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Mapping Cultural and Archaeological Features in the Fujairah Emirate using a Terrestrial Laser Scanner.

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Abstract

The Fujairah Emirate in the United Arab Emirates (UAE) has many important cultural and archaeological sites. These include the Fujairah and Al-Bithna Forts and the Al-Bidyah Mosque. With increasing tourism patronage and development of major infrastructure projects in Fujairah, these sites are increasingly under threat. Their present condition requires careful mapping for proper management and future preservation efforts. In 2012, a group of researchers from the School of Mathematics and Geospatial Science at RMIT University, in conjunction with the Fujairah Tourism and Antiquities Authority (FTAA) in the UAE, undertook a number of Terrestrial Laser Scanning (TLS) surveys of these sites. These surveys will document their present condition and form an ongoing baseline study to monitor the impact of increased tourist patronage and climate change at these sites. They will also add to the marketing and tourism promotional activities of the FTAA.

Key words: Terrestrial Laser Scanning, Heritage, Archaeology, Tourism, Modelling

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Introduction.

The reconstruction and restoration of cultural, heritage or archaeological sites is important and requires 3D mapping. Traditionally, this mapping has been mainly undertaken using total-stations, and/or photogrammetric methods. These can be very laborious techniques and may not acquire data at suitable spatial resolution for intricate details. Terrestrial Laser Scanning (TLS), combined with digital imagery is more effective and provides the possibility of 3D-reconstruction. This technology has been successfully applied in the documentation of many historic buildings, archaeological features and natural features throughout the world. These surveys have been used for the development of virtual-reality models, assisting in restoration planning or virtual

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reconstruction. They can also be used to produce other products that are not only valuable for experts, but also fascinating for the general public.

In January 2012, a group of researchers from the School of Mathematics and Geospatial Science at RMIT University were invited by the Fujairah Tourism and Antiquities Authority (FTAA) in the United Arab Emirates (UAE) to undertake TLS mapping surveys of various important cultural and archaeological sites in the Fujairah emirate. These included the Fujairah and Al-Bithna Forts and the Al-Bidyah Mosque. The sites have significant historical and cultural significance and are also major tourism attractions within the UAE. The surveys were conducted as part of an ongoing RMIT research project and will form an ongoing baseline study to monitor the impact of increased tourist patronage and climate change. They will also add to the marketing and tourism activities of the FTAA and also assist in future preservation and restoration efforts.

The team undertook 10 days of fieldwork using a Trimble CX laser scanner. The registered point clouds were processed to produce accurate 3D models of these sites. We also used orthophotos collected through the CX instrument and a digital camera for realistic rendering of our 3D models. This paper describes these procedures and presents results from this study. It will discuss the possibility of producing an information system for use in future tourism activities in the Fujairah Emirate.

TLS Technology and Archaeological Applications

Mapping archaeological and heritage sites typically require the production of scaled maps and plans. These complement photographs, drawings, illustrations, sketches and help provide a clearer description of the site or feature (UNESCO Website 2012). Traditionally, tapes and compasses, theodolites, levels and/or total stations have been used for this purpose. For mapping more intricate details, orthophotos from close range photogrammetry are useful. Very accurate measurements can be obtained from these orthophotos, however defining a common reference system can be difficult, particularly for featureless facades. TLS point clouds have the benefit that each point is registered in the instruments reference frame upon measurement. As a result, dimensions can be extracted directly from the point cloud.

Modern TLS instruments locate and map target objects by either 1) observing the time of flight (TOF) or 2) change in phase of a reflected laser signal. These instruments make observations in this manner at rates of tens of thousands per second, generating massive point cloud data scenes. Each is more suited to specific applications. For instance, the TOF approach can measure over very large distances (e.g. 400m), but is slower and less accurate than phase based observations. Conversely, phase based observations are rapid and accurate but presently limited to shorter ranges. Both approaches are suitable for swiftly collecting reliable, high-resolution data and save hundreds of person-hours of effort in collecting data in comparison to traditional mapping techniques.

A number of considerations must be made when applying TLS to archaeological, cultural and heritage mapping applications. Many sites often have complicated geometry that make obtaining a complete point cloud difficult. As a result they may require different scales of survey (Balzani *et al.*, 2004). Some researchers utilise long-range TLS scanners to map their sites in a complete local context but at decreased accuracy and resolution. Others use photogrammetric techniques and products (orthophotos) integrated with TLS point cloud data for realistic rendering of 3D digital models and façade mapping (Alshawabkeh and Haala 2004, Yastikli 2007, Lerma *et al.*, 2010). Recently, ground based TLS surveys have been complemented with Unmanned Aerial

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Vehicle (UAV) data (Eisenbeiss and Xhang 2006, Lambers *et al.*, 2007) for a more complete contextual survey. A major issue of this approach is that the very large datasets are produced, which must be manipulated and then archived efficiently.

