of the areas to be recorded. We think that a rigorous experimentation must be produced to test the effect of using antennas mounted on vehicles, wheel-equipped rods of back-packs, in order to optimize the fieldwork results. Finally, we can point out to interruptions of signal reception, topographic barriers or sky clearance as technical problems with GPS.

On the other hand, there are many reasons to take into account GPS as a source for obtaining quality and detailed DEMs. It is a versatile and flexible solution for teams working at a landscape scale, being able to

implement it almost everywhere. Implementation of regional and national networks of reference base stations frees us from using triangulation pillars, providing the most precise differential correction for capturing data with mobile receivers. It requires only a single person to operate, not depending on a visual connection like that needed by the prism rod of total stations. It is also easier to maintain, because does not need to be regularly recalibrated. Relative limitation for producing point clouds should also be considered an advantage, because it means a more optimizing and selective process. It avoids the huge volume of noise generated by LIDAR, and, unlike this one or photogrammetric restitutions, provides directly a Digital Elevation Model rather than a surface model. Finally, GPS data can be easily managed and analyzed with GIS packages for geostatistics (as we will see below) and thematic mapping by feature coding.

### 3. Early Roman fortifications in La Serena Region

The case studies we have used are several archaeological sites located in the region of La Serena (Badajoz) (Figure 1). These are selected examples from a wide group of fortifications known in archaeological literature from the 80's of 20th century (RODRÍGUEZ DÍAZ and ORTIZ ROMERO, 1990, 1998).



Figure 1: Location map of case studies.

Their chronology and functionality are far from generating academic consensus. However, in general, we can say that it is a distinctive form of habitat in various parts of the Iberian Southwest during the transition from Protohistory to Roman times. Our interest on them is contextualized in a diachronic archaeological study in the territory of La Serena developed in recent years by the Merida Institute of Archaeology. Many of these sites are well preserved, so conditions are very favorable for obtaining a large amount of data about their internal structure and

construction techniques just from surface measurements. For this reason our priority was the development of recording methods that could take advantage of all this information, within a line of work that seeks to explore the advantages of non-destructive techniques (aerial photography, surface survey and geophysical prospecting).



Figure 2: Aerial view of the archaeological site of Egado del Gravamen. Photograph by Victorino Mayoral.

We chose the case studies looking for a representative sample of the two main groups of fortifications on which we are researching. First, along the plains of the Ortigas valley, there is a wide group of settlements that occupy small hills that stand out little above their immediate space. They have a fairly uniform design consisting of small square buildings with large blocks of masonry, surrounded by one or more enclosures.



Figure 3: Aerial view of the archaeological site of Cancho Roano enclosure. Photograph by Javier Fernández Ruano.

As a sample of these sites we have selected Egido del Gravamen (Quintana de la Serena) and Cancho Roano (Zalamea de la Serena), both in the province of Badajoz (Figures 2 and 3).

The first one is a small settlement less than 1300 sq m long. It is located on the edge of a small stream, on a granite outcrop that stands out just four meters above the surrounding land. On surface we can see a concentration of Roman brick and tile, together with abundant fragments of common pottery, locally-made large containers and some imports (Gallic and Hispanic *sigillata*). Regarding visible structures, the most prominent feature is a rectangular building 13.3 x 8 m long composed of large granite blocks (some almost 3 m long).

The Cancho Roano enclosure has virtually the same chronology and size, although the absence of data on its central structure suggests a typologically different settlement.

Secondly, in the region we find a group of fortifications with a strong preference to occupy prominent locations and with a very wide visual domain. Their structures are sometimes very monumental, and reflect a clear concern with the defense of their perimeters. Plans are very diverse and its internal organization is complex.

Perhaps the best example of this group is the fortification of Merchanas (Don Benito, Badajoz) (Figure 4), with large walls of cyclopean fabric and several enclosures that take full advantage of natural breaks in the bedrock to restrict access. We have no excavation data for these kind of sites. Surface pottery indicates the existence of an Imperial Roman occupation, although a Republican chronology has been traditionally argued for these fortifications.



**Figure 4:** Aerial view of the archaeological site of Castejón de las Merchanas. Photography by Victorino Mayoral.

#### 4. Equipment and methodology

Two different double frequency devices were used for the survey: a Leica GPS 1200 in the case of Cancho Roano, and Trimble R8 GNSS in the other sites. GPS data were collected during July 2008 (Cancho Roano) and October 2009 (Egido del Gravamen and

Merchanas). First of all we marked topographic references in the sites with the support of correction provided by trig points of the National Institute of Geography. None of them was more than 3 km far from at least one site. This procedure ensures the highest possible level of precision in data collection. Once this task was accomplished we carried out topographical survey in Real Time Kinematics mode. It is based in a fix receiver located in a well known coordinates point (Figure 5a) that corrects in real time the measurements taken by a rover (mobile antenna) (Figure 5b). Figure 6 shows the GPS data points distribution taken with the GPS receiver in Merchanas site. As can be seen, the data distribution in this site is irregular due its topographical configuration. This is a key factor that determines the final measured data distribution and, hence, the final quality of the DEM. This technique allows obtaining immediate results with sub-centimetric accuracy. At the same time we outlined a detailed plan of visible walls and other structures.



