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On the Airborne Lidar Contribution in Archaeology: from Site Identification to Landscape Investigation

Nicola Masini[1], Rosa Coluzzi[2] and Rosa Lasaponara[2]
[1]*CNR-IBAM (Institute for Archaeological and Architectural Heritage)*
[2]*CNR-IMAA (Institute of Methodologies for Environmental Analysis)*
Italy

1. Introduction

Historically, aerial photography has been the first remote sensing technology extensively used for surveying surface archaeological remains as well as for detecting underground archaeological structures through the reconnaissance of the so-called "soil" and "crop marks" (Crawford, 1929). Soil-marks are changes of colour or texture due to the presence of surface and shallow remains. Crop-marks frequently appear as differences of height or colour in crops which are under stress due to lack of water or deficiencies in other nutrients caused by the presence of masonry structures in the subsoil. Crop-marks can also be formed above damp and nutritious soil of buried pits and ditches. Such marks are well visible from aerial photos, especially during the spring season.

Nowadays two new technologies have strongly improved the performance of remote sensing in archaeology: (i) the Very High Resolution (VHR) satellite images and (ii) the airborne laser scanning.

The launch in 1999 of IKONOS, the first satellite sensor which acquires VHR imagery, opened new perspectives in the field of archaeo-geophysics.

The main advantages of VHR satellite imagery compared to aerial photos, are the synoptic view, the multispectral properties of the data and the possibility to extract geo-referenced information.

The use of data processing algorithms, from classifications methods to geo-statistics, from Principal Component Analysis to convolution filtering, enable us i) the extraction of land patterns useful for palaeo-geographic and palaeo-environmental investigations (Masini & Lasaponara, 2006); ii) the discrimination of surface archaeological remains from the surroundings (De Laet et al., 2007).

From 1999 up to now, the spatial resolution of satellite data has strongly increased, thus providing also valuable support to site discovery by means of soil/crop marks detection. The multispectral bands, available at a resolution four times lower than panchromatic channel, could be pan-sharpened by using image fusion algorithms available in several image processing software routines, thus allowing us to emphasize moisture and vegetation changes linked to the presence of buried archaeological deposits (Lasaponara & Masini, 2007).

The "great run" of satellite technology for reaching the resolution of aerial images seems have arrived at the end with GeoEye1 (launched in September 2008) which provides 41 cm panchromatic and 1.65 m multispectral imagery.
However, for archaeological applications, VHR satellite as well as aerial images (including hyperspectral data) still present limitations in detecting all the possible features of cultural interest.
We refer to archaeological remains covered by dense vegetation (forest, wood etc.) and, in many cases, to microrelief in bare-ground sites linked to the presence of anthropogenic earthworks and shallow remains.
In the first case, satellite images are capable to only detect big structures covered by forest. In such regard, we cite the identification of a Maya settlement in the jungle of northeast Guatemala (Garrison et al., 2008).
As concerns the second limitation, the visibility of micro-relief depends on many factors, such as off-nadir viewing angle of the collected imagery, time of image acquisition, view geometry, sun angle (micro-topographic relief variations are more visible in early morning or late evening) and surface characteristics (the presence of surface chaotic building material could make the detection of geometrical microrelief pattern very difficult; see, for example Lasaponara & Masini, 2005).
The above-said restrictions of optical imagery could be overcome by airborne laser scanner (ALS), also referred to as Light Detection And Ranging (LiDAR). It provides direct range measurements mapped into 3D point clouds between a laser scanner and the earth's topography.
ALS sensors can penetrate vegetation canopies allowing the underlying terrain elevation to be accurately modelled. Therefore, it is a powerful tool for recognizing and investigating archaeological heritage in wooded areas, usually well preserved due to the vegetation cover which protects the sites from erosion and from possible damage of mechanical ploughing.
Currently, a LiDAR survey could be carried out by two different types of ALS sensor systems (fig. 1) : (i) conventional scanners or discrete echo scanners and (ii) full-waveform (FW) scanners. The first, generally, delivers only the first and last echo, thus losing many other reflections. The second is able to detect the entire echo waveform for each emitted laser beam, thus offering improved capabilities especially in areas with complex morphology and/or dense vegetation cover.
Nowadays the majority of published studies are based on data collected by conventional ALS, for the management of archaeological monuments (Barnes, 2003), landscape studies (Shell & Roughley, 2004; Challis, 2006) and archaeological investigations to depict microtopographic earthworks in bare ground sites (Corns & Shaw, 2008) and in forested areas (Sittler 2004; Devereux et al., 2005; Crutchley, 2008; Gallagher & Josephs, 2008).
The potential of FW LiDAR for archaeological purposes has been assessed in a few studies, among which, for sake of brevity, we cite the study of an Iron Age hill fort covered by dense vegetation (Doneus et al 2008) and the investigations performed on two medieval settlements, located on bare ground hilly places (Lasaponara & Masini, 2009; Lasaponara et al., 2010).
This chapter is organized as follows: in Section 2 the available laser scanner technology is described; in Section 3, we focus on methodological issues, from data filtering to post processing; in Section 4 we deal with the state of the art of ALS in Archaeology; in Section 5 we show the investigation results obtained from two tests sites; finally, conclusions follow in section 6.

2. Conventional and Full-waveform ALS

ALS is an active remote sensing technique that provides direct measurements of the earth's topography, mapped into 3D point clouds.
The laser scanner, mounted to an aeroplane or helicopter, emits near infrared pulses, at a frequency rate of 30.000 to 100.000 pulses per second, into different directions along the flight path towards the terrain surface.
Each pulse could be reflected one or more times from objects (ground surface, vegetation, buildings, etc.), whose position is determined by computing the time delay between emission and each received echo, the angle of the emitted laser beam, and the position of the scanner (determined using differential global positioning system and an inertial measurement unit).
There are two different types of ALS (fig. 1): i) conventional scanners based on discrete echo and ii) FW scanners.

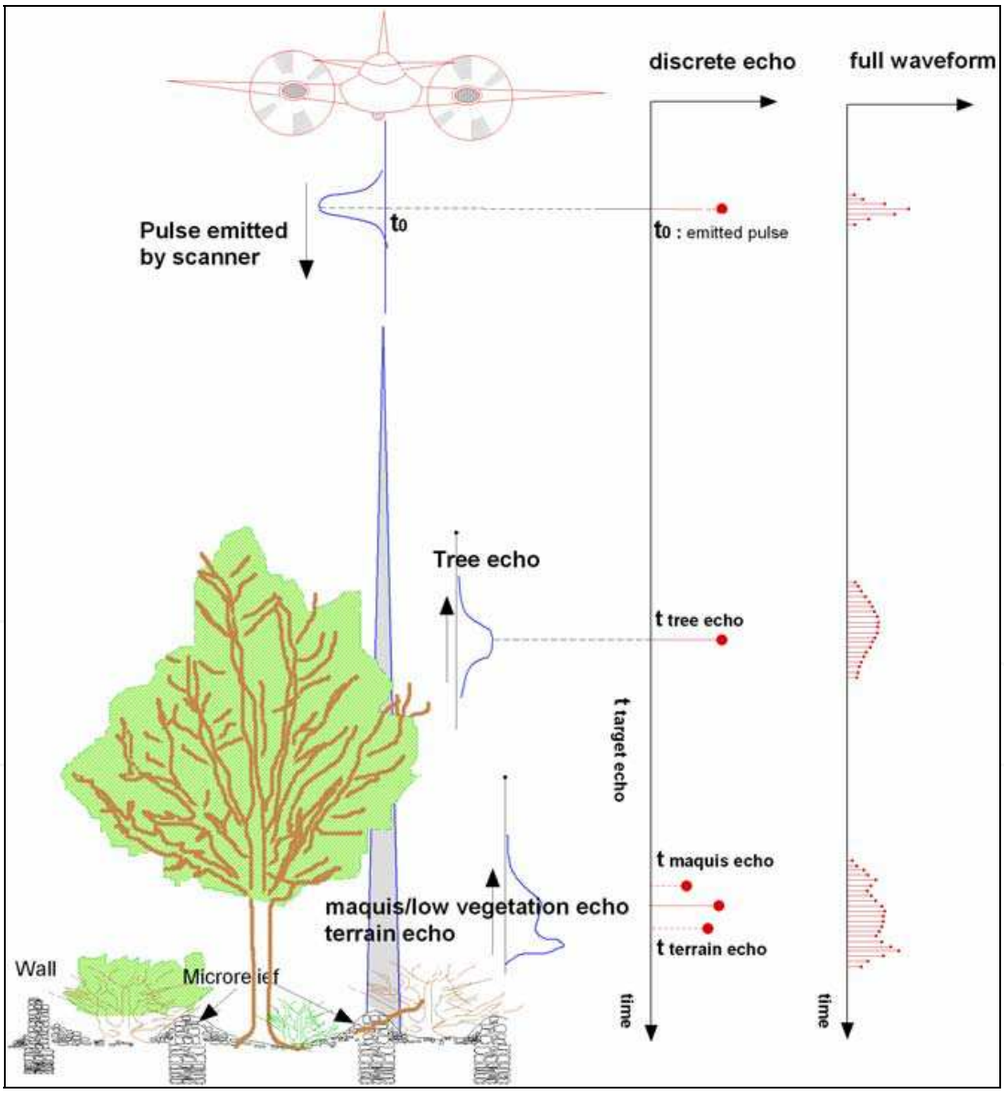


Fig. 1. Conventional and full-waveform ALS.