TLS point cloud data can be processed to provide various deliverables. These include 3D CAD models, Geographic Information Systems (GIS), Augmented Reality (AR) Tourism Information Systems, Web Mapping (I.e. Google Earth) and 3D rapid prototype printing. For example, the Greek Acropolis restoration is being assisted using TLS 3D point clouds and geographic information systems (GIS) (Egglezos *et al.*, 2008, Moullou *et al.*, 2008). This ensures that the restoration activities maintain the character of the heritage site and also assists with the construction of newly installed features. Also from these 3D models, small scale resin or plaster models can be created using rapid prototype printers (Goedert *et al.*, 2005). Such models make it possible to check for design flaws prior to construction, thus saving time and money.

In the UAE, there is a data deficiency where known data is either out of date or not widely distributed and difficult to find (Gliddon and Aspinall 1997). This includes information about prior restoration activities and archaeological excavations at the sites surveyed in this research. The incorporation of TLS data into a GIS has been investigated widely (e.g. Drap and Long 2001, Meyer *et al.*, 2007, Drap *et al.*, 2009) and provides an excellent archival capability and research tool for modern archaeologists and researchers and a potential solution to this problem. In GIS, TLS data and models can be linked with archival maps, documents and photos. Properly maintained, these databases could be made available on the internet for many researchers and the general public. A good example of this approach is the CyArk project (http://archive.cyark.org/). This website maintains an active database of non-commercial TLS projects around the world at important tourism and archaeological sites.

Historical Notes on Study Sites in Fujairah and Context of TLS Surveys.

The Fujairah Emirate is one of seven emirates within the UAE. It is situated on the eastern side of the UAE (Figure 1), bordering the Gulf of Oman and is the only Emirate with mountainous topography. Fujairah is more fertile than the inland UAE and receives a high heavy seasonal rainfall (King and Maren-Grieseback 1999). This emirate is rich with natural and cultural treasures. These include many natural wadis, ancient forts and royal palaces and important religious mosques.

Fujairah is advertised as an 'authentic Arabic' tourism experience. It is now an important tourism destination outside of Dubai and Abu Dhabi. However, many important sites are experiencing increased tourism patronage and thus must be protected from natural and human threats. Further, the development of oil refineries and large hotel resorts along the Fujairah coastline threaten many of the existing and the undiscovered sites. The Fujairah Tourism and Antiquities Authority (FTAA) have recognised the value of these sites and are currently undertaking a restoration program of twenty ancient sites across the Emirate (Deberky 2012).

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Figure 1 – Location of Fujairah (Courtesy of Nations Online Project)

Archaeology in the UAE began as recently as 1959 (Hellyer 1998). Blau (1995) notes that between 1958 and 1993, foreign archaeologists from Australia, Belgium, Denmark, France, Germany, Iraq, Japan, Spain, Switzerland, United Kingdom and United States of America, as well as archaeologists attached to various local authorities, have all worked at locations throughout the UAE. These efforts have been related to the identification, excavation and restoration efforts of many important sites. Ziolkowski (1999) states that thanks mainly to recent work carried out by students from the University of Sydney, the East Coast, including Fujairah, is beginning to reveal a rich and diverse cultural history. From the literature that is available, the following historical summaries can be provided for each site.

Fujairah Fort

The Fujairah Fort (Figure 2) is an important cultural and tourism landmark in the Fujairah Emirate. It is situated in central Fujairah City close to the Fujairah Museum of Antiquities. It is located high on a hill, approximately 20m above sea level and 3 km from the coastline (Fujairah Tourism Website 2012). Built in 1670, the Fort is the central structure in a larger settlement, which is the ancient foundation of the modern city (United Arab Emirates Ministry of Interior Website 2012). It received significant damage during English naval bombardment in 1925. The Fort is strategically placed to guard the entrance of the nearby Wadi Ham. It is large and contains three circular towers and one square tower. Within the Fort is a large courtyard, with entrances leading to a number of rooms and guard towers. Restoration of the fort has been recently completed and is now open to tourism activities (Zacharias 2009).

