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# Applications of terrestrial laser scanning in coastal engineering

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**Abstract**
Terrestrial Laser Scanner (TLS) is a remote sensing technique which was developed for surveying primarily industrial and mine applications. Nowadays the use of TLS expands in several environmental sciences offering new capabilities. In this paper TLS is applied in coastal engineering research in order to measure sea water surface and nearshore bathymetry. The advantage of the instrument is its capability in surveying spatial and vertical resolution over distances, though under certain sea surface and wind conditions. The measurements are compared with classical surveying techniques. The results are encouraging and can contribute into developing a hybrid observation system for coastal monitoring.

*Keywords: Terrestrial Laser Scanner; water wave surface; nearshore bathymetry; coastal engineering;*

## 1. INTRODUCTION

Coastal management activities demand increasingly high resolution topographic datasets. Creating fast, low-cost and accurate coastal DEMs (Digital Elevation Model) is an important issue that helps in wave and morphodynamic modeling. Comparing DEMs from different surveys detect sediment transport and calculate changes in profiles and volumes.

While classical surveying (total stations) and RTK (Real Time Kinetics) methods provide high accuracy bathymetry, they are time consuming for large spatial coverage. Photogrammetric and airborne lidar methods can provide faster surveys for wide areas, though with lower accuracy and at increased cost. The number of modern survey equipment and techniques available reflects the distinct ranges of spatial scales and environmental conditions for which each of them is best suited [1].

Terrestrial Laser Scanner (TLS) or terrestrial Lidar is a remote sensing technique developed for surveying in primarily industrial and mine applications. Nowadays the TLS use expands in several environmental sciences offering new capabilities. Although the implementation of TLS in monitoring coastal geomorphology is particularly extensive in beach recession [2], cliff erosion [3,4] and mobile scanning [5], however, this remote sensing technology is also promising in detecting sea surface [6], wave profile evolution [7] and wave breaking [8], whereas in fluvial research has also proved helpful in detecting water surface roughness [9] and shallow water depth of 0~1m [10].

## 2. METHODOLOGY

Conventional red wavelength Lidar does not penetrate water column very well, thus limiting information on water depth, whereas green wavelength has the potential to be used for bathymetric information [9], since water absorbs green wavelengths at a slower rate than red.

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The TLS can record three-dimensional spatial data from targets within a specified line of sight; its opto-mechanical design produces rapid changes in the vertical angle of the emitted laser pulses and combined with a gradual rotation of the TLS unit in the horizontal plane, allows a view of all targets surrounding the TLS [7].

In order to investigate the use of green wavelength TLS in coastal engineering applications, an experiment is carried out to survey the nearshore bathymetry (both foreshore and inshore) and to possibly detect water surface. In the present work a Leica ScanStation2 is used having a pulsed laser at 532-nm wavelength. The distance range of the instruments is up to 300m, with a scan rate of up to 50,000 points/sec and a nominal accuracy of 6mm in position (for distances of 0~50m) and of 4mm in distance. Typically at least three spherical targets are also provided and deployed within the sight scanning view of the TLS, so once they are connected to a local or national geodetic network (e.g. by using a Total Station or a GPS RTK receiver) then later on the TLS data can be geo-referenced.

## 2.1 Study Site and Field work

The selected study area is a small pocket beach located in Artemida ("Loutsa") of Attica in Greece (Figure 1a). The beach is sandy with its front covered by sea wracks. The experiment has been conducted in spring 2014 under clear/sunny atmospheric and calm wave conditions.


**Figure 1**. a) The study site b) The deployment of the TLS (Terrestrial Laser Scanner), the TS (Total Station) and one of the spherical targets in the field site c) Measuring bathymetry by classical surveying techniques.

Initially, a topographic network was established and georeferenced with the RTK method by using a Stonex GPS receiver. In addition, the network stations, the position of two spherical TLS targets and of two fixed points were measured by a Leica TS (Total Station) model TS02 (Figure 1b). The TLS was mounted 2.65m above the sea surface, with a panoramic view of the beach front, since surveying from an elevated position helps reducing the shadowing on the lee side of the incident object [9]. The operation of the instrument is carried out via a laptop with the help of Leica Cyclone software. At first, an extensive field of view (FOV) was photographed and scanned with spatial (Horizontal) by (Vertical) sampling of 5cm by 5cm. Furthermore, eight (8) scans followed by changing the horizontal FOV but keeping constant the Vertical FOV between $0^0$ to $-45^0$. In total nine (9) data burst were collected (Table 1). Upon the scanning completion, a topographic survey was also conducted in order to obtain the bathymetry (Figure 1c) and the elevation of the sea surface.

