Control in LASER scanning of coastal erosion at Happisburgh, North Norfolk, UK

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Key words: Geospatial, surveying, LASER scanning, coastal erosion

SUMMARY

Coastal erosion is constantly being researched in the UK and around the world, the establishment of detailed 3D models which can be overlaid with high degrees of accuracy is essential to the calculation of erosion rates and volumes of material being displaced. The establishment of the erosion rate is critical for infrastructure and people residing near the coast as protection or relocation might be required. Parts of the North Norfolk coastline have one of the highest rates of coastal erosion in the UK (Cambers, 1976; HR Wallingford, 2001, 2002; Thomalla & Vincent, 2003), which makes them excellent locations for research into monitoring through the use of LASER technology.

This project investigated using multiple Topcon LASER scanners for the creation of a 3D model to assess erosion at Happisburgh in North Norfolk, one of the quickest eroding coastlines in the UK and the establishment of survey control over ≈1000+ metres of coastline. The main problem encountered at Happisburgh is due the high rate of erosion the first 50 metres in land could be considered unstable (Poulton, et al., 2006) and therefore not suitable for the installation of permanent reference datum' (Lim, 2005). During the survey numerous issues where encountered, some were solved before the returning site visit, others would be addressed if the project was undertaken again.

The conclusion reached at the end of the project was that it is possible to detect and measure coastal erosion. Happisburgh has sections of coastline that are eroding at a rate of ≈13 metres per year this is within the bounds of other surveys findings over the last 20 years (Poulton, et al., 2006). The establishment of control points in a large survey site of 1000+ metres is difficult to process within the survey using target reflectors as the local control grid, but it is possible with thorough planning and software manipulation to achieve control on a survey.

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1. INTRODUCTION

The research conducted for this study deals with the problems encountered using Terrestrial LASER Scanners (TLS) to scan a rapidly eroding and changing coastline in the UK, how a repeatable survey can be made over a period of time, and how those models that can be overlaid to a high level of accuracy through the use of survey control.

Control is defined by establishing reference or datum points in 3 Dimensional (3D) space within the surveying area and using them to locate each model in order to align them. This study will be undertaken along a section of the North Norfolk coastline due to the high level of erosion experienced in this location which makes establishment of control difficult as these points can be easily destroyed through the cycle of the erosion process. TLS is the technique and science of accurately determining 3D position of any measured point based upon angles and distances from the measuring location.

In this study only Topcon TLS have been used. The newer instruments GLS1500 & GLS2000 collect a large number of data points (>30,000 & >120,000) per second, these create large data files which can be difficult to manipulate within a computer due to processing resources of the graphics card.

The UK is predicted to spend £25 billion on coastal defences as a result of climate change by 2035 (Royal Geographical Society, n.d). To ensure these defences are value for money and correctly constructed to best protect the coastline, accurate surveys are required. This can be undertaken using TLS or other methods e.g. Unmanned Aerial Vehicles (UAV) using Light Detection And Ranging (LiDAR).

This study will investigate TLS for coastline research; discuss issues encountered and establishment of survey control upon an eroding and constantly changing coastline.

2. BACKGROUND

The Topcon LASER scanners used will be GLS-1000 & GLS-1500. The data will be processed using Topcon ScanMaster version 2.71.0.0. The conditions between scans will be considered stable without any storm surges due to the lack of daily site weather and tidal condition data. Access to the site was limited to maximum of 1½ day scanning this was due to the size and scale of the area being scanned, including limited daylight, and tidal conditions.

Establishment of control on site is created from either local ‘known’ physical datums e.g. target points or permamakers or via the use of a total station a control grid of fixed markers can be created based upon a fixed distance apart e.g. 150m.