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Figure 2 – Photograph of modern and restored Fujairah Fort

Al-Bithna Fort

Al-Bithna Fort (Figure 3) is situated north of Fujairah City close to the Bithna township. Both the Fort and the township are located in the Wadi Ham. Wadi Ham has historically been an important and strategic inland route from the coast to inland Fujairah (Ziolkowski and Al-Sharqi 2009). It is believed the Fort was built in the first half of the 18^{th} century, during a period of civil war (Van Meir 2010). In this context, the purpose of the Fort was to act as a strategic outpost and also as a sur (an enclosure wall) for the local population (Ziolkowski and Al-Sharqi 2009).

The Fort is rectangular in shape with two large guard towers on the south-west and north-west corners. Within the Fort is a large courtyard, which provided entrance to the guard towers and access to a room for the guards (Van Meir 2010). Many of the Fort's major features have collapsed or have been damaged at various points in time (Ziolkowski and Al-Sharqi 2009). Restoration efforts were nearing completion at the time of this survey.

Al-Bidyah Mosque

The Al-Bidyah Mosque (Figure 4) is located north of Fujairah City, near the township of Al-Bidyah in the northern extent of the Fujairah Emirate. The mosque is unique in the UAE as it contains four domes, supported by one central pillar. Radio-carbon dating approximates the construction age of the mosque around 1446 AD, which also makes it the oldest mosque in the UAE (Pound 2012). Near the mosque are two large watchtowers and recent excavations have also identified a major fort structure in Al-Bidyah. The mosque is used frequently for daily prayer and is a popular tourist stop. The authors had to frequently stop work during daily prayer sessions.

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Figure 3 – Al-Bithna Fort after restoration

Figure 4 – Al-Bidyah Mosque after restoration

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The mosque is constructed from local material. The entrance to the mosque is a double wooden door which leads into a small courtyard fenced by low walls. The mosque is approximately 7m square. On the mosque roof are four circular dome structures (above each room). These structures distinguish this structure from other old and modern mosques in the UAE as each dome is unequal in size (UNESCO web site 2012). The north wall of the mosque is built into the rock mountain. Due to these complexities and limited time, we were unable to perform scans within the mosque. UNESCO considers the Al-Bidyah mosque suitably important such that it is tentatively listed on their protected heritage site list in early 2012.

Scanning Surveys of the Sites and Post-survey Registration Procedure.

The team used a Trimble CX Terrestrial Laser Scanner (TLS) for this research. This instrument is a phase-pulse hybrid scanner, capable of measuring up to 50,000 points per second, to a nominal range of 80m (Trimble Navigation Ltd. 2012). At each site we performed numerous scans from multiple locations to obtain the most effective coverage. The location of the scan stations at Fujairah Fort is shown as an example in Figure 5. Data was collected at both a low resolution (general scan) and a high resolution (for important architectural details). In high resolution mode, data was collected at regular spacings of a few centimetres. At the Fujairah and Al-Bithna Forts we also scanned the internal courtyards. We established local control at each site using differential GPS to allow repeated surveys in the future related to our baseline study.

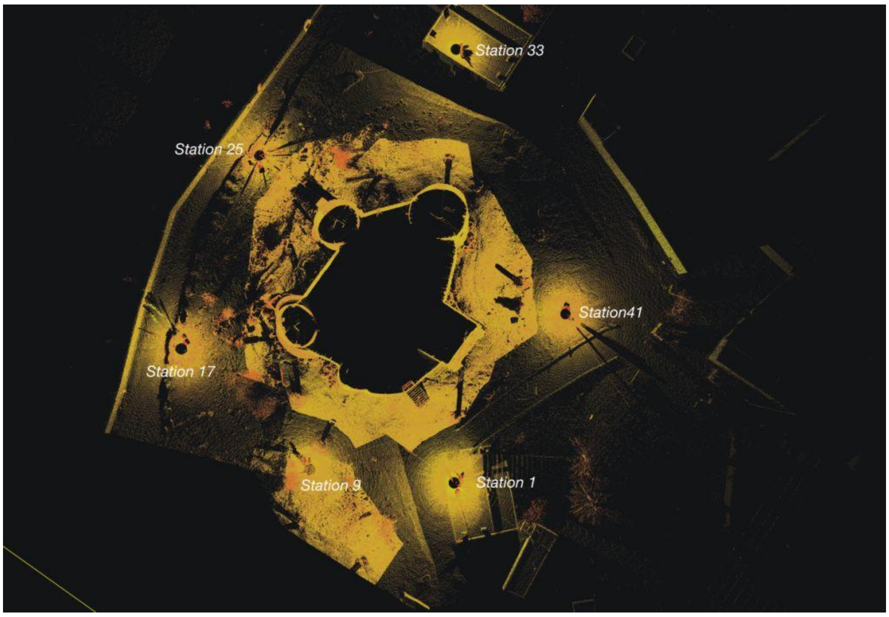

Figure 5 – Distribution of scan stations around the Fujairah Fort

The targets used in this research were black and white square targets designed for a high intensity return in the point cloud. Prior to point cloud registration, these targets were examined to ensure they had been scanned fully, to ensure accurate registration. All scans were then registered using a target matching bundle adjustment process in Realworks ™ software (Trimble Navigation Ltd. 2012). In this process, targets in different point clouds are first matched based on their geometry or arrangement. These targets are then used to merge the point clouds through a bundle adjustment, minimising residual RMS values.

In this software, target matching is undertaken either automatically or semi automatically. Automatic matching, registers all targets in all point clouds at once, while the semi-automatic matching approach, registers selected point clouds only. In this

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research, we found that the selection of target matching techniques depended primarily on the characteristics of the structure being scanned. For example, the Fujairah and Al-Bithna Forts were large and required many scans. Subsequently, it was not possible to have the same targets in every point cloud and these clouds had to be matched sequentially (i.e. semi automatic approach). The Al-Bidyah mosque was much smaller and we could place targets visible from all stations. As a result, we used the automatic matching technique for adjustment of the control for this project. Both registration approaches provided satisfactory results for the respective projects.

Modelling

Our modelling was produced using Trimble Realworks ™ software (Trimble Navigation Ltd. 2012) which allows meshing, image draping and CAD production. We used this software to produce accurate as-built plans and models for mapping changes (over the long-term) and visualisation products for online tourism for our sites. This process required manual data editing and segmentation and was time-consuming and laborious. However we produced accurate and useful products.

Meshing and Texture Mapping

Following the registration and removal of unnecessary points, we first produced meshes for the remaining point clouds. To ensure an accurate and realistic mesh, we segmented our point clouds into major components of the sites. We found this approach to be more efficient as various layers and point clouds can be displayed individually. With such large datasets, the meshing procedure proved difficult, but excellent results were achieved. We are able to see very small variations in the surfaces at each site. This will be sufficient to identify any damage or other changes over time. As an example of the level of detail visible in these meshes, we include a photograph and the corresponding mesh of the oak door at the entrance to the Al-Bidyah mosque (in Figure 6 below). This door contains very intricate carved details which are clearly captured in the meshes.

Our meshes were textured using coloured photos taken through the CX camera (othophotos) and from a standard digital camera. We found that using the photos taken though the CX camera may result in a poor texture as the photo was often stretched or distorted to fit the mesh. We found better results were obtained by rectifying digital camera photographs onto the mesh through common registration points. An example of this is shown in Figure 7, of the re-textured mesh for the Al-Bithna Fort. It is noted that best results are achieved when digital camera photos are taken in full sunlight, to avoid banding and contrasting in the textures.

For these models to be correctly viewed in Google Earth, the point clouds had to be resampled, to simplify the meshes. This was due to computer memory constraints and limitations of the 3D layers in Google Earth. Fortunately, this approach did not affect the final product significantly and our Google Earth models successfully visualised the sites with sufficient detail. These will be used for tourism and marketing purposes by the FTAA.

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Figure 6– A photograph of the Al-Bidyah door (on left) and corresponding modelled mesh (on right).