The first detects a representative trigger signal for each laser beam (see fig. 1).
The second digitizes the complete waveform of each backscattered pulse; thus allowing us to improve the classification of terrain and off terrain objects, such as low vegetation, buildings, and other man-made structures lying on the terrain surface (Doneus et al, 2008). This enables us to obtain DTMs with accuracy less than 0.1m and therefore to detect archaeological structures and earthworks even under dense vegetation cover.

3. Theoretical consideration on ALS data processing

3.1 Theoretical consideration on the extraction of DTM from ALS

In order to obtain a Digital Terrain Model from airborne laser scanning raw-data processing is essential. This process is generally called filtering., namely the discrimination of point clouds into terrain and off-terrain points and the elimination of erroneous points, such as, low points and aerial points.
The following step is the classification (also joined with a segmentation process) of raw LiDAR data, which allocates off-terrain points into specific classes, defined "a priori" (i.e. before applying the classification).
Many different algorithms have been published for ALS data filtering. A list of the most commonly used filters is reported below: (i) Morphological filtering, (ii) Progressive densification, (iii) Surface based filtering, (iv) Segment based filtering, (v) Spline interpolation filtering.

i. Morphological filtering: this group is based on the concept of mathematical morphology, a set of theoretical method of image analysis which provides a quantitative description of geometrical structures based on a set of operators. Morphological filtering was published by Lindenberger (1993), Vosselmann (2000), Sithole (2001), Roggero (2001), Lohmann et al. (2000).
   Filtering methods of Lindenberger (1993), Vosselmann (2000), Sithole (2001) and Roggero (2001) are applied to point clouds; whereas Kilian et al. (1996) and Lohmann et al. (2000) methods are applied to raster data.
ii. Progressive densification: this group is based on the classification of the whole data set starting with a small given point cloud and increasing them iteratively. The most popular progressive densification method is the progressive triangular irregular network (TIN) densification devised by Axelsson (2000). Another similar method was proposed by Sohn and Dowman (2002).
iii. Surface based filtering: in this case the whole point cloud belong to terrain surface and then, iteratively, points are removed according to a step-by-step refinement of the surface description. Surface based filters were proposed by Kraus and Pfeifer (1998) and Elmqvist et al. (2001).
iv. Segment based filtering: this group is based on the concept that classification is not based on single points but on segments, a set of neighbouring points with similar properties. In general, the point cloud segmentation is performed in object space or features space. In a step to step process, neighbouring points are merged to form a segment as long as their properties are similar with respect to some thresholds. Segment based filtering methods were proposed by Sithole and Vosselmann (2005), Sithole (2005), Tovari and Pfeifer (2005).
v. Spline interpolation filtering: this method was proposed by Brovelli et al. (2001; 2003) and implemented in the GIS GRASS software. To classify point clouds, first a bilinear spline interpolation and later a bicubic spline interpolation are performed.

A comparison and performance evaluation of these different filtering algorithms were provided by Sithole and Vosselmann (2004). They suggested that filtering methods can be categorized into the following four groups, on the basis of the structure of bare earth points in a local neighbourhood: (i) slope-based, (ii) block-minimum, (iii) surface-based and (iv) clustering/segmentation.

i. Slope based algorithms measure the difference in slope (or height) between two points, and assume that the highest point belongs to an object if the slope is higher than a given threshold value.
ii. Block-minimum algorithms assume as discriminant function a horizontal plane with a corresponding buffer zone above it, which defines a region in 3D space where bare earth points are expected to reside
iii. Surface-based filtering methods assume as discriminant function a parametric surface with a corresponding buffer which defines a region in 3D space where ground points are expected to reside.
iv. Finally, clustering/segmentation filtering approach assumes that any clustered points belong to an object if their cluster is above its neighbourhood.

Among the above-said filtering groups, the surface-based category appears to provide the best results in separating points on a ground surface from other points (Sithole and Vosselman, 2004). Examples of surface-based algorithms are: Axelsson (2000), Briese and Pfeifer (2001), Elmqvist (2001), Sohn (Sohn and Dohman, 2002), Wack and Wimmer (2002).

- Axelsson's (1999) algorithm is based on a progressive Triangulation Irregular Network (TIN) densification. Starting from a coarse TIN surface (obtained from reference points which are neighbourhood minima), new points are added, though an iterative way, if they meet criteria based on distances to TIN facets and angles to the vertices of the triangle.
- Briese and Pfeifer (2001) is a hierarchic based method. Starting from an approximate surface it performs interpolations in each hierarchy level by assuming weight values based on vertical distance of the points to the same approximate surface, thus allowing us to carry out the classification.
- Elmqvist algorithm(2001) is based on the concept of membrane floating upwards from beneath the point cloud, which defines the form of the bare-Earth.
- Sohn algorithm (Sohn and Dowman, 2002) uses a two-step (downward and upward) progressive densification of a TIN. The first operates a triangulation of four points closest to the corners of the rectangular bounds of the point cloud. The lowest point within each triangle is added to the triangulation. This process is repeated until no triangle has a point beneath it. The second step is performed in order to extract other bare-Earth points not caught by the downward.
- In the Wack and Wimmer (2002) algorithm a raster DEM is generated from a raw point cloud in a hierarchical approach.

The circumstances under which the filtering methods could meet difficulties and limits (Sithole and Vosselman, 2004) are generally the following: i) outliers; ii) spatial and morphological object complexity; iii) attached objects; iv) low vegetation; v) and geomorphological discontinuities.

i. Outliers could be low (caused by multi-path errors and errors in the laser rangefinder) and high (birds, low-flying aircraft, or errors in the laser range-finder).

ii. The spatial and morphological object complexity is a circumstance which typically characterizes a urban environment. In particular the filtering algorithms are likely to fail in presence of very large objects, very small objects (elongated objects, low point count, such as vehicles), very low objects (walls, cars), and complex shape.
iii. The attached objects are objects spanning the gaps between bare-earth surfaces such as buildings on slopes, bridges, natural/artificial ramps.
iv. As concerns the vegetation, the classification problems are mainly related to vegetation on slopes and low vegetation.
v. Finally, the most typical geomorphologic discontinuities are due to steep slopes and sharp ridges.

An overview of the different algorithms for the filtering of airborne laser scanning data is provided also in Pfiefer (2003), Sithole (2005).

3.2 Theoretical consideration on general details on Digital Elevation Model

Digital Elevation Model (DEM) is defined as any digital representation of the continuous variation of the relief over space (Burrough & McDonnel, 1998). More information about DEM are in Morre et al. (1991); Weible and Heller (1991); Wilson and Gallant (2000).

A Digital Terrain Model (DTM) is a model of the bare earth surface in digital form, a Digital Surface Model (DSM) is a model in the bare earth and objects are attached to it, such as buildings and vegetation.

In general DEM can be assembled, depending on the source and/or preferred method of analysis, into three different data structures: a) a Grid-DEM which is a regular square matrix where each pixel is an elevation (see fig.2a) b) The Triangulated Irregular Networks (TIN) model is a surface as a set of contiguous, non-overlapping triangles. Within each triangle the surface is represented by a plane. Each vertex is a known elevation value. An example of TIN is shown in fig. 2 b; c) The Contour structure is based on the concept that landscape can be divided into small, irregular shaped polygons based on contours lines and their orthogonals. An example of Contours is shown in fig. 2c

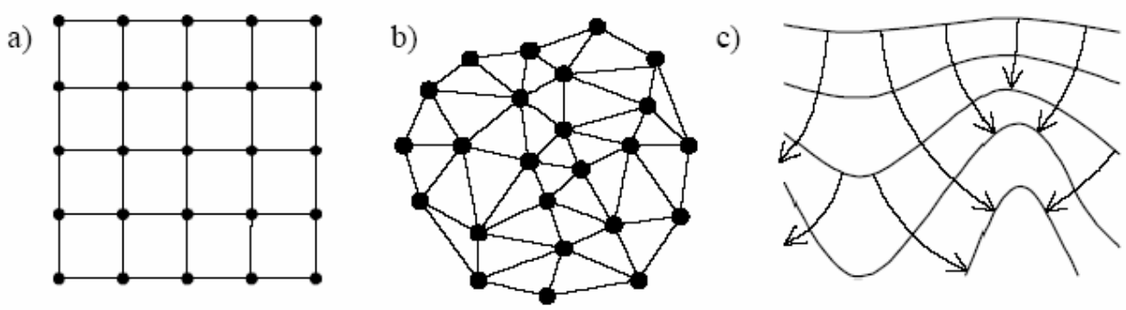


Fig. 2. Typical DEM data structures: a) DEM grid; b)TIN; c) Contours (by Moore et al.,1991).

Recently, a new classification was proposed by Hengl and Evans (2009). They divide DEM in two big groups: vector-based and raster-based. TIN-DEMs and Contour-DEMs are part of the vector-based group; Grid-DEMs are raster-based group.

Grid-Dem was the most widely used data structure in the past due to its simplicity, but it has the following disadvantages: i) it is not able to represent abrupt changes in elevation easily; ii) important details of the land surface in flat areas are missed; iii) it increases the

difficulty to calculate specific catchment areas accurately; iv) the computed upslope flow paths is tending to zig zag across the landscape.
Moreover, Grid-DEMs appear as a continuous-surface but in reality they are not continuous. For that when the DEM pixel dimension is selected it will not be possible to understand if it is representative of an abrupt change of the land surface.
The grid heights are typically determined by surface interpolation and approximation methods like inverse distance weighting, moving last squares, linear prediction, or kriging.
A method, often used for altitude data, is inverse distance weighting (IDW: for this and other interpolation techniques). In this method, the estimated value of a grid cell depends on its distance to neighbouring data points. In general, the greater the distance, the smaller the data point's influence on this value. This relation depends on an exponent that is defined by the user. In addition, the user determines the radius within which data points are used to calculate a grid cell value. The radius and exponent are determined on the basis of expert judgment. The disadvantages of this method are: (i) its tendency to smooth out small-scale relief, and (ii) the clustering effect around data points.
Another widely used interpolation method is a Triangulated Irregular Network (TIN).
This method produces a network of triangles that connect all data points. The values of the grid cells are calculated using the slope and shape of the triangles. The user determines (based on expert judgment) the maximum length of the triangle sides and an exponent.
TIN-DEM is able to incorporate discontinuities and is efficient to represent roughness terrain because the density of the triangle can be varied easily. For that it can represent easily abrupt changes on the land surface. On the contrary it is not as good for graduated changes of the land surface because TIN is not continuous. This causes that abrupt changes appear as unnatural effects related. The most popular interpolation to create a TIN-DEM is the Delaunay triangulation, based on Voronoi diagrams.
The final interpolation method herein listed is Kriging, considered to be based on the most solid theoretical principles. This method assumes that, a variable's value can be estimated through the data's spatial characteristics. The spatial characteristics are modelled in a variogram, where the squared difference of pairs of data points is plotted as a function of their spacing. Based on the position of these points in the variogram, a mathematical function is generated and then used for the interpolation. The way the researcher interprets the spatial relationship is explicitly expressed via the type of function chosen and the method to obtain the best fit. Thus, the choice of the interpolation parameters is (to a certain degree) objective, since it is based on the variogram. The disadvantages of kriging are the complexity of the method and the difficulties of filtering out the natural trends in larger study areas.
For the representation of DSM and DTM the same data structures and interpolation methods are in use.
A comprehensive discussion on the generation of 3D terrain models can be found in Pfiefer (2005).

4. ALS in Archaeology: overview of applications

In this section, we will provide a brief overview on the application of aerial LiDAR in archaeology in different countries. In the last decade, several national agencies acquired LiDAR data for different monitoring purposes mainly linked to environmental issues. The availability of these data has strongly encouraged investigations in the field of archaeology.

For these reasons, the majority of studies are mainly focused on the assessment of LIDAR capability in archaeology and generally exploited the data processing already done for other purposes. Therefore, this overview does not report the data processing or the methodological approaches because they are generally skipped in the available in literature, but it summarizes the significant experiences and results achieved by archaeologists in different environments.

4.1 Germany

One of first papers on the use of ALS in archaeology was published by Sittler (2004). The authors exploited the data acquired (2000-2004) for obtaining an accurate DEM for the entire Germany , in the framework of the project "Land and Survey bureau of the Baden-Wurttemberg State". This project aimed at providing comprehensive altimetry data-set with a resolution at around 1 meter and an accuracy at around 50 cm in height.
Sittler (2004) used part of this data set to analyze woodlands near Rastatt (30 km south of Karlsruhe, in South West Germany, including a sandy and dry flat terrace near the River Rhine. The visual analyses enabled the detection of patterns of the earlier medieval landscapes, including earth mounds and ridge and furrow structures. Moreover, using the 3D analyst extension of ArcView 3.2, quantitatively analyses were carried out to extract sizes of the detected patterns, such as, surface area, volume, length and width of the ridge and furrow as well as surface roughness and undulation.
On the basis of these successful investigations, subsequently (May 2009), the State Office for Cultural Heritage Management of Baden-Wurttemberg, launched a three-year new project aimed at obtaining an archaeological mapping of Baden-Wurttemberg using high resolution ALS data, covering an area of 35.751 km2.
Within this project, Hesse (2010) developed and implemented a new tool for archaeological prospection: the Local Relief Model (LRM). It is based on the removal of large-scale landscape forms from the data, thus allowing us to obtain local and small-scale elevation differences. In particular, LRM measures correctly and directly heights and volumes of small-scale features and extracts details of local topography without using numerous combinations of illumination azimuth and elevation.

4.2 Netherlands

In the Netherlands, the Dutch Ministry of Public Works initiated the setup of the so-called Actueel Hoogtebestand Nederland (AHN), namely `Up to date height data base of The Netherlands'. LiDAR data were collected from 1996 to 2004. The database consists of interpolated airborne laser altimetry data covering the whole country and contains at least one point per 4 m2 outside forests and one point per 16 m2 inside forests.
Humme et al. (2006) used a part of this dataset to study a Bronze Age village and 2500-year-old Celtic field system, near Doorwerth (East of the Netherlands). They proposed a method to filter the large scale topography component out by using a kriging interpolation method. Using this method the authors enhanced road beds, foot-paths and the earth walls surrounding the Celtic field system.
Van Zijverden and Laan (2003) used Lidar data for predictive modelling in the Holocene parts of the Netherlands (site of Eigenblok, in the municipality of Geldermalsen) in addition to the conventional data source such as soil, geomorphologic, geologic and palaeogeographic maps.

4.3 United Kingdom

In 1999, the Environment Agency of UK commissioned a LiDAR survey (fig. 2) for monitoring river corridors and coastal areas of England and Wales. (Brown, 2008). In general flights were organized to collect 5 – 10 points m2 and, after an appropriate processing, the LiDAR data were typically supplied in 2 km square tiles with a 2 m grid resolution in ESRI ASCII grid format. These data comprised a single return without the possibility to access and separate First Pulse, Last Pulse or intensity data.

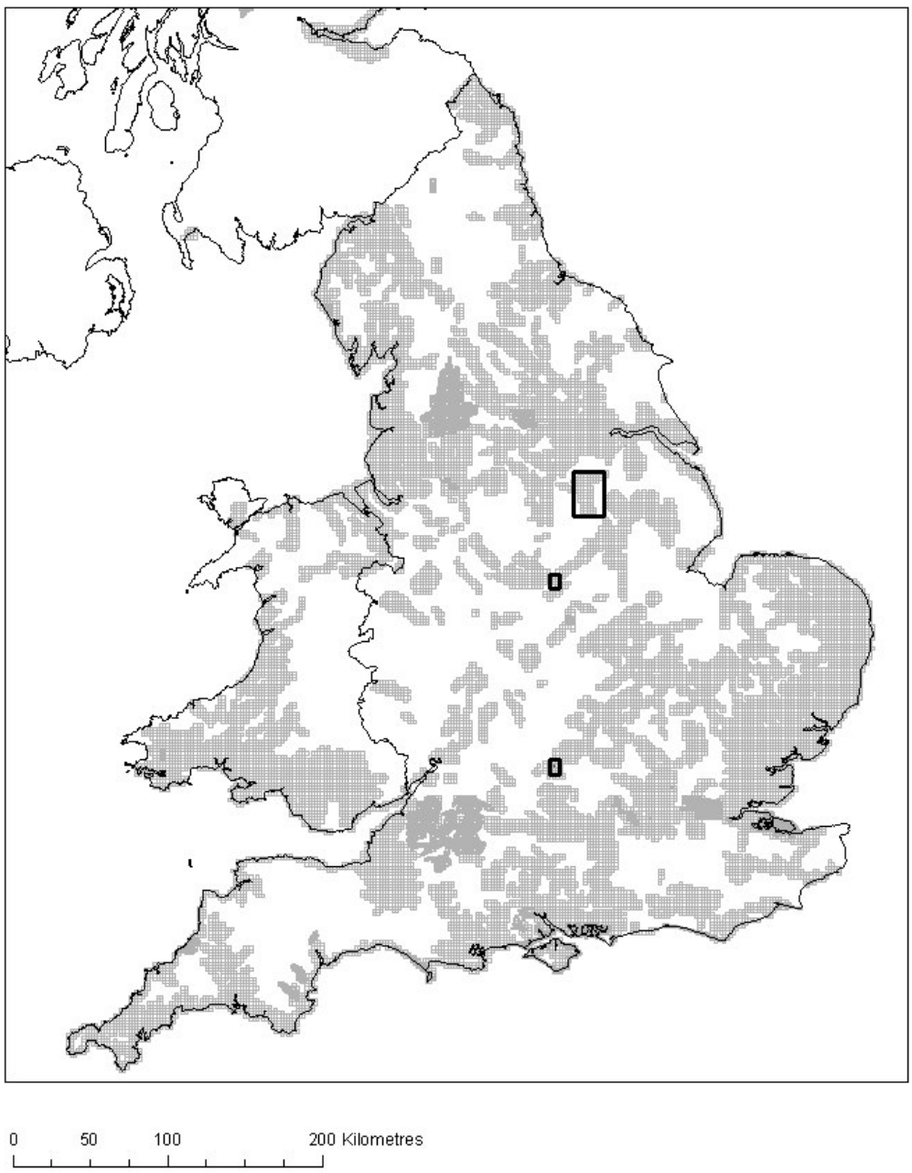


Fig. 3. Map showing the extent of the 2005 LiDAR coverage in grey (courtesy of Environment Agency)

Since 2002, such huge Lidar datasets has been exploited for archaeological prospections (Holden et al., 2002; Challis, 2006; Challis & Howard, 2006; Challis et al., 2008).

By exploiting different way of visualization of DTMs (shading procedure and vertical exaggerations), Holden et al. (2002) was able to identify and record the slight earthwork traces of a Roman Fort at Newton Kyme (in West Yorkshire) which was under the plough for decades. This site was characterized by earthworks, less than 1 m in height, and, for that, it had been missed by previous traditional aerial surveys.

This study led the English Heritage to commission a LiDAR survey specifically for archaeological investigation of the famous Stonehenge World Heritage Site. The project took place in the period March-July 2001 and was focused on the assessment of how many known sites not completely levelled by ploughing could be detected in the Stonehenge using LiDAR survey. To this aim, DTM and DSM were derived from the last and first pulse LiDAR point cloud, respectively, with a ground resolution of 1 m. Data interpretation was facilitated using color coding or continuous grey scale to enhance topographic details; whereas, "a digital sun", i.e. changing the direction of the digital illumination on the DSM was applied to visualize features.

The results of this investigation exceeded any expectations, as described in Bewley et al. (2005). In detail, LiDAR strongly contributed to the study of the Stonehenge landscape and to the detection of unknown sites. This was done by means of: i) the elimination of vegetation which hid features of archaeological interest, thus allowing to analyze their "inter-visibility" respect to the monumental area and to explore their spatial relationships; ii) the determination of the "Stonehenge view" of the other monuments using the Viewshed analysis; iii) interpretation of Relief shaded images to enhance the topographic location of unknown and known Neolithic sites; iv) Integration of LiDAR with images from CASI (Compact Airborne Spectrographic Imager) to provide information of vegetation, geomorphology and other features useful for the study of the landscape.

LiDAR data provided by the Environment Agency were used by Challis (2006) to map alluvial geomorphology. The author presents three different way of producing a DTM suitable for geoarchaeological purposes: (1) a 3x3 "grid cell variance filter" to remove areas of the DSM above a threshold limit (set at a 66.6° slope gradient), and replace them with new elevation values obtained by interpolating the gaps, (2) a high-pass filter to remove landscape clutter; (3) the generation of a simulated first and last-pulse from a single return. Challis suggests that all these three methods produce DTM with artifact but, for most geoarchaeological applications, the access to the first and last pulse data is desirable; whereas, the removal of landscape clutter is not a critical point to be addressed and, therefore, it can be skipped. Challis showed that LiDAR products, in particular the DSMs, are particularly effective for mapping features in floodplains dominated by lateral channel movement and desiccated peat. Whereas, it is less effective in upper river banks, which are dominated by rapid erosion with poor survival of palaeo-landscape features as well as in lower river banks where accretion is the dominant process.

Later, Challis et al. (2008) assessed the potential of LiDAR to enhance existing records of the historic environment of the River Dove valley. These data were compared with the existing inventory of sites and with a selected sample of vertical aerial photographs. Authors grouped earthwork features of archaeological interest in different categories including: agricultural remains (such as ridge and furrow), settlement remains, quarries and other features considered as evidence of past human activity. Each feature was listed and digitized as a polygon within a GIS environment, and compared with pre-existing records of the historic environment held by the local authorities. First, the number of sites found by LiDAR was compared with the number of sites in the existing Historic Environment

Records; then a selected number of aerial photographs was used to assess their extension. Around the 84.4 % of the archaeological features captured by the LiDAR survey were previously unknown. Anyway, it should be considered that some known features already recorded were not recognized by LiDAR. The majority of these were cropmarks or artifacts and buildings

Crutchley (2006) used LiDAR data derived from UK Environmental Agency to analyze four different case studies (Southrey, Barlings cemetery, Stixwould, Bardney environs). He employed a vertical scale exaggeration of elevation to analyze the LiDAR data for microrelief identification. Crutchley showed that Lidar clearly has potential for recording certain site types and especially in highlighting relationships between sites in the broader landscape, nevertheless, he highlighted the importance of not using LiDAR data alone, but as a part of all readily available sources.

Barnes (2003) studied the Salisbury Plain Area, located in the heart of Wiltshire (Southern England),. In this area, extensive remains dating back from the Neolithic (ca. 4000–2400 BC) to the late Roman period (5th century AD) are still visible as earthworks. Around 2300 individual sites and burial mounds were recorded. Two different LiDAR data set, acquired in January and February 2001, were used along with CASI imagery, which were very useful to map bare ground, to identify archaeological earthworks and different types of scrub.

Devereux et al. (2005) conducted a study in a prehistoric hill-fort at Welshbury Hill, in the Forest of Dean, Gloucestershire. The prehistoric earthwork was scanned using a conventional ALS Optech ALTM 3033 system of the Unit for Landscape Modelling of the Cambridge University. Two separate surveys of the site were conducted with a spatial detail at (i) 4 points per square meters and (ii) 1 point density per square meters respectively. Point clouds were converted to 0.25 m and 1 m grid respectively. To ensure the maximum laser penetration, the surveys were conducted in winter (on February 2004), when the leaves are falling and understory is at minimum. The DTMs revealed a possible Bronze Age field system varying the direction of the illumination source to easily detect feature on hill shaded DEMs.

4.4 Greece

In Greece, Rowland and Sarris (2007) used LiDAR combined with multi-sensor airborne remote sensing data from CASI and Airborne Thematic Mapper in order to locate the presence of exposed and known buried archaeological remains in Itanos (Eastern Crete). The LiDAR data were acquired using an Optech ALTM 3033 high-resolution airborne laser scanner with a point density of 1 per square meter. In this research DEM derived from LiDAR was used to identify the presence of new archaeological features such as, abandoned terraces and a circular depression.

4.5 Ireland

In Ireland, in the framework of the Discovery Programme aerial LiDAR were acquired in 2007 using the system FLI-MAP 400. Some studies were carried out on the basis of this dataset to map and identify archaeological features, among them, we cite Carns and Shaw (2009) Data were acquired for two different sites: (i) abandoned medieval settlements in Newtown Jerpoint (Kilkenny) and (ii) a prehistoric hillfort in Dún Ailinne (Kildare). The two surveys were carried out at two different resolutions (Newtown Jerpoint 50 pts/m2, Dún

Ailinne 15–30 pts/m2) in order to successfully record subtle topographic features in the two different investigated environs. The authors suggest that LiDAR can well record subtle features of archaeological interest at high spatial resolution, with a great level of definition, in short time and with a cost-effective way.

4.6 Belgium

In Belgium, Werbrouck et al. (2009) performed an interdisciplinary landscape study concerning the history of the settlement and environments in the north of Ghent (Flanders). This study is manifold and aimed to create a 'clean' topographical surface to be (i) investigated by archaeologists and (ii) used by soils scientist in their modelling procedures. The study area covers around 1400 km² which corresponds to the northern part of the Pleistocene valley of the Scheldt River.

Stal et al., (2010) focused on investigating remains of trenches of the First World War around Mount Kemmel, in Flanders. According to the authors, even if some of these trenches still exist, they have today subtle height differences with the surrounding surface, and, therefore, can not be detected by conventional techniques, such as fieldwalking and/or aerial photography, but LiDAR can overcome these drawbacks. An aerial survey was carried out in 2008 with an average point density of around 5 points per square meter. They obtained (i) a DSM from a random division of points interpolated with a grid at fixed resolution of 50 cm; and (ii) a DTM after filtering out non-ground points at the same resolution as DSM (50 cm). Then, the DTM was manipulated using filter also based on convolution.

On the basis of the obtained results, the authors pointed out that LiDAR DTM was a very useful tool for detecting subtle remains of trenches of the First World War, but, the data processing and filtering techniques are a critical step. This requires a careful evaluation and selection of the procedures useful to emphasize and detect microrelief. For example, for this study, Laplace and high-pass filter were not satisfactory, whereas Sobel filter and the pseudo-hillshade offered good performance.

4.7 Austria

The limits of conventional ALS in discriminating the low vegetation and underlying terrain have been dealt with by Pfeifer et al. (2004).

Doneus et al.(2008) investigated the potential of full-waveform airborne laser scanning (RIEGL Airborne Laser Scanner LMS-Q560), to investigate an Iron Age hillfort located in a forested area called Purbach, in Austria. Authors discuss in detail the LiDAR data processing and filtering. According to the authors the full-waveform scanner allowed more off-terrain points to be removed from the raw data than a conventional ALS and this creates a better terrain model. A good filtering between terrain and off-terrain points is very important to improve the archaeological detection of subtle micro-topographic features such as barrows obscured by forest. The resulting DTM reveals the entire hillfort with even subtle structures, as for example small shallow depressions on top of round barrows, which result from looting. A comparison with a detailed topographic mapping of the visible archaeological traces from the 1960's demonstrated that even very low earthwork features. As for example round barrows with a vertical extension of 20 cm (or even less), were identified in the DTM even tough been missed by the original trained surveyors in the field.