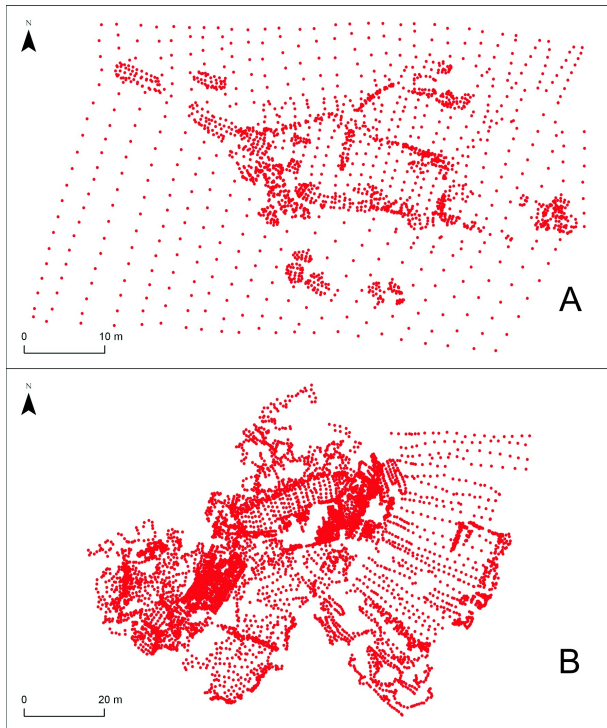
**Figure 5:** DGPS in the field. A.-Base station placed in a fixed point tied to the National Geodetic Network. B.-Measuring with the rover pole.

The simplicity and agility of the data capture procedure allowed recording large sets of point data very quickly. For example, a detailed archaeological plan and around 2500 elevation points in Egido del Gravamen (Figure 6a) took no more than four hours since the arrival to the site. It included a careful drawing of every single block of visible structures. In Merchanas more than 7000 points were recorded (Figure 6b). We thus think that this method provides a high density of information, giving at the same time choice to a very carefully thought-out decision in data capture.

#### 5. Results and discussion

Both Cancho Roano and Egido are located in accessible and quite flat places, which favoured data collection. Merchanas, on the contrary, is located in a rough area with dense vegetation of trees and bushes, which made data collection difficult and produced wide blanks in data distribution.

Histograms of Cancho Roano and Egido show a normal distribution, chiefly the first one, but Merchanas do not, maybe due to the mentioned gaps.



**Figure 6:** Point distributions of survey in Egido del Gravamen (A) and Merchanas (B).

We put into practice spatial interpolation (see a synthesis in BURROUGH and MACDONNELL, 1998; BOSQUE, 2000; and archaeological applications in WHEATLEY and GILLINGS, 2002; CONOLLY and LAKE, 2006) to GPS data for generating micro-topographies of these archaeological sites. Together with the aforementioned sites we added other two study cases of hill-top fortifications (Castillo del Portugués) and low-land locations (Fuente las Pilas). Spatial interpolation is a mathematical procedure for predicting (or estimating) the values of a certain variable in specific locations using known values of the same variable in other locations. Interpolation applied to elevation data results in Digital Elevation Models (DEMs), that is, digital representations of the distribution of the elevation variable (Z) across a 2D space defined by XY coordinates. For each archaeological site, we tested several spatial interpolation methods and compared the results in order to see which DEM depicts topography in a more accurate and, also, visually realistic way.