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**Table 1**. The FOV and the resolution (sample spacing) of the scans

| Scan number | Field Of View | | Sample Spacing | |
|---|---|---|---|---|
| | Horizontal | Vertical | Horizontal | Vertical |
| 1 | $345^0$ x $180^0$ | $0^0$ x $-45^0$ | (0.05x0.05)m | |
| 2 | $65^0$ x $66^0$ | $0^0$ x $-45^0$ | (0.02x0.001)m | |
| 3 | $67^0$ x $68^0$ | $0^0$ x $-45^0$ | (0.001x0.001)m | |
| 4 | $69^0$ x $71^0$ | $0^0$ x $-45^0$ | (0.02x0.02)m | |
| 5 | $72^0$ x $75^0$ | $0^0$ x $-45^0$ | (0.05x0.05)m | |
| 6 | $75^0$ x $78^0$ | $0^0$ x $-45^0$ | (0.05x0.05)m | |
| 7 | $50^0$ x $90^0$ | $0^0$ x $-45^0$ | (0.05x0.001)m | |
| 8 | $50^0$ x $90^0$ | $0^0$ x $-45^0$ | (0.1x0.001)m | |
| 9 | $80^0$ x $90^0$ | $0^0$ x $-45^0$ | (0.001x0.1)m | |

## 2.2 Data Processing

Initially the established topographic network is solved and geo-referenced to the Hellenic Geodetic Reference System (H.G.R.S.87), followed by the calculation of tachymetric points. A bathymetric surface is produced (Figure 2a) in AutoCAD Civil 3D software and finally, with the help of an alignment, a bathymetry profile is created.

The TLS point-clouds are then geo-referenced in Leica Cyclone software by using two spherical TLS targets and two fixed points (Figure 2b). The RMS of the registration was found 4.8cm. Thus, a TLS bathymetric surface is also produced and a profile is then created at the same alignment and same position with the tachymetric survey (Figure 3b).

**Figure 2**. Orthophoto of the beach field site with (a) over-imposed bathymetric contours derived from Total station bathymetric survey and (b) with the TLS position and scanned area..

Figure 3a presents an intensity plot of all the TLS data collected at the field site (using Modelspace function ); intensity values of the TLS data are particularly useful for detecting shorelines [11] since colour variations may depict related variations in elevation/depth. Figure 3a clearly shows that TLS point density reduces dramatically with distance away from the instrument, with most data captured within 25 m away from the scanner location. Nevertheless, some TLS points from the sea surface are mixed with seabed reflections, thus making the data interpretation more difficult (Figure 3b). The scan angle may also severely affect TLS data density, which rapidly reduces as the scan angle approaches the horizontal [9].

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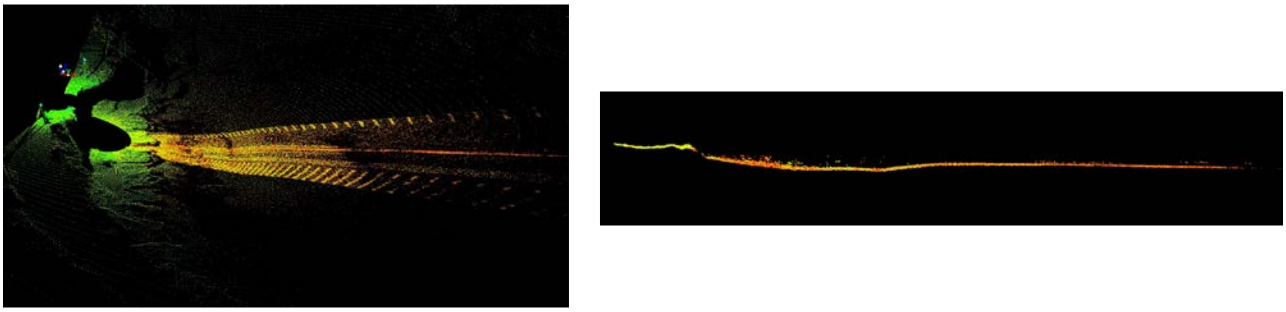

**Figure 3**. a) Intensity plot of all the TLS data collected at the field site b) Profile derived from TLS (Scan No.3)

For each TLS scan the instrument managed to survey the bathymetry and provide a seabed profile cans No 4, 6, 8 and 9 resulted into profiles without much noise; Especially scan No. 3 taken at high resolution (1mm x 1mm) and being less noisy in the range of 7~20m from the TLS location managed to survey micro-scale seabed sand ripples (Figure 4a and b); Heritage [12] showed that finer resolution of roughness leads to a better prediction of modelled flow velocity in rivers.