4.8 Italy

In Italy Coren et al. (2005) used LiDAR data along with hyperspectral images to improve information on the archaeological area of Aquileia (UD, North-East of Italy). Hyperspectral data allowed the identification of specific humidity, vegetation and thermal conditions, whilst accurate geometric information were provided by LiDAR. Feature detection was carried out using different filters, such as, High filter, Low filter, Laplacian Filter, etc.

Danese et al. 2008 focused on the processing of DTM obtained from LiDAR using the Viewshed Analysis to obtain information about the extension of the area under the "visual control" of a Mediaeval castle clinging to the top of a hil. Moreover, the authors also attempted a reconstruction of the medieval landscape based on the estimation of the location of the cultivated areas within given time slices. The LiDAR- DTM was also processed using site catchment analysis based on the distance that could be travelled out from the focus during the course of a day's journey. Results from this study allowed the identification of potential land uses obtained for one/two hour(s) Site Catchment.

Lasaponara et al. (2010a) focused on the potentiality of the latest generation of airborne ALS in the detection and spatial characterization of microtopographic relief linked to archaeological features. The investigations were carried out for Monteserico, an archaeological area in the Basilicata Region (Southern Italy) characterized by complex topographical and morphological features, which make air/space prospection very difficult. The LiDAR survey allowed the detailed identification of small surface relief and differences in height produced by surface and shallow archaeological remains (the so-called shadow marks), which were not visible from ground or from optical data set (aerial photo and satellite images). Using the high resolution DTM obtained from LiDAR the authors reconstructed the urban shape of the medieval village in great detail. The authors pointed out that the DTM-LiDAR data is a powerful instrument for detecting surface discontinuities relevant for investigating cultural features.

Moreover, the same author groups evaluated the capability of LiDAR data (Lasaponara et al. 2010b) to detect and discriminate micro-topographic relief linked to archaeological remains from natural geomorphological features. Results from the analyses performed in processing the DTM-LiDAR using geostatistical methods pointed out that the LiDAR is a powerful instrument for detecting macro and micro elevation changes, which are generally very critical to evaluate. The DTM obtained from LiDAR provided a sound basis for geomorphological interpretation, useful to detect surface discontinuities (e.g. breaklines, lineaments) and forms as well as to identify surface features relevant for geomorphological processes of the study area.

Finally, the authors suggested that despite the great potential of LiDAR in archaeology, the use of ALS data encounters serious challenges and still requires specific research, addressed to both (i) pre-processing (filtering and classification) to obtain detailed DTM and also to (ii) the post-processing to extract information (pattern extraction, classification). This challenge has been partially addressed by Coluzzi et al (2010) who defined the data processing chain along with the threshold-based algorithm for the classification of ground and non-ground points and for the detection of archaeological remains. The classification of laser data was performed using a strategy based on a set of “filtrations of the filtrate” (for more detail see section 4). Appropriate criteria for the classification and filtering were set to gradually refine the intermediate results in order to obtain the vegetation heights and to discriminate between canopy, understory and micro-topographic relief linked to terrain or earthwork. To test the algorithm performance, some sample areas on hill environments with different morphological

features and cover types, were processed and analyzed. Results from these investigations pointed out that the devised data processing enables the detection of micro-topographic relief in sparsely as well as in densely vegetated areas. The most important facts to cope with different environmental situations are mainly linked with (i) the resolution of the acquired data set and (ii) the data processing chain specifically devised for archaeological purposes.

4.9 USA

In the USA LiDAR in Archaeology represents a very small percentage of the applications of LiDAR. For sake of brevity we cite the follwing experiences.

Harmon et al. (2006) assessed the utility of 1 m resolution LiDAR for studying historic landscapes in two eighteenth-century plantation sites located near the Chesapeake Bay, in the state of Maryland. DSM LiDAR used in this study was obtained from the first return, whilst DTM from the last return. Relief detection was carried out by a visual analysis and also using enhancement of DEM based on hillshade surface models and contours maps.

Gallagher and Josephs (2008) used LiDAR to detect pre and post-European sites in the dense woodland of Isle Royale National Park (Michigan, USA). LiDAR data were collected with a conventional sensor and filtered by using TerraScan software. Grid DTM was derived from the last return (ground level) processed with a spatial resolution of 2 meters.

LiDAR bare-Earth models were used to 'see through' the vegetation in an effort to: (i) identify cultural features prior to the implementation of a pedestrian reconnaissance survey; (ii) aid in the development of a more informed survey strategy; and (iii) produce more efficient and cost-effective research design.

The identification of potential archaeological features from the LiDAR- DEM was based on four visual criteria and the degree to which the features appeared anthropogenic versus non-anthropogenic:

i. Shape: large or small; linear, sinuous, rectilinear, circular, conical, or cubic; mounded or depressed.
ii. Pattern: isolated, clustered, aligned, scattered.
iii. Texture: degree of smoothness or coarseness, based on the frequency of tonal changes on the image.
iv. Shadow: it provides an impression of the feature's shape in profile and can be a primary aid in feature recognition. Finally, shadows can also act to obscure irrelevant features.

Thirty-two potential archaeological features were interpreted from the imagery; 18 were previously recorded. A field survey enabled the localization of the larger number of features (previously recorded or newly discovered). Romain and Burks (2008) used LiDAR data for studying a 2000-year-old road that was mapped several times in the 1800's and was subsequently destroyed by urbanization or cultivation in Ohio. A segment of road was preserved in a wooded area with 30 cm embankments rising above either side of the path. Several profiles taken along the road showed that its morphology matched another ancient road segment in a different part of the state. In order to locate the parallel-walled Road leading from the Newark Octagon toward Ramp Creek, the authors used conventional LiDAR survey, which send out between 2000 and 5000 pulses per second. DEM was obtained at 2 meters. Results form Romain and Burks investigation showed that LiDAR provide not only surface maps, but, also new useful information extracted from the profile tools.

Chase et al. (2010) applied LiDAR-derived images in a tropical region, the jungle in Caracol, Belize, to study a very important ancient Maya site. The survey carried out by Optech GEMINI Airborne Laser Terrain Mapper (ALTM) covered a total area of around 200 sq km. The LiDAR derived product were a 1-m (DEM) for bare earth, and a 1-m Canopy Surface Model (CSM) for canopy top points. LiDAR data helped to reconstruct the topography of the landscapes, but, also structures, causeways, and agricultural terraces – even those with relatively low relief of 5 to 30 centimeters. Moreover, they were useful to demonstrate the ability of the ancient Maya to radically modify the landscape in order to create a sustainable urban environment.

5. A LiDAR approach for archaeological purpose

In the following section a methodological approach based on the use FW LiDAR is shown for two study cases in Southern Italy (fig. 4). One is Monte Serico, a bare-ground site located in Basilicata dating back to Medieval Age. The DTM has been used to identify microrelief related to the urban fabric of the medieval settlement.
The other study case is the Wood of Incoronata (in Apulia) which covers an interesting palaeohydrographical pattern.

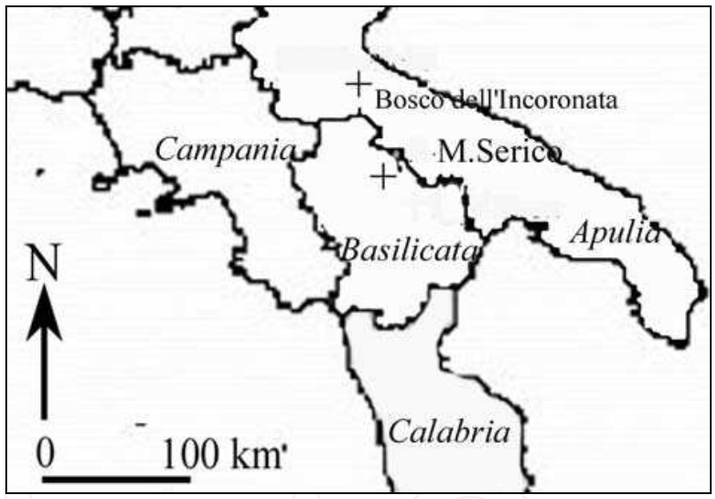


Fig. 4. Location of the study cases.

5.1 From data filtering to classification

The identification of archaeological features (form earthworks to surface structures) for both bare and densely vegetated areas, requires a very accurate DTM. To this aim, it is crucial to carry out the classification of terrain and off terrain objects by applying adequate filtering methods. In the examined study cases, we adopted the progressive Triangulation Irregular Network (TIN) densification method by Axelsson (2000). The algorithm starts from a coarse TIN surface obtained from reference points which are neighbourhood minima. Then new points are added, in an iterative way, if they meet criteria based on distances to TIN facets and angles to the vertices of the triangle. This algorithm has been embedded in Terrasolid's Terrascan commercial software (http://www.terrasolid.fi/en/products/terrascan). For its implementation, some parameters included maximum building size, terrain angle, iteration angle, iteration distance, and maximum edge length have been assigned.