Happisburgh has been the subject of many coastline studies as it experiences some of the fastest erosion rates within the UK. It used to be a managed retreat, but due to the high cost of a sea defence solution. The geology of Happisburgh is composed of a layer cake sequence of several tills, separated by beds of stratified silt, clay and sand, this makes the susceptible to rapid erosion by the sea (Hart,1987; Lunkka, 1988; Hart, 1999; Lee, 2003). It has been the subject of repeated investigations by the British Geological Survey (BGS) and other researchers. Estimates of erosion vary on site from 0.30 to 0.75 metres per annum within the North Norfolk area and an average of 0.9 metres per annum across the entire Norfolk coast from 1880 to 1967 (Cambers, 1976; HR Wallingford, 2001, 2002; Thomalla & Vincent, 2003). Analysis shows that the Norfolk coast has retreated landward approximately 1 to 2 km over the past 900 years. Analysis at Happisburgh was undertaken using a Riegel LPM2K terrestrial LASER over a period of 5 years (2001-2005). The setup position of the scanner was established using Differential Global Positioning System (DGPS). No direction mention of target stations is made, but an assumption could be made that they had been used as direct quote is “at least three common points in each scan to assist with orientation”. The dGPS whilst accurate would not allow for the accuracy shown in the findings from the study unless an ICP algorithm was used with the data. An erosion rate of 30 metres over 3 years was calculated from the results (Figure 1Figure 1 Happisburgh erosion (Poulton, et al., 2006)). Other studies quoted ranges between 6 to 18 metres per year. This high rate of erosion could mean any datum markers (permamarks) could be a risk of being lost if they had been used.

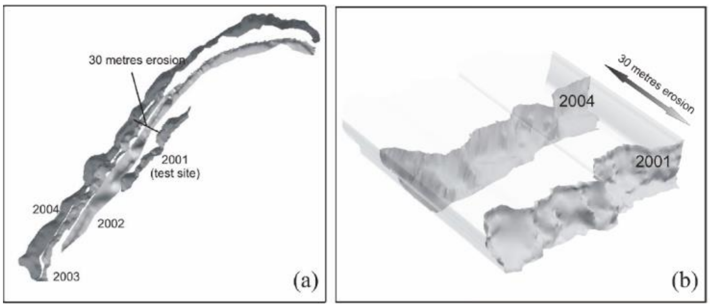

Figure 1 Happisburgh erosion (Poulton, et al., 2006)

Figure 2 shows Happisburgh between 1996 - 2012 the groyne defences and revetment offering some protection to the coastline between 1996 - 2006, in the area without defences or where they had failed the coastline has eroded considerably with that rate continuing into 2012. This highlights how quickly the coastline can change

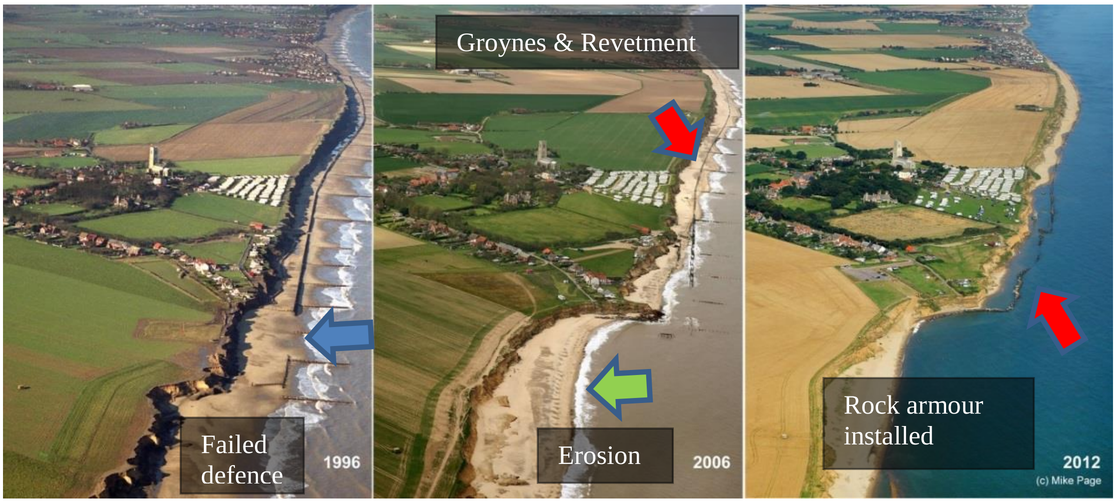

Figure 2 Happisburgh erosion (Tyndall Centre, 2012) (©Mike Page)

Between 1996 – 1999 the revetment failed (blue arrow) this caused the cliff to erode by 50 metres over a 3-year period (Ohl, et al., 2003). In 2004 rock armour was installed to the replace the failing defences and offer protection to the houses and trailer park, it was repositioned in 2013 due to defence works.

The current control methods used with in industry are

- Permamark positions with GPS co-ordinates recorded;
- Retroflective target stickers applied to existing building;
- Installation of fixed stations which allow to the mounting of tribrachs.
- Geo-referencing, this is where GPS co-ordinates are applied to known locations in the scan to fix its position to the real world. The co-ordinate systems used by surveyors are ETRS89 (European Terrestrial Reference System), WGS84 (World Geodetic System) and Snakegrid. Snakegrid takes ellipsoidal (latitude and longitude) coordinate data and flattening out the surface, then assigns Snakegrid Easting and Northing to the data.
- An Iterative Closest Point (ICP) algorithm can be used in the comparison to minimize differences between two point clouds, this allows for models to be overlaid automatically of different densities.

3. METHODOLOGY

The main objective at the start of the survey was to establish datum positions which would be situated in locations safe from the cliff face erosion but possible to sight from a beach position. 3 retroflective target stickers where located near the entrance ramp of the beach, with several redundancy targets attached to objects within 200metres inland from the cliff face. A datum point was established 400m away on a building to create a fixed point for closing out the survey model. It was envisaged this stickers would survive the weather conditions between the survey dates and into the future.

The site was surveyed using a TopCon GLS-1000 and GLS-1500 (x2), 3 target stations on tripod where used at the local stations moving along the beach with the scanners, this allowed all the data to collected and tied together in single model. The GLS-1000 was used to create the topography scanner on the cliff surface inland at a density of 50mm, with the GLS-1500's for high resolution scanning of the cliff face at a density of 20mm.

CASE STUDY

The final model created from 2 site visit each taking 1.5 days is 1277m in length, 555m in width, consisting of 185 million data points. During the processing of the data, numerous errors in the capturing of the data and methodology of the survey were discovered. Some of these were corrected before the return visit, or attempts made in the post processing to reduce the errors effect upon the results.