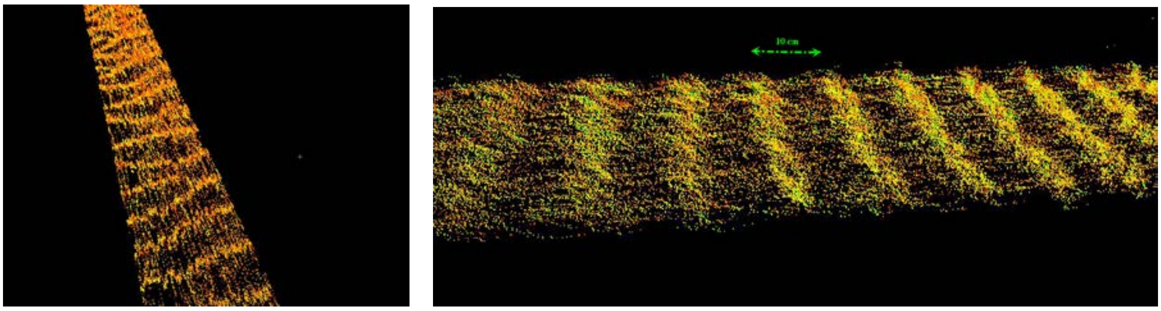

**Figure 4**. High resolution (1mm x 1mm) TLS Scan No.3 revealing the micro-bathymetry of bed ripples under clear shallow water conditions.

## 2.3 Results

Figure 5 shows the comparison of a bathymetric profile derived from conventional Total Station survey (TS profile) and from TLS measurements. The TS profile is considered as the “real” seabed topography. Within the first 10m from the shore the vertical differences between the two profiles are up to 10cm, increasing to 30cm at 10-20m distances, and finally reaching 40cm at 26m from the shore; after 26m distance the TLS becomes unable to survey the bathymetry, due to the incline angle becoming too obtuse.


***Figure 5****. A profile comparison derived from Total Station survey (red line) and TLS (green line) measurements.*

The TLS bathymetry points when evaluated against the TS measurements (used as a reference) result into a Root Mean Square Error calculated for N=50 points by Equation 1:

$$RMSE_Z = \sqrt{\frac{\sum (Z_{TS} - Z_{TLS})^2}{N}} = 0.1981 \sim 20\% \qquad \text{(Equation 1)}$$

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The 20% difference between the TS and TLS profiles can be explained by the fact that the laser beam experiences refraction; furthermore, Milan [9] reports that the resulting error in TLS bathymetry points can also be depth dependent. The accuracy of the TLS measurements can be improved by performing refraction correction model as proposed by Smith [1] for fluvial research at smaller depths and also for detecting the water surface [13]. Nevertheless, detecting water surface using TLS measurements can be problematic because reflections from a smooth water surface are specular and a laser return is only achieved when the incident angle of the beam is approximately perpendicular to the surface [6]. Therefore, complimentary water turbidity measurements need to be taken simultaneously with the TLS scans. In addition, the water surface needs to be adequately turbid in order to create diffuse reflection, since clear water, such as that found in laboratory tests, is not considered a suitable medium for laser beam reflection. The TLS returns should be validated to ensure that they are coming from the seabed layer and not from the water column or the water surface.

## 3. CONCLUSIONS

A green wavelength TLS was used to survey nearshore bathymetry and sea surface. The results are encouraging, since the TLS manages to detect seabed topography, especially within the foreshore, whereas at small depths 0~1m the instrument can capture micro-scale seabed formations. The overall TLS accuracy can be further improved by performing refraction correction models; in addition by implementing several scanning positions and mounting the instrument at higher elevation may improve the survey coverage, thus providing new potential to validate morphodynamic models within the swash zone. Although, degradation of point accuracy, precision and resolution are expected, however, they may fall within acceptable levels depending on the purpose of the survey [14]. Despite that commercial green TLS instruments have not been originally designed for detecting sea surface and bathymetry, further research can be carried out taking into account the scanning range and geometry, such as suitable incidence angles, intensity values and filtering techniques. Finally, the TLS technology can be combined with video cameras, developing a 24-hour hybrid observation system for coastal monitoring.

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