The initial setup involved importing all the necessary raw data into the processing software, applying coordinate transformations and calibration, which is based on the comparison of the laser data produced by different flight passes which overlap each other.
Later, both DSMs and DTMs have been obtained from the classification, which was herein performed using a strategy based on a set of "filtrations of the filtrate". The workflow can be summarized as follows: i) Low point Classification; ii) Isolated points Classification; iii) Air points; iv) Ground Classification; v) Classification of points below surface; vi) Classification of points by class; vii) Classification of points by height from ground for different heights.
The data classification process started by including all the point cloud into a single class, called the default class. Then, the elimination of outliers points has been performed through classification of : (i) "low points", (ii) "isolated points", and (iii) air points. The first has found single points or groups of points with a height lower than 0.5 m compared to the other points within a ray of 5 m. The second routine has identified isolated points such as points present in the air (for example birds, etc.). The third one has detected points present in the air not classified as isolated points.
The following processing step has been based on the Axelsson TIN model (Axelsson, 2000) in an attempt to define a "ground" surface. To accept or reject points as being representative of the "ground" it has been necessary to define some geometric threshold values, which prescribe possible deviations from the average topographic surface.
A triangle of the primary mesh is progressively densified by adding a new vertex to a point inside it. The "Classification of points below surface" allowed us the identification of points under the surface level, such as wells or similar. Such classification was performed setting the standard deviation value at 8 with 0.01 m tolerance value.
The latest two classifications (vi and vii) identified and classified points according to a given class or height, respectively. All points left into the default class have been considered as vegetation. Finally, using "Classification of points by height from ground for different heights" three classes have been considered low (< 0.25), medium (0.25 to 2 m) and high (> 2 m). Further classification enabled the discriminations of cars, walls, buildings, vegetation types, etc. Finally, the DTM was created using Terra Modeller on the basis of the classification of terrain and off terrain objects performed using the whole processing chain from (i) to (vii) step.

5.2 Post processing: the shading procedure approach.

In order to emphasize archaeological features with particular reference to micro-relief shading procedures have been used. Several routines, embedded in commercial software allow different solutions, such as the visualization of the elevations by using color graduations and the slope of the terrain, in order to identify the portions of the terrain that are relatively flat vs those that are relatively steep.
For the visualization of elevations it is useful to enable Hill Shading option to view elevation data as shaded relief. With this option shadows are generated using the loaded elevation. To do it, it is necessary to light the DTM by an hypothetical light source. The selection of the direction parameters (zenith angle z and azimuth angle) depends on the difference in height and orientation of the micro-relief of potential archaeological interest. Single shading is not the most effective method to visualize and detect micro-relief. If features and/or objects are parallel to the azimuth angle, they will not create a shadow. As a result, it would not be possible to distinguish them.

The problem could be solved by observing and comparing DTM scenes shaded by using different angles of lighting, as done for the two study cases and presented in the following sections.
In addition the different shaded DTM scenes have been processed by using the Principal Components Analysis (PCA) (Stal et al. 2010), which is a linear transformation which decorrelates multivariate data by translating and/ or rotating the axes of the original feature space, so that the data can be represented without correlation in a new component space. For our application, the PCA transformed the input shaded DTMs in new components in order to make the identification of distinct features and surface types easier. The major portion of the variance is associated with homogeneous areas, whereas localized surface anomalies will be enhanced in later components, which contain less of the total dataset variance. This is the reason why they may represent information variance for a small area or essentially noise and, in this case, it must be disregarded.
Finally, convolution filtering techniques (Laplacian, directional, Gaussian High Pass) have been performed

5.3 Monte Serico case study

5.3.1 Study area and previous investigation

Monte Serico site is found on a hill located with an elevation of around 590 m a.s.l. which faces over a wide territory characterized by hills and plain crossed by the Basentello river in the Northeast side of the Basilicata Region (Southern Italy, see fig. 4).
From a geological point of view, the stratigraphic sequence is composed of Subappennine Clays, Monte Marano sands and Irsina conglomerates. Sporadic herbaceous plants grow over the investigated area.
Historical sources state that around the 11th century, a castle was built on the hill; whereas a village is attested to the 13th century and gradually abandoned between the end of the 14th and the first half of 15th century. Today the only buildings remaining are the castle and a church (see A and B in fig. 4). On the southern side of the hill, the presence of earthenware, pottery and crumbling building materials, indicates the existence of a buried settlement. The latter has been discovered in 1995, by means of aerial photos (Masini 1995). The use of QuickBird images allowed us to improve the spatial characterization of the urban shape (Lasaponara & Masini 2005).
A more detailed reconstruction of the urban fabric has been obtained by LiDAR survey carried out by GEOCART on 20th September 2008 using a full-waveform scanner, RIEGL LMS-Q560 on board a helicopter.
The data filtering and classification has been performed as described in section 4.1. Table 1 shows the threshold values assigned to classify ground and non ground points. The classification allowed us to obtain a DTM which puts in evidence the urban fabric characterized by a radio-centric pattern on the southern slope of the hill which develops according to the level curves (see fig. 5). Such features are also visible from the 1995 aerial image (Masini 1995) and the satellite data (Lasaponara & Masini 2005).
The DTM (fig. 5) shows other micro-relief which exhibit an alignment in the E-W direction, at southwest of the hill.
The geomorphological study based on the analysis of DTM allowed to better discriminate, respect to the available optical dataset, the features of archaeological interest from those linked to geomorphological phenomena (erosion and creep) (Lasaponara et al. 2010).
In the study of Lasaponara et al. (2010), the only post processing has been performed by using spatial autocorrelation statistics. It was mainly aimed at enhancing geomorphological

features. It allowed us to better survey landslide niches on the south-western foot of the hill and linear erosion phenomena on the Southern slope, and discriminate the morphological step and the lithological boundary between the Irsina conglomerates and the Monte Marano

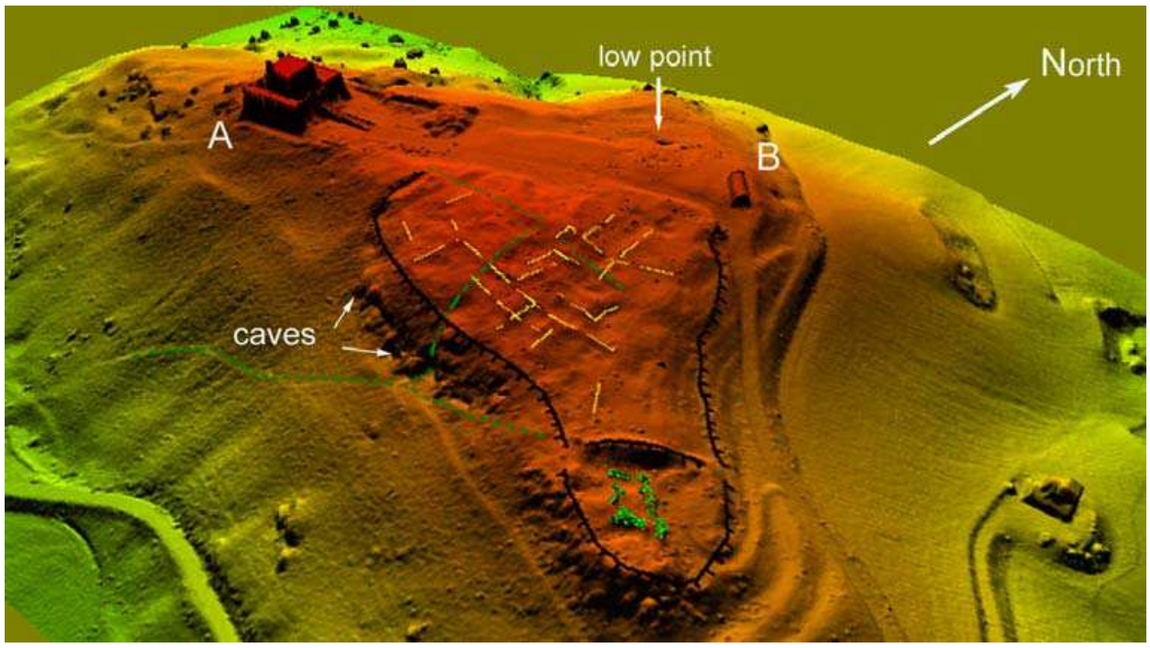


Fig. 5. Monte Serico study case: 3d DTM with archaeological interpretation of micro-relief. The picture shows a radio-centric urban shape, the castle (A), the church (B), some caves along the southern morphological step and the location of a point below surface, related to the presence of an under-ground cave.

Parameter	Maximum building size (m)	Terrain angle (°)	Iteration angle (°)	Iteration distance (m)	Max edge (m)
value	60	88	20	0,80	5

Table 1. Threshold values assigned to classify ground and non ground points

5.3.2 Post processing of DTM to improve the knowledge of Monte Serico: aims and results

The same DTM already analyzed in Lasaponara et al. (2010) is herein object of further post processing using different shaded DTM scenes. For Monte Serico study case, the comparative analysis of different shaded DTM seems to be particularly suited, due to its complex morphology which makes the accurate identification of archaeological micro-relief very difficult.

The visual analysis of shaded DTM, obtained from different light sources, highlights additional archaeological features. In particular the shaded DTM at azimuth equal to 90° (fig. 6a) shows rectangular micro-relief at the centre of the southern slope. Whereas in the shaded DTM at azimuth equal to 360°, several other micro-relief could be observed at south eastern angle of the scene (fig. 6d).