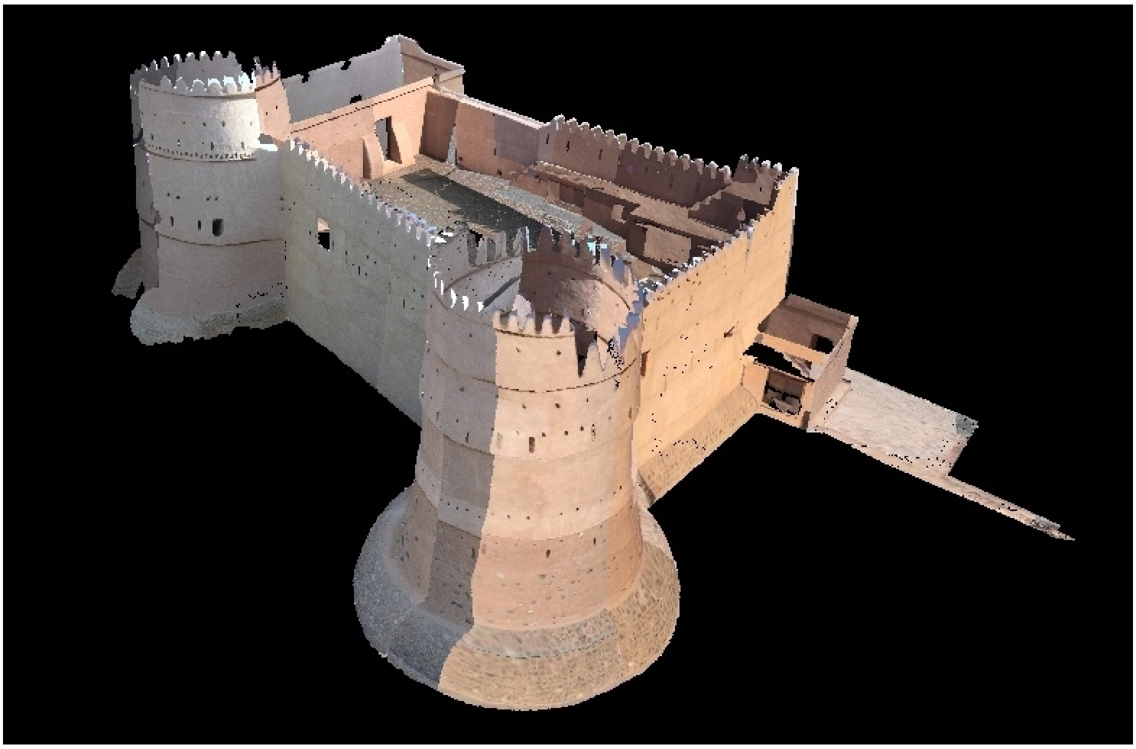

Figure 7 – Retextured mesh of Al Bithna Fort using digital camera photos.

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Discussion

From this research, we first recognise the importance of selecting a suitable scan resolution based on the nature of the mapping undertaken and the purpose of the model. In our research we performed high resolution scans at each site, which proved suitable for modelling very intricate details. These datasets will be useful for the ongoing change-mapping planned at each site in this research. However, producing these models was computationally intensive using standard desktop computers. Further, these datasets had to be significantly resampled (reduced) such that the data could be manageable and displayed on Google Earth ™.

It is important that consideration is given to appropriate field procedures (scanning resolution and instrument stations) prior to entering the field. Specifically, whether high resolution scans are necessary at all parts or only select regions in the target area. Performing high-resolution scans only where required would considerably speed up the field mapping process. It is also preferable to use the automatic target matching approach; however this is limited by the scale of the survey being conducted.

For realistic image draping it is also essential that consideration is given to the quality of the photos collected. We noticed that when using photographs taken through different cameras at different times of the day and in different lighting conditions were used for this process, some poor results were achieved. Further, when the orthophotos taken through the CX laser scanner were used for draping curved surfaces, these photos were significantly distorted and stretched. It is suggested that in the future a more regimented approach for obtaining high quality digital camera imagery is undertaken. This would entail taking overlapping photographs in direct sunlight which are face on to the surface being photographed. Such a process may result in a large number of photographs; however these would be of better quality and would suffer less from distortion and stretching on the meshes.

Based on the difficulties identifying and obtaining existing data and publications of prior research we experienced, we strongly recommend the establishment of an information system (e.g. a GIS). This would serve multiple purposes, including a data archive, research tool and marketing opportunity. This would be an excellent method of documenting the ongoing restoration and archaeological activities currently undertaken at many sites in Fujairah. Our ongoing research into the influence of human-made and climate change at these sites would be the basis of such a system. This is a future goal for our research group here at RMIT University.

Conclusions

The results of our research have proved the suitability of the CX laser scanner and associated software for mapping cultural and archaeological sites within the Fujairah Emirate. Our models are also suitable for marketing tourism activities in Fujairah and will be used for this purpose. This research also provides baseline data for future monitoring of the effects of human-made and natural activities in at each site. Yearly campaigns are planned to repeat these surveys for this purpose. It is anticipated that this data will also be used to establish a GIS. This will provide an important research tool for the future.

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