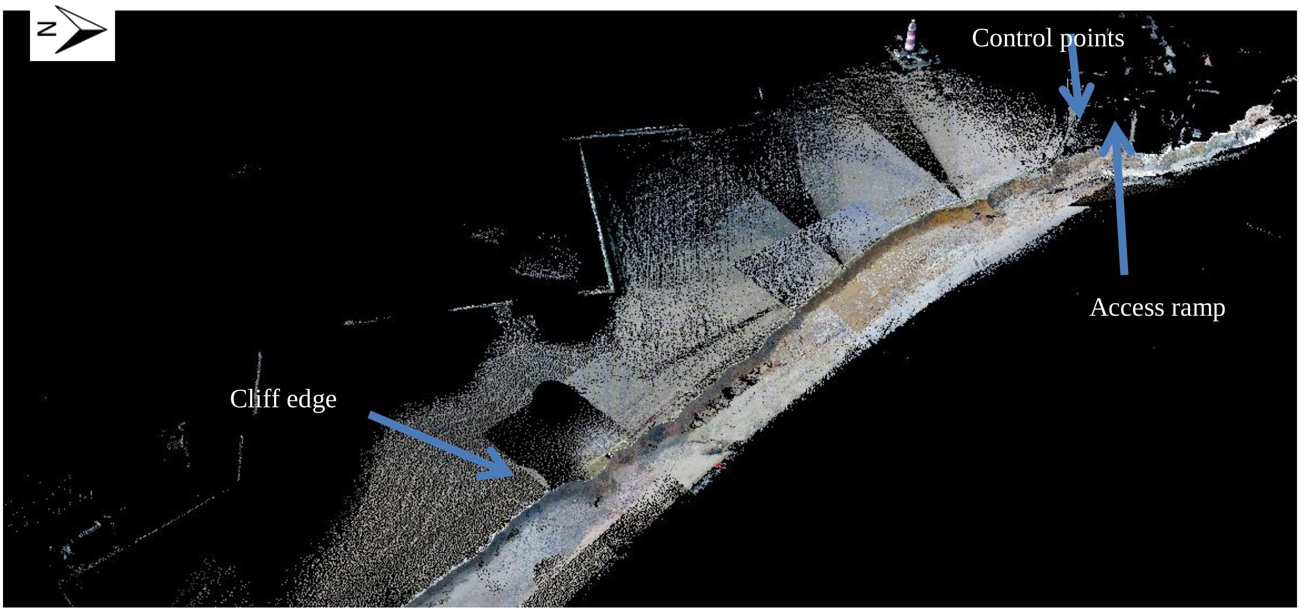

Figure 3 Final model

The survey from day 1 and 2/3 is joined together using control points (retroflective stickers) it was noted that due to minor errors in the accuracy it could have a large effect upon the z axis at the end of the model ≈800m away. An investigation upon how much their error could affect the z axis was undertaken, but due to limitations within the software all 3 control points must exist within a single scan position on each day. The white sign contained 2 of the control points a 3rd was added using a location further away to help correct the z axis problems encountered.

Using the sign as a basis, Equation 1 was created in which CP1 remains static in there ‘x,y,z’ position and CP2 has an error in its ‘z’ location. Figure 4 shows how the function is derived.

Equation 1 Z_{Offset}

$$Z_{offset} = x \times \tan\left(\frac{o}{a}\right)$$

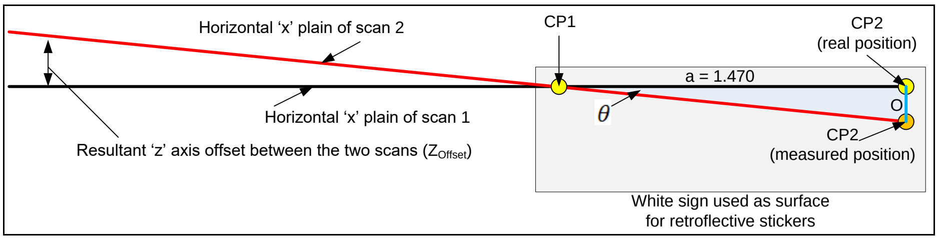

Figure 4 Diagram for Z_{Offset} calculation

Table 1 Differences in Z_{Offset} along the model

a (m)	o (m)	Angle °	x = 5m	x = 1000m	
1.1470	0.001	0.038	0.003	0.663	Z_{Offset} (m)
1.1470	0.057	1.111	0.097	19.376	Z_{Offset} (m)

The models final length is 1000m and from the Table 1 a 0.001m error (in z axis on the sign) will create alignment results of 0.663m at the ‘z’ axis at the floating end of the model. This is because the ‘floating end’ cannot be constrained to the other model to reduce the error. The 0.057m (in z axis on the sign) error is due to the scan density and the manual selection of the data points.

There is a requirement within the software to have all the control points available within a scan station, this means that the software has significant limitations when trying to alignment large models together like this one.

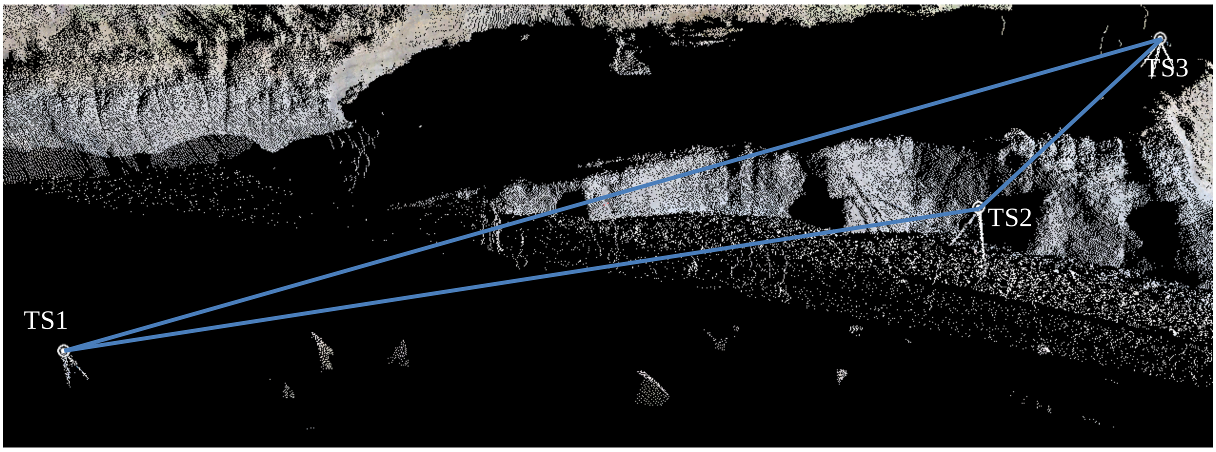

Figure 5 Triangulation of the 3 TS's

Triangulation of each of the TS's per scan (Figure 5) was undertaken to uncover the source of the error (Table 2)