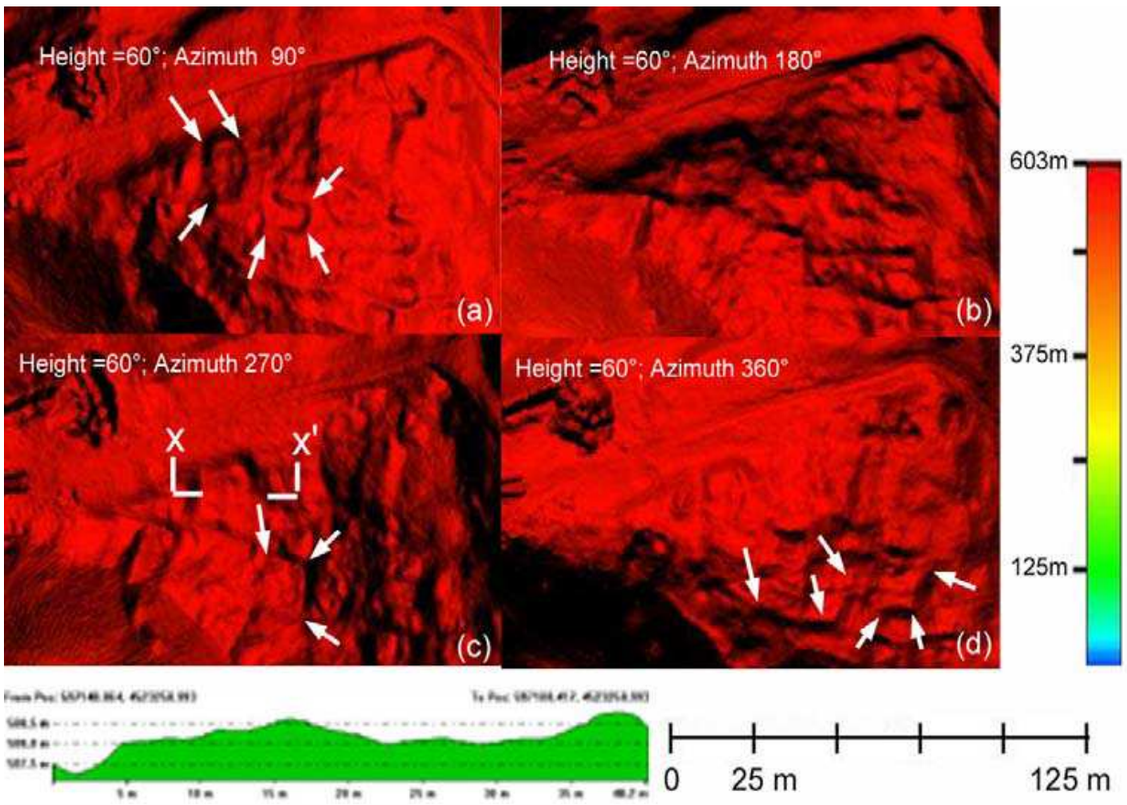


Fig. 6. Shaded DTMs at zenith angle of 60° and azimuth angles, from a to d, respectively equal to 90°, 180°, 270° and 360°.

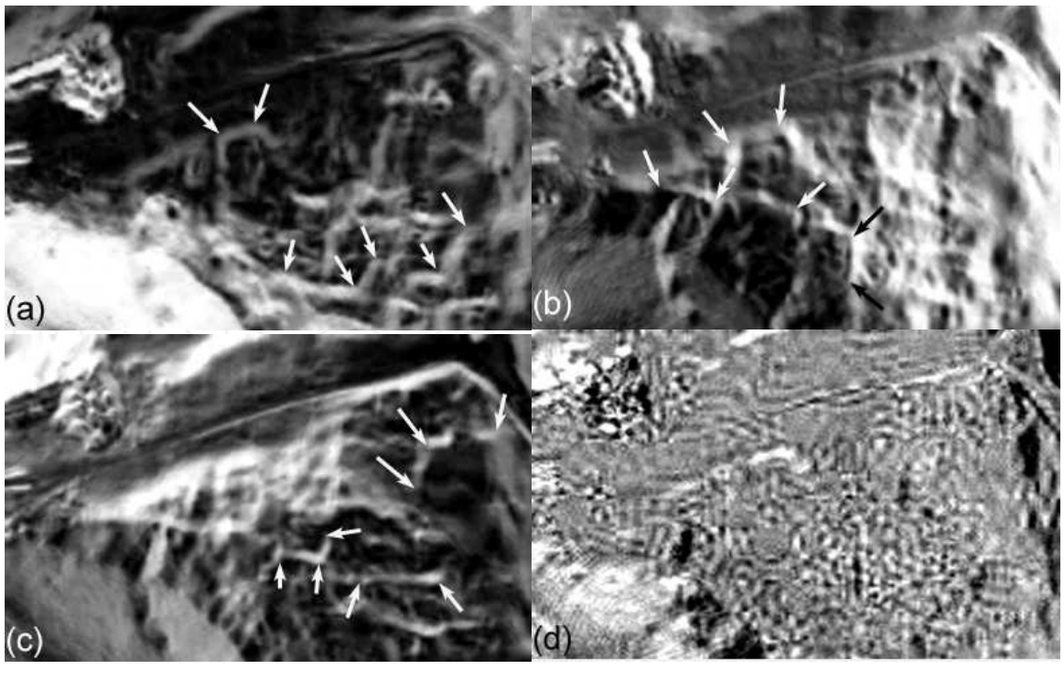


Fig. 7. The first four principal components.

These shaded DTMs have been further processed using Principal Component Analysis. It provided additional information on the urban fabric and emphasized archaeological features, already visible from shaded DTMs.
In particular, the result of the first component (PC1) is the average of all input shaded DTMs and looks like an edge thinning of the pattern of micro-relief (see fig. 7a).
The second component, PC2 emphasizes some micro-relief at southeast, mostly aligned in E-W direction.
The third component, PC3, improves the visibility of features at South and North of the shaded DTM.
Finally, the fourth component, PC4 is disregarded because it contains substantially noise.

5.4 Wood of Incoronata

The second study area, herein considered, is the natural park of Bosco dell' Incoronata that has an extension of around 1060 ha, with 162 ha of woodland (*Quercus pubescens*) and 115 ha of prairies.
The study area is located 12 km away from Foggia within the Tavoliere delle Puglie in the Apulia Regione (see fig. 4).
The investigated area is an important site from the naturalistic, historical and archaeological point of view. Bosco dell'Incoronata is an ancient lowland forest that was still present in the medieval time, and has been characterized by long and intensive human activity probably from Neolithic to Middle Ages (Mazzei, 2003) as evident from archaeological remains and historical documentation. As regards to the medieval time, historical record attests that Frederick II of Hohenstaufen (26 December 1194 – 13 December 1250) used to spend long periods in Foggia, which was a strategic position to reign over a vast territory extending from German to Sicily.
During Frederick's kingdom two royal residences, "*Palacium Pantano*" in S. Lorenzo and the "*Palacium dell'Incoronata*", were specifically built or restored for the imperator. Both of them were located very close to Foggia. Over the years "*Palacium Pantano*" has been widely investigated and partially restored, whereas the location of "*Palacium dell'Incoronata*" is still unknown today. It is thought that such location is very close to the Bosco dell'Incoronata and probably within the medieval forest area which is still present today and also known as the Frederick's woodland.
Our investigations have been mainly focused on the identification of traces of ancient landscapes and paleao-environmental features in order to improve knowledge about the transformation of the territory. Knowledge about palaeo-landscape features still fossilized in the modern landscapes is a crucial point and an invaluable data source for performing detailed archaeological investigations, for the identification of the environmental changes and of the underlying processes.
Unfortunately, in this area traces of past human activities are quite subtle and scarcely visible from aerial photographs and optical satellite images, because of the intensive agricultural activity of the whole area. Arable lands appear everywhere from images shown in figure 8 a s a result of the major post-war land reforms. This long and intense agricultural activity, along with the use of agricultural equipment and machinery for production, has generally destroyed traces of past landscapes.
Nevertheless, subtle microtopographic relief may be still preserved and visible from a detailed DTM.

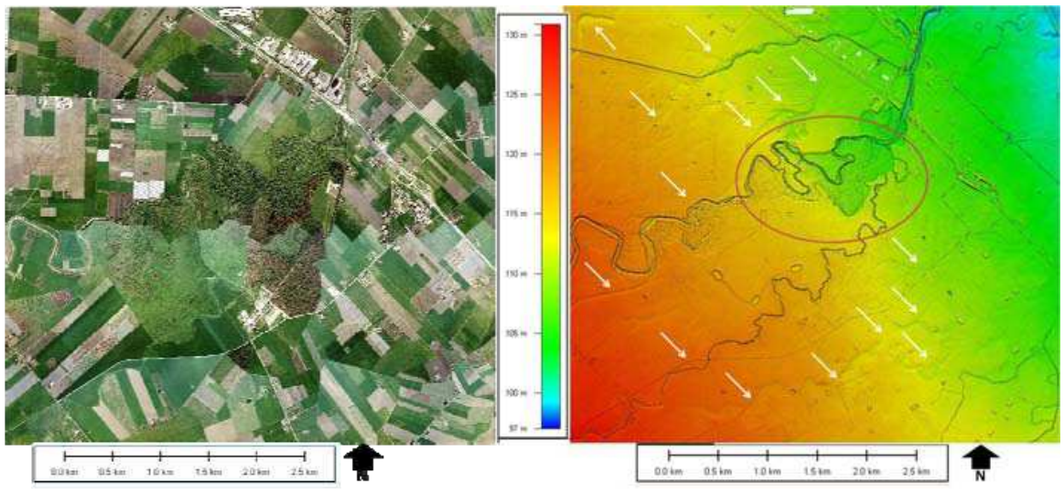


Fig. 8. Bosco dell' Incoronata within the Tavoliere delle Puglie (Southern Italy). (left): Orthophoto at a spatial resolution of 0.15 m. (right): DTM . White arrows denote the palaeodrainage system. The red circle show the complex system hidden by the woodland.