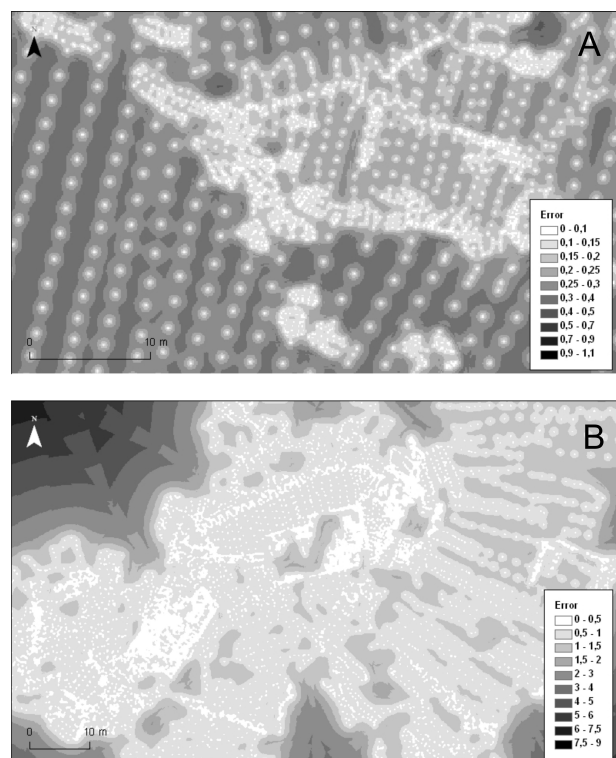
We tried out four different interpolation methods: Triangulated Irregular Network (TIN), Inverse Distance Weighted (IDW), Radial Basis Functions (RBF) (also known as Spline method) and Kriging. We chose these specific methods because their wide use and their suitability with point data. The software used is ArcGIS, specifically the Create TIN tool (into the 3D Analyst module) for TIN, and the Geostatistical Analyst module for IDW, RBF and Kriging.

TIN method generates a vector layer consisting of a surface formed by triangles whose vertices are the original points, with XYZ values. TIN DEMs have a quite unrealistic faceted appearance, although this does not necessarily mean that it is not a good topographical representation, chiefly if data points register significant topographical features (peaks, ridges, valleys, holes and so on).

IDW method produces a raster layer calculating each cell Z-value using the nearest points. These points are determined establishing how many are used or, alternatively, defining a vicinity with a specific radius. IDW method considers the Z-value of each point and the inverse value of the linear distance between it and the cell. One parameter of IDW method is the power applied to the inverse of distance. The higher the power, the greater the inverse effect of distance. Customary power values are 1 or 2. Nevertheless, IDW method can calculate the optimum power value for a certain data set; this helps to generate a smoother DEM and to avoid the “bull’s eye” effect, that is, local holes around data points due to an excessive weight of the local value.

RBF fits a curved surface or spline to the sample points. A spline is the mathematical expression of a flexible ruler or a rubber membrane. There are several RBF methods, depending on the mathematical formulation of the spline.

Kriging method, as IDW, also uses a vicinity, but in a more complex way. TIN, IDW and RBF are deterministic methods. Kriging, on the contrary, makes a previous spatial statistic analysis of data and establishes



**Figure 7:** Standard error of Kriging interpolation in Egido del Gravamen (A) and Merchanas (B).

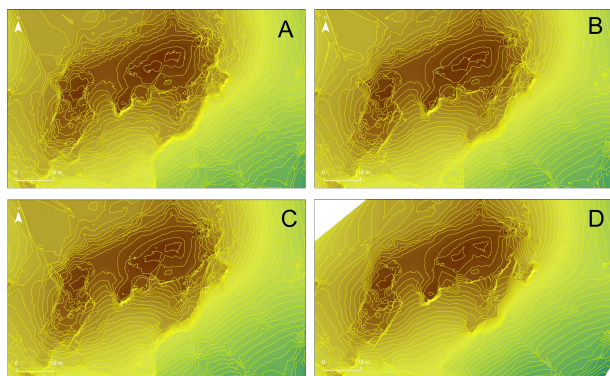
the calculation algorithm based on such analysis. Moreover, it can complement the estimated Z-value with a standard error that gives an idea about the quality of the estimation (Figure 7a and 7b). Besides the local analysis, Kriging also can consider a global trend, that is, a general form of the distribution of the variable in the whole area, and put it apart by means of a mathematical function.

We put into practice the mentioned interpolation methods to each data set in order to compare the results and assess their quality. Apart from TIN, each method can be applied in many ways depending on several parameters. We tested the following:

- TIN.
- IDW, applying three different powers: 1, 2 and optimal value.
- RBF, using three different types of splines: Completely Regularized Spline, Spline with Tension and Thin-plate Spline.
- Ordinary Kriging, using three different variogram models (Spherical, Exponential and Gaussian). Besides, we did it both without considering any global trend in the model and considering it, specifically a 2nd order polynomial one. The reason for including this type of global trend is that the 3D observation of point clouds shows a bell-shaped general form in all the case studies, just the shape that a 2nd order function mathematically describes.

A vicinity of 10 points was used in IDW, RBF and Kriging, leaving the rest of the parameters by default.

