ГОДИШНИК НА УНИВЕРСИТЕТА ПО АРХИТЕКТУРА, СТРОИТЕЛСТВО И ГЕОДЕЗИЯ СОФИЯ

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TERRESTRIAL 3D LASER SCANNING ON LIVINGSTON ISLAND, ANTARCTICA

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ABSTRACT

This paper describes field activities and initial processing results from the first terrestrial 3D laser scanning project on Livingston Island, Antarctica, carried out in the framework of a joint international cooperation between the University of Mining and Geology "St. Ivan Rilski" – Bulgaria, the Bulgarian Antarctic Institute, the Association of Polar Early Career Scientists – Bulgaria, and the Istanbul Technical University. Through a 3D laser scanner, a pair of dual-frequency GNSS receivers, and state-of-the-art data processing software, precise georeferenced 3D models of the interior and exterior of the Bulgarian Antarctic Station "St. Kliment Ohridski" are to be created, and the short-term movement of the Perunika Glacier is to be evaluated. The paper reveals some key field data collection and data processing details, illustrated with 3D examples from the Livingston Island chapel "St. Ivan Rilski".

Introduction

The Bulgarian Antarctic Station "St. Kliment Ohridski" is located on Livingston Island, the second largest island of the South Shetland Archipelago. The station's first accommodation barracks were transported on the Soviet research vessel "Michael Somov" in April 1988 by a team of Bulgarian scientists – Prof. Christo Pimpirev and Borislav Kamenov. Ever since, it had

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become the center of the Bulgarian polar science, providing accommodation and scientific infrastