Mobile Laser Scanning of Intertidal Zones of Beaches using an Amphibious Vehicle

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Abstract

The construction of Digital Surface Models (DSMs) of intertidal zones of beaches is a challenging task. In this contribution, the use of a mobile laser scanning configuration on an amphibious vehicle (ARGO) is discussed. This mobile mapping system contains a Terrestrial Laser Scanning (TLS) in profiler mode, an Inertial Navigation System (INS), an RTK Global Navigation Satellite System (GNSS) and a PC with real-time project management software and storage capacity. Previous performance studies have demonstrated that this set-up is very promising for intertidal surface modeling in comparison with other measurement techniques as conventional topographic methods (GNSS or total station measurements). The configuration with the ARGO also enables spatial data acquisition under unsettled weather and difficult terrain conditions. Moreover, the technique appears to close the spatial incompleteness between land measurement and measurements in shallow water (with a depth of less than a few meters). A reliable survey methodology using such an ARGO is presented, based on the first results of a field campaign at the beach of Raversijde (Belgium) in the spring of 2013. The accuracy of the DSMs acquired with the ARGO is also discussed in this paper. The quality of the mobile laser scanning data is limited by various factors, specifically related to this beach environment. The humidity of the sand is a first factor that plays an essential role and is taken into account with the planning of the acquisition in relation with the twice-daily low and high tide. The incidence angle of the laser beam is related to the slope of the surface and the measured distance. The platform speed also has a significant influence on both the accuracy and the point density of the results. The measurements of two reference surfaces using static terrestrial laser scanning indicate a maximal acceptable range of 14 m. Moreover, a comparison between the mobile laser scanning data, acquired with a final speed of 6 km/h, and the reference surface on the beach indicate an accuracy of cm-level. The comparison is performed both on a beach covered with sand and on the concrete breakwater. These results and experiences will be used for later campaigns in the same area, aiming at the coverage of a large beach with high archaeological potential.

Key words: surface modelling, mobile mapping, laser scanning quality assessment

1 INTRODUCTION

The knowledge of the underwater cultural heritage in the Belgian North Sea is rather limited. Yet this submerged heritage forms an important aspect of our cultural heritage and offers huge possibilities for scientific and cultural purposes. However, this unique underwater archive is in danger due to increasing economic activities at sea, such as aggregate extraction, wind farms, dredging, fishing, etc. The project SeArch (www.sea-arch.be) offers a solution to this challenge via the development of an efficient acquisition methodology and an approach towards a sustainable management policy and legal framework. One of the contributions of the Department of Geography (Ghent University) is to create an innovative survey methodology which allows accurate and cost-efficient evaluation of the archaeological potential in the intertidal zones of the Belgian beaches.

Coastal modelling suffers heavily from data gaps between land and shallow waters. It is obvious that this area may be considered as the link between hydrography and topography, where the environmental conditions involve different incompatible or difficult physical parameters that have to be fathomed. On the one hand, common onshore techniques are not able to measure the surface topography under water due to significantly different medium conditions. On the other hand, bathymetric techniques cannot be applied in intertidal zones, due to the limited draft and the disability to operate outside the water. A thorough maritime and coastal management system requires full coverage with detailed Digital Surface Models (DSMs).

When using laser scanning for beach measurements, different important parameters are already discussed in literature, like the influence of sun elimination, sand parameters [Křemen et al., 2006] or the influence of range, local slope and surface parameters [Soudarissanane et al., 2011]. It can be shown that onshore acquisition techniques may be adapted in order to fill the gap. The selection of a specific sensor or series of sensors is finding equilibrium between different requirements, like resolution, accuracy, speed, price, etc.

2 METHODOLOGY

Initially, Airborne Laser Scanning (ALS) and Airborne Laser Bathymetry (ALB) seemed to be the most appropriate acquisition techniques for the shallow water detection. However, the Belgian coast environment is a challenging one. First, the turbidity of the North Sea is very high (the seafloor is not or hardly visible). Second, the weather conditions are rough (strong wind, frequent rain fall). Third, the water conditions of the sea can change suddenly and remain hardly predictable. And fourth, the beaches can be very crowded during the summer holidays. An ALS or ALB technique does not work in such environment. Therefore, a terrestrial solution was considered, such as a Mobile Terrestrial Laser Scanning (MTLS) system to survey the intertidal zones.