Table 2 Distance between target stations (in metres)

Distance (m)	STN - A	STN - B	Difference
TS1 - TS2	26.472	26.423	0.049
TS1 - TS3	35.446	35.411	0.035
TS2 - TS3	9.918	9.917	0.001

Table 3 Scan Order

Scan order	
STN - A	STN - B
TS1	TS3
TS2	TS2
TS3	TS1

Table 3 also includes the order in which the target scans were undertaken before the main scan was executed. This linked with the location of the LS gives the answer after TS3 was scanned from DF_STN-B, the tripod slipped on the wet rock armour and created the error seen in the table.

If TS3 had been rescanned after TS1,2 there would not have been any error in the data. (The fault is with TS3 not the other stations)

The effect of the accuracy error is shown in Figure 6 the error between these two scans are x=0.017m & z=0.197m.

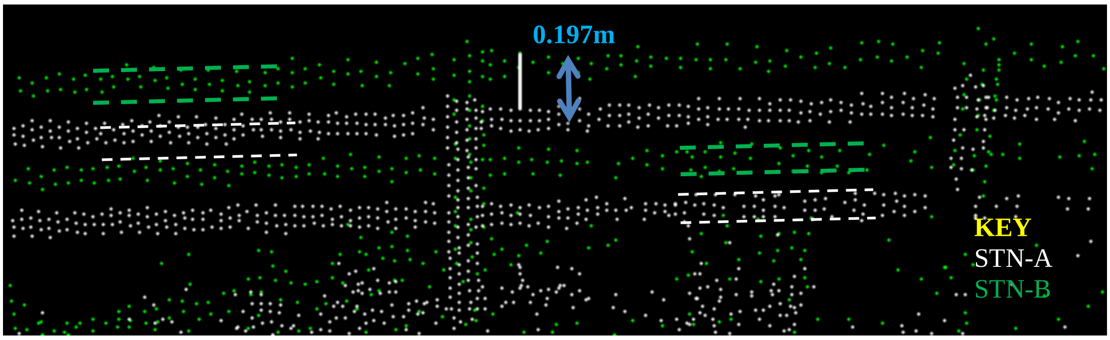

Figure 6 Offset in data between DF_STN-A & DF_STN-B

Figure 7 shows the scan overlay after the correction has been applied. It is seen that the two fence outlines have become a single fence with the different scan points along the sections.

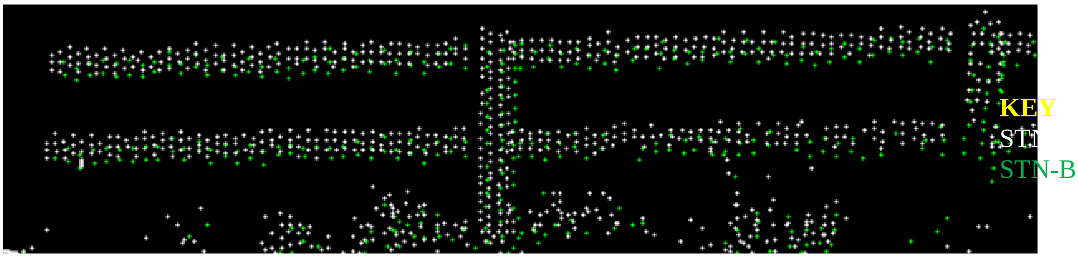

Figure 7 Data overlay after correction

Although the error created from misreading the location of TS7 to TS9 appears small, this has created a large error in the ‘z’ axis when these 3 scans are tied together on their own as shown in Figure 8. The z offset in this figure is 0.957metres, but reduces as it gets near the beach