We compared DEMs elaborated from them. In general terms, IDW products (Figure 8a), specially the contours layer, exhibit the “bull’s eye” effect, despite the application of the optimized power value. Kriging (Figure 8b) products look better, with a smoother and more realistic appearance. RBF DEMs show how surface folds where there sample points concentrate and becomes smoother in empty areas (Figure 8c). Finally, in figure 7d can be seen how TIN DEMs are particularly



**Figure 8:** Visual comparison of raster DEMs obtained by IDW (A), Kriging (B), Splines (C) and TIN (D) of Las Merchanas survey.

sensible to data holes, covering them with large and unrealistic triangles.

IDW, RBF and Kriging interpolations were also numerically tested. For this task, we randomly sampled a 10 % subset of data points in each site and put them apart, generated the DEMs with the remaining 90 % and calculated the Root Mean Square Error (RMSE) from the difference between the Z-values of the points belonging to the 10 % validation subset and their corresponding estimated values in the DEM.

If we compare the RMSE of these different methods in each site (Table 1), we may hold the following ideas:

- Kriging clearly gives better RMSE in the five examples, particularly if one uses the spherical or the exponential variogram.
- Regarding IDW, results show the advantage of optimizing the power, which in almost all the examples (apart from Castillo del Portugués I) gives the best RMSE.
- RBF methods give an heterogeneous scene, in some cases with very bad RMSE (Merchanas, Castillo del Portugués I), or very good in others (Cancho Roano). These differences suggest that this method seems more sensible to sample data structure than Kriging or IDW.
- Concerning Kriging, spherical and exponential variograms give very similar results. Moreover, their RMSE are generally better than those resulting from trying out the Gaussian variogram.
- Although the apparent bell-shaped general form of the topography of the sites, an improvement considering a 2nd order global trend does not seem to happen. This probably means that local variations have a strong weight in the micro-topography.

## Conclusions

To conclude, our first consideration is that DGPS is the best option for highly detailed topographic surveys in archaeological sites under certain conditions. On one hand, regarding the size of the target site, there is a threshold beyond which time spent in intensive manual measuring becomes unacceptable. There are, nevertheless, alternative strategies that should be implemented for massive data capture (gridding, use of back or wheel mounted devices).

Experimentation with the results obtained through different interpolation methods (TIN, IDW, RBF and Kriging) yields some objective assessment of error sources. Both the interpolation procedure and the data structure influence the quality of the resulting DEMs.

Kriging shows the best results, with minor RMSE values and also a softer visual appearance. IDW gives acceptable models, but surfaces use to be affected by the “bull’s eye” effect, deriving from the excessive weight of

Interpolation method		Egido del Gravamen	Fuente las Pilas	Recinto de Cancho Roano	Castillo del Portugués I	Merchanas
IDW	Power=1	0,2319	0,1652	0,1646	0,3407	0,2875
	Power=2	0,2420	0,1743	0,1420	0,3144	0,2764
	Power optimized	0,2319	0,1652	0,1265	0,3244	0,2756
RBF (Spline)	Regularized	0,2671	0,1663	0,1422	0,5538	0,5824
	With tension	0,2091	0,1685	0,1046	0,2929	0,2937
	Thin plate	0,2226	0,2661	0,1021	0,3245	0,4238
Kriging (no trend)	Spherical v.	0,1952	0,1657	0,1124	0,2219	0,2303
	Exponential v.	0,1954	0,1656	0,1129	0,222	0,2303
	Gaussian v.	0,2183	0,1598	0,1536	0,3347	0,3009
Kriging (trend)	Spherical v.	0,1936	0,1584	0,1878	0,2227	0,2289
	Exponential v.	0,1961	0,1574	0,1758	0,2228	0,2287
	Gaussian v.	0,2131	0,1609	0,2104	0,2960	0,2879

**Table 1:** RMSE values obtained for each interpolation method used in the different archaeological sites.

nearest point values. TIN surfaces fit adequately to sites topography, but have the handicap of an unrealistic faceted appearance, specially when sample points are scarce.

Alternative techniques for 3D restitution, e.g. low altitude digital photogrammetry, can work pretty well with complex, clean structures (as excavated sites), since its main result is a surface model rather than an elevation model. In a landscape context, ability of GPS to identify visible structures partially covered by vegetation, and capacity to carefully select measurement distribution is an adaptive advantage. In the nearest future a wide access to LIDAR technology will dissolve these dilemmas.

But in the mean time, survey-grade GPS allows a balance between information density and time spent, all in addition to a detailed control over the decisions about the distribution of observations. While the cost of these devices is still high, its implementation is widespread in surveying services. Secondly, precisely because of its widespread use, we think it is imperative a thorough assessment of data quality and a careful use of interpolation surfaces derived from them. Specifically archaeological issues that arise in the analysis of these models make inevitable our direct intervention and a minimal knowledge of the calculations underlying the final result.

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