The system configuration of the MTLS used in this paper is very similar to an ALS set-up. A laser scanner, a Global Navigation Satellite System (GNSS) and an Inertial Navigation System (INS) are the main components, mounted on a driving platform. As in airborne applications, the combination of GNSS and INS measurements by the Position and Orientation measurement System (POS) provides highly accurate positioning, while the laser scanner produces a very precise point cloud. The accurate determination of the calibration parameters is also essential for the correct use of MTLS [Skaloud and Lichti, 2006].

MTLS has already been applied for river bed mapping [Vaaja et al., 2011] and also on beaches for coastal protection applications [Bitenc et al., 2011]. For intertidal beach modelling, the driving platform needs to perform in very shallow water, but also in shifting sand. Therefore, an ARGO, an amphibious vehicle, was used (Figure 1, left & middle). Although 2D profile scanners can be used for MTLS, it is also possible to deploy regular Static Terrestrial Laser Scanning (STLS) systems configured as a profiler. Nevertheless, the centimetre accuracy of both systems is comparable. MTLS has the advantage of generating point clouds of the surface in a strip-wise manner as with airborne scanning. Using the ARGO, the scanning height will be more or less equal to the height of a scanner on a tripod. The issue concerning the large incidence angles can be reduced by limiting the scanning range and allowing enough overlap between subsequent strips [Vosselman & Maas, 2001].



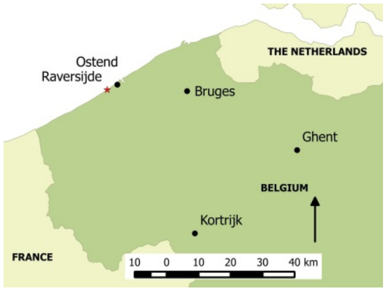

Figure 1 ARGO vehicle without (left) and with devices (middle),
Location of Raversijde (right)

The test site is situated at the beach of Raversijde, near Ostend (Figure 1, right). The area is chosen for its high archaeological potential, a criterion drawn by the SeArch project. The test site consists of three areas which are separated from each other by breakwaters. In the south, the beaches border on a dike. The survey took place at the end of spring 2013. During those days, the weather conditions were cloudy and it was not raining. Moreover, the beaches were not crowded with tourists at that time.

3 EQUIPMENT AND SET-UP

The MTLS technique is a configuration of different apparatuses: a laser scanner (Leica HDS6200), an INS (iXSea LandINS) and a GNSS receiver (Ashtech Magellan Proflex 500). As a consequence, a latency computation and a calibration of the configuration were indispensable before starting the survey. After the computation, a test survey with the ARGO could start. Besides the MTLS survey, STLS is applied using a Leica HDS6100. On account of the known accuracy of STLS, the Digital Surface Models (DSMs) constructed from the data served as reference surfaces to verify and compare the accuracy of the MTLS data. While the MTLS method was executed on the whole test area, STLS was restricted to a small area parallel to a breakwater in order to cover the intertidal zone as well.

The STLS technique is known for the acquisition of a huge amount of accurate detail points from a fixed laser scanner position. The quality of the DSMs of the laser scanning techniques (MTLS and STLS) is limited by various factors, specifically related to the beach environment. Those factors have to be taken in account during the survey. First, the beach of Raversijde has a limited slope of about 0.95° and the tidal variation in water level is about 5 m. Therefore, the beach is at low tide about 300 m wide. An important drawback is the fact that on flat terrain, the incidence angle of the laser beam will be very large. For the STLS technique, the scanner is placed on a tripod, meaning that the scanning height is around 1.5 to 2.0 m. Even with a range of 8.5 m, there will be an incidence angle of 80°, resulting in large beam spots or radiation angles. Thereupon, lower signal to noise ratios will occur and lower point accuracies will be reached [Soudarissanane et al., 2011]. Secondly, the humidity of the sand plays an essential role in the accuracy of the acquired DSMs. It has been demonstrated that the sand moisture is one of the components, besides grain size, that defines the reflectance parameter [Leu, 1977]. As the sand properties of the Belgian beaches are identical on the intertidal area [Deronde, 2008], the grain size diameter is a constant parameter (about 120 µm or 'Well sorted very fine sand' according to the Gradistat method [Blott et al., 2001]) and the influence can be omitted in this paper. A preliminary study reveals that the sand moisture has a negative influence on the point density and the accuracy of the data. As it is impossible to avoid surveying soaked sand in an intertidal zone, the moisture can be taken into account. Therefore, the acquisition planning depended on the twice-daily low and high tide. These first two parameters were secured by analysing the STLS data. The speed of the ARGO is the third factor that has a significant influence on the resolution and accuracy of the results. During the beach measurements in this project, the speed was fixed at 6 km/h.