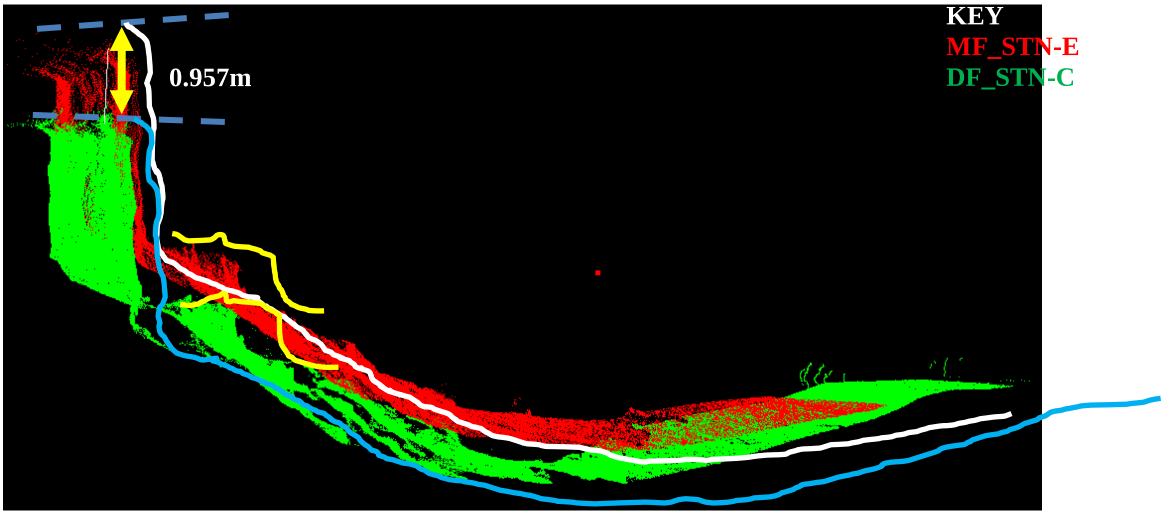

Figure 8 Day 3 Location x-20 to x-15

The main control points used for the aligning of the model have been located around a notice board sign near the access ramp of the beach. and show the point clouds of this sign, in most of the scans the control points have been captured, but some have been missed, this has created problems when tying together the models between the surveys,

Table 4 Day 2 - Day 3 control points only

Name	Tie Point (TP) Count	TP Error X	TP Error Y	TP Error Z	Manual Tie Point
CTRL_TPC_1	2	0.001	0.000	0.000	N
CTRL_TPC_3	2	0.000	0.000	0.000	N
CTRL_TPC_4	2	0.001	0.000	0.000	N
Average		0.001	0.000	0.000	
Max		0.001	0.000	0.000	

A similar accuracy error was encounter when processing the last 3 target stations on the survey as shown in the table below.

Name	Tie Point (TP) Count	TP Error X	TP Error Y	TP Error Z	Manual Tie Point
D3_TPC_TS7	3	0.024	0.011	0.002	N
D3_TPC_TS8	3	0.021	0.006	0.002	N
D3_TPC_TS9	3	0.044	0.006	0.001	N
Average		0.030	0.008	0.002	0.013
Max		0.044	0.011	0.002	

A triangulation of each of the TS's per scan (Figure 9) was undertaken to uncover the source of the error (). Some of the distances between the stations correlated, which gives confidence as to which scan was creating error in the constraints

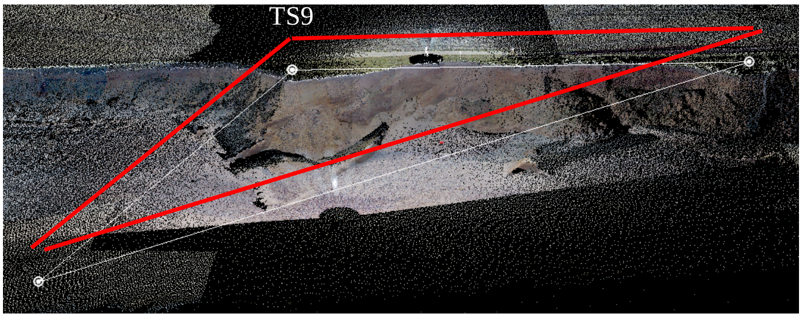

Figure 9 Final target station setup at end of survey

As the error in the target scans for TS7-TS9 cannot be corrected without the need for time consuming investigation or the implementation of an ICP algorithm (Oppikofer, et al., 2009) it has been accepted. As TS8 & TS9 are floating in space their accuracy cannot be increased, because no data points exist in their scans.

Figure 10 & Figure 11 show the erosion along the section of the coast line next to the rock armour as shown in the photographs. From these it was visually possible to see the differences in the scans and shaded areas in them, which shows that some erosion has occurred between the scans.

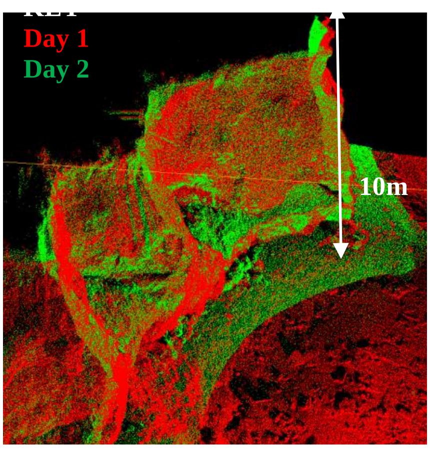

Figure 10 Cliff view

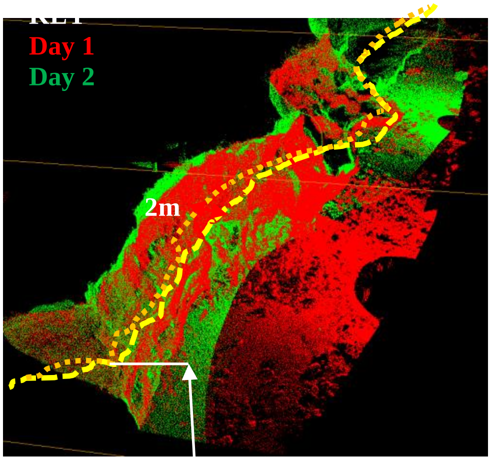

Figure 11 Cliff view

Figure 12 is a profile cross section in the area of interest, from this the top of the cliff has eroded by 1.5m and 0.8m at the toe. Extrapolating the erosion rate of the cliff gives an answer of 13.03m^2 per metre. This was consistent with the findings of other studies (Poulton et al, 2006).

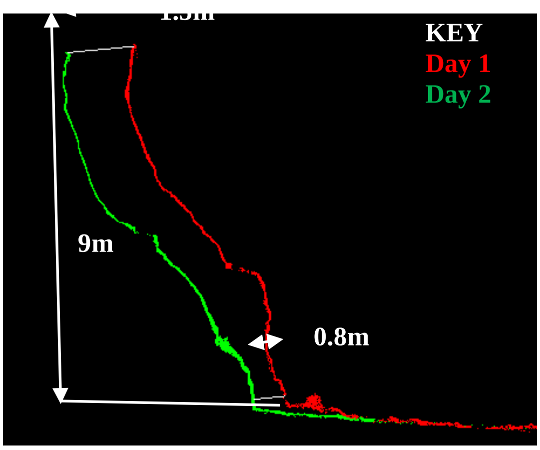

Figure 12 Cross section profile

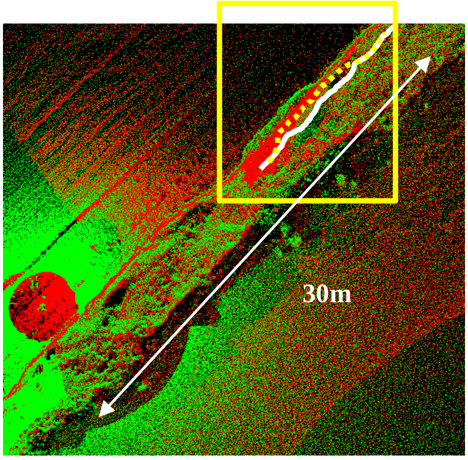

Figure 13 Erosion in small area on undefended coast line

Figure 13 shows the undefended section of the coast which has not the same rate of erosion, could be due to the beach height level helping to stop the tide lapping it. A return visit to the site on 17/07/2016. Figure 14 shows how it has changed compared to Figure 15, the pool has been created since the survey was undertaken; a beach surface profile line has been added based upon visual references. The swash zone has changed and the erosion rate will have reduced. This change in the tide can be monitored through the mapping of the beach (Almeida, 2013)