In order to throw light on the landscape changes an investigation based on the use of LiDAR data has been made (Lasaponara et al. 2010). The survey has been carried out by using a full-waveform scanner, RIEGL LMS-Q560 on board a helicopter. The data filtering and classification has been performed as described in section 5.1. Table 2 shows the threshold values assigned to classify ground and non ground points.
In our previous study (Lasaponara et al. 2010) we showed how spatial autocorrelation statistics applied to the DTM–LiDAR can help to detect surface discontinuities and microtopographic relief linked to palaeoenvironmental features.
In this study case, we want test how LiDAR data can contribute to the knowledge of the historical landscape, exploiting and processing different shaded DTMs.
Figure 8-left shows the orthophoto of the area, acquired simultaneously with the LiDAR data. It has a spatial resolution of 0,15 m. In the image we can recognize the woodland, which is very close to the Cervaro river.

Parameter	Maximum building size (m)	Terrain angle (°)	Iteration angle (°)	Iteration distance (m)	Max edge (m)
value	60	88	4	1,40	5

Table 2. Threshold values assigned to classify ground and non ground points for Bosco dell'Incoronata.

The DTM extracted from the LiDAR data (see fig. 8, right) visualizes the general topography of the valley and reveals extensive geomorphological details of the plain, not visible from the orthophoto (fig. 8, left), such as a wide and complex drainage system (see circle red in fig. 8, right) covered by dense tree canopy.
Other palaeo-riverbeds along with modern rivers and channels, on agricultural areas, are also more evident in the DTM (see white arrows, in fig. 8, right) than in orthophoto.
To better identify the palaeo-hydrographical pattern, different shading views of DTMs have been observed. Then the PCA is applied on the shaded DTMs.

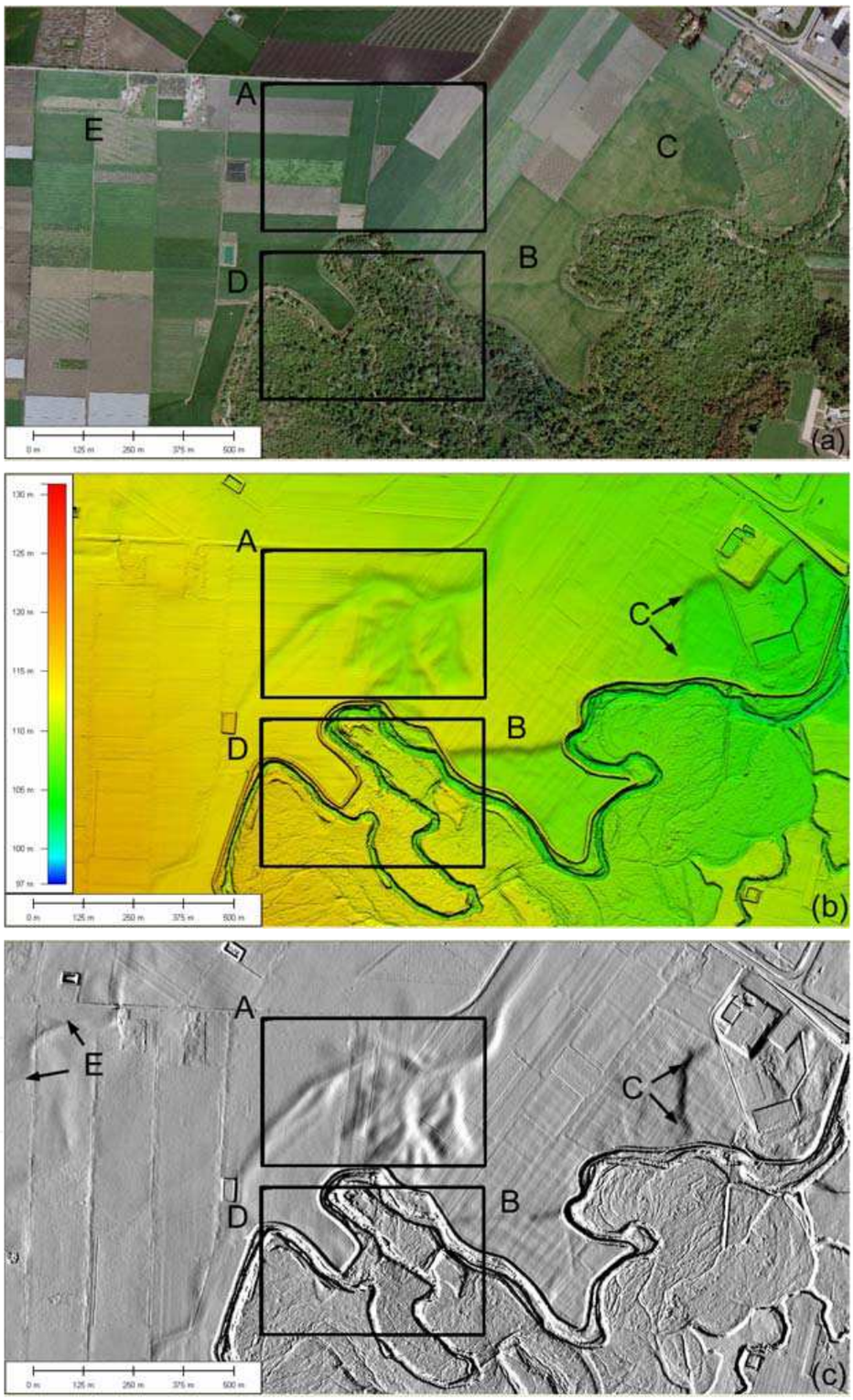


Fig. 9. Detail of the study area. Orthophoto (a); shaded DTM at azimuth angle equal to 90° (b); PC1 result (c).

Figures 9a-c, shows the orthophoto, a shaded DTM view and the first component (PC1) of a a part of the study case.
The comparison of these pictures puts in evidence the improvement of
i) the shaded DTM scene respect to the orthophoto; ii) and PC1 compared to the DTM, respectively.
In particular the DTM (fig. 9b), highlights the palaeoriverbeds A and the riverbed D which are not and less visible in the orthophoto, respectively (fig. 9a) whereas the edge of the terraces B and C are visible from both the orthophoto and DTM.
Finally, PC1 (fig. 9c) puts in evidence the above mentioned features (emphasizing any of them, such as A), and other features not visible in the DTM, such as the palaoeriverbed E and some land divisions which overlap on the palaeoriverbed C.

7. Conclusions

In this chapter we offered on overlook of Airborne Laser Scanning for archaeological purposes. In particular in the first part (sections 2-4), we have dealt with the potential and limitation of the available laser scanner technology, the rational basis of LiDAR data processing (from data filtering to classification) and the State of Art of ALS in Archaeology.
In the second part (section 5) we showed the potential of using and processing point clouds surveyed by an Aerial full-waveform laser scanner on two sites of archaeological and natural interest. Their characteristics did not allow to investigate the two sites with the same effectiveness by means of remotely sensed optical data.
The first one is non vegetated hilly plateau, with several microrelief evidence linked to the existence of a buried settlement dating back to Middle Ages.
The second one is a wood which covers a palaeodrainage basin whose study is important for the reconstruction of the palaeoenvironmental setting.
The employed methodology has been based on two main steps. 1) the classification of terrain and off terrain objects performed using a strategy based on a set of "filtrations of the filtrate"; 2) the post processing based on comparing DTM scenes shaded by using different angles of lighting and following processing by PCA.
Such approach allowed us to improve, respect to the available optical data, the identification and interpretation of : i) microrelief for reconstructing the urban shape of the medieval site; ii) and the palaeoenvironmental features of the wooded site.

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Ever since the invention of laser by Schawlow and Townes in 1958, various innovative ideas of laser-based applications emerge very year. At the same time, scientists and engineers keep on improving laser's power density, size, and cost which patch up the gap between theories and implementations. More importantly, our everyday life is changed and influenced by lasers even though we may not be fully aware of its existence. For example, it is there in cross-continent phone calls, price tag scanning in supermarkets, pointers in the classrooms, printers in the offices, accurate metal cutting in machine shops, etc. In this volume, we focus the recent developments related to laser scanning, a very powerful technique used in features detection and measurement. We invited researchers who do fundamental works in laser scanning theories or apply the principles of laser scanning to tackle problems encountered in medicine, geodesic survey, biology and archaeology. Twenty-eight chapters contributed by authors around the world to constitute this comprehensive book.

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Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
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Phone: +86-21-62489820
Fax: +86-21-62489821

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