4 RESULTS & DISCUSSION

In total, three areas separated by breakwaters had to be surveyed with the MTLS method. In order to avoid the maximum soaked sand and to maximise the overlap, the survey was well planned by taking the tides into account. The measurements started on the highest point of the beach (closest to the dyke) and they were executed in lines parallel to the dyke. As the laser scanner could not receive any data from the surface below the vehicle (dead angle) and that particular area had to be surveyed as well, the distance between two consecutive parallel lines was limited to 14 m. This range was chosen due to the process of the STLS data, which revealed that the acquired data was sufficiently accurate until approximately 14 m. To finish, the breakwaters and a transverse line (at right angles on the other lines) on each area were surveyed. This last surveyed line was used to elaborate a comparison with the other lines.

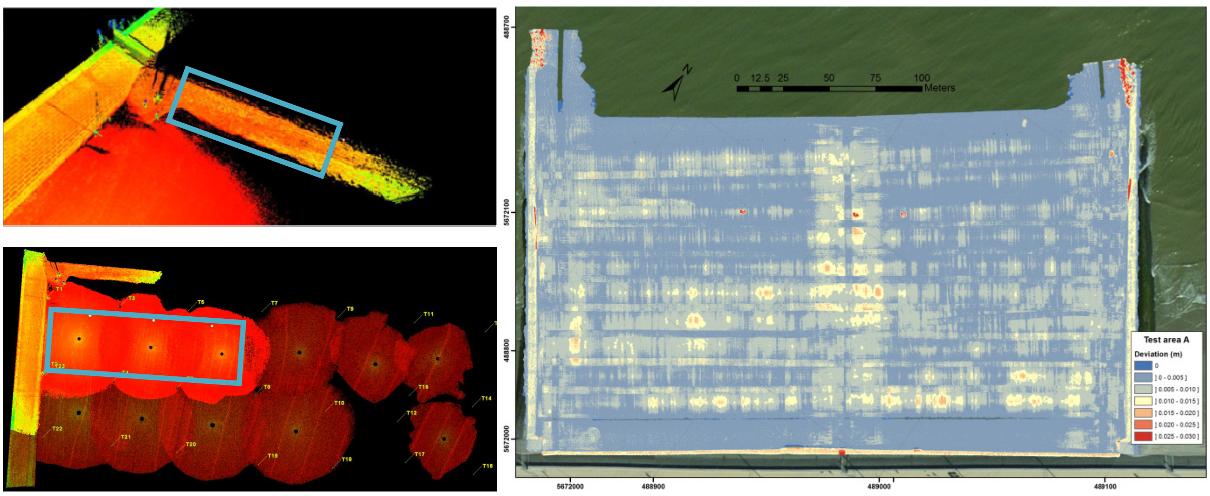

Figure 2 Visualisation of the reference surfaces (rectangle) on STLS data: the breakwater (left top) and the beach (left below) – Standard deviation map of the ARGO data; 10 cm² resolution (right)

After cleaning the noise of the data, the errors between two consecutive lines and between the parallel lines and the transverse line were computed. In overview, the analyses showed that the values were below the MTLS *a priori* accuracy. Furthermore, a map is created which presents the standard deviation of each 10 cm² of the same area (Figure 2). A visible pattern of lines indicates the driving pattern of the ARGO. The standard deviation seems to be quite high in the middle of the area. This can be explained by the higher speed of the acquisition of the transverse survey line and the lines parallel to the breakwaters. Furthermore, an increasing standard deviation is visible in almost each middle of two consecutive lines. This is explained by the following rule: the closer to the survey line, the higher the point density and accuracy. In the middle of two lines, the point density is approximately equal from both sides and the accuracy is equally moderate. Therefore, the standard deviation is less at that range.

The comparison of the data between the MTLS and the STLS is important, because the difference between both methods depends on the mobility of the devices. Two surfaces are compared, taking into account the STLS data as reference: the sloping side of a breakwater and the already quoted small area on the beach (Figure 2). A *point to mesh* computation of the data reveals a relatively high accuracy, with deviations in altimetry of only several cm. Generally, the accuracy comparison of the ARGO with the STLS technique provides good results. Moreover, this ensures that the MTLS method is reliable.

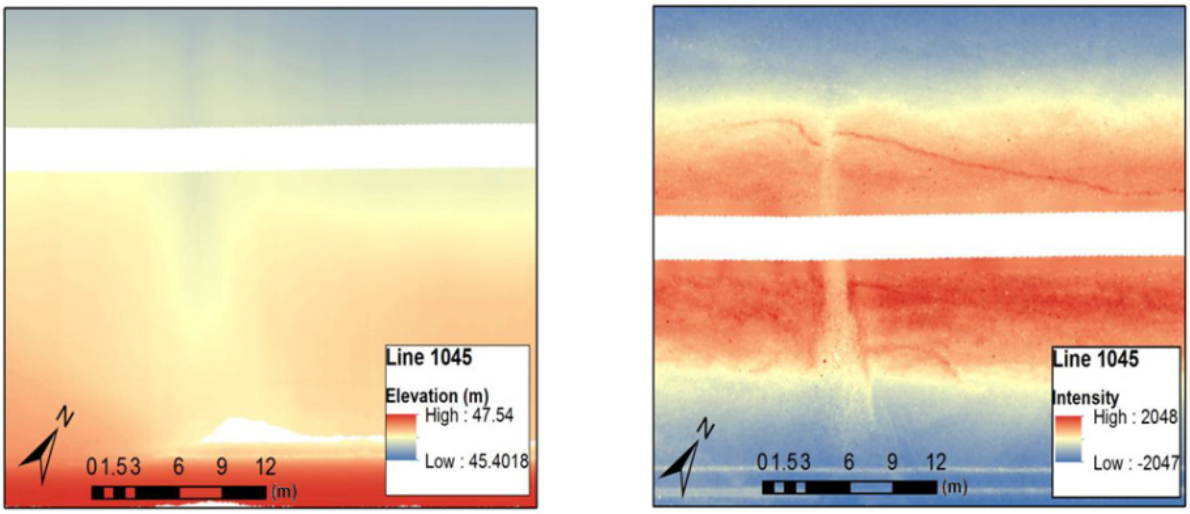

Figure 3 DSM (left) and intensity map (right) acquired from the same track line

Finally, a zoom has been executed to one particular survey line to show the opportunities of the MTLS method (Figure 3). The DSM provides the topography of the area. In fact, the most interesting figure in the field of archaeology is the intensity map. Furthermore, the intensity variations unveil a change in the surface properties based on which archaeological features or structures can be discovered that are not directly observed at the site. In the case of the presented figure, the location of a former stream can be observed.

5 CONCLUSION

The MTLS method has shown really impressive results, particularly on the breakwater. Taking the STLS data as the reference surface, the deviations in altimetry are of cm-level. The survey time, point density and high accuracy are the main advantages of the MTLS method. Moreover, the amphibious vehicle itself is also a good argument because of its usability in all terrain conditions. MTLS is a satisfying acquisition technique for intertidal zones. Besides, it can also be extended to other types of areas as port and civil inspection. Furthermore, the acquired data has shown that it could be used for other applications than topography measurements. For instance, the intensity information could be used to other fields as archaeology. As a perspective, a hydrographic sensor (single beam) can be added to the amphibious vehicle to survey in shallow water (depth of 0 to 5 m).

ACKNOWLEDGEMENTS

We thank the SBO project SeArch from IWT for the financial support of the survey. Alexis Boisseau is thanked for helping to process the data and summarising the results.

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