Figure 14 Happisburgh beach 17/07/2016

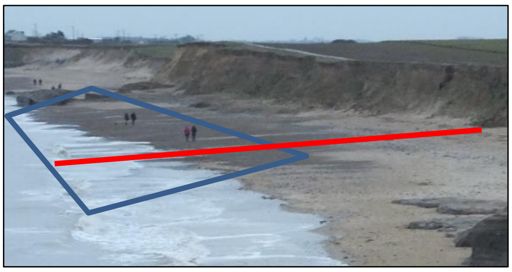

Figure 15 Happisburgh beach 20/02/2016

4. DISCUSSION

When surveying around the rock armour, retroflective target stickers were used as temporary stations as the TS on tripods could not be moved as they were required by the other surveyors. In previous surveys these stickers have proven themselves to be reliable.

These stickers were bonded to the rock armour with multipurpose adhesive to ensure they did not move during the day. Upon processing the data, it was discovered that 2 scans did not align although the software and scanner had reported successful target scan of the sticker, in fact the results were 10.859 metres apart (distance in x=10.743m & y=1.587m); on closer inspection and input from the surveyor on the events of the day, the rock armour was wet and contained quartz. These combined to make parts of the rocks surface give a higher signal return than the sticker making the scanner misreport the location of the target sticker.

The small retroflective target stickers have been very reliable in past surveys in Happisburgh however, they proved difficult for the LASER to measure due to the background environment on the rock armour which was wet, this created a highly reflective surface depending upon the angle of the rock surface and the quartz contained with the rock meant the LASER misreported the location of the target sticker. This has been resolved with the blackboards for target stickers to be affixed to thus nullifying reflections of the rock armour.

Using the impact adhesive for the retroflective stickers is a good idea as it increases their endurance on-site. The limited life of the sticker due to the bonding surface or vandalism must be taken into account. This method is useable if the survey has a short duration e.g. 60 days.

Additional large targets on tribrachs are definitely required for a survey the scale of the Happisburgh ≈1000m which involving 3 scanners. The recommendation is for 6 tribrach to establish a local station grid, reducing the need to leapfrog the stations along the site and also it means that a scanner is not waiting for another to complete its targeting. The scanning station can move location for it to start its target capture thus saving downtime during the day.

The options to improve overlay comparison accuracy of the Happisburgh model used in this report are:

- Selecting different manual tie points using the ScanMaster software and reviewing the accuracy table, but this will take time via trial and error;
- Different software e.g. Leica Cyclone which can match point cloud data via ICP algorithm;
- Write software code to interrogate the ScanMaster data or exported point cloud in an open source file format, and apply an ICP to report the positions required to be selected within ScanMaster.

The captured data from the surveys is valid but reprocessing using ICP would increase accuracy and alignment of the scans dependent upon the scan density of the areas used for the alignment.

The order for registering the models together at Happisburgh prove critical as 'the wrong order' increased the offset errors in the z axis dramatically. The permutations of the registration order must be recorded and accuracies reviewed to find the most accurate logical sequence for joining all the scans together across the timeframes. The error encounter registering the models is due to the methodology ScanMaster uses in averaging the positional location in the tie point constraints and therefore was viewed as a software limitation.

5. CONCLUSION

Old school techniques with target scans reliable and solid, provides redundancy, and enabling the repeatbality of the survey control, more target stations would be required to provided greater redundancy. Consideration of reflectivity of surface conditions of the environment (e.g. Quartz) need to be managed to avoid rouge points.

Inland small retroflective target stickers difficult to sight by eye and by the LASER scanning >150m although dependent upon the background and surrounding surfaces they have been successful. .

Collection of data points in the same location as the target stations helps with correction by using them as manual tie points if the target scans are invalid, but this need to be a last resort. A methodology of sequencing for procesing the tie points need to be established.

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BIOGRAPHICAL NOTES

Derek Spalton has worked in industry for over 20 years prior to joining the University of Derby, where he has focussed upon Surveying and is currently studing for a PhD related to LASER scanning. He is actively involved with several professional bodies.

David Froggatt has worked within the UK rail industry for over 20 years dealing with data processing, manipulation, infrastructure measurements and LASERs. He graduated from University of Derby with a BEng (Hons) in Civil Engineering then completed the MSc in Civil Engineering in 2016. He continues to explore his interests in LASER scanning and drone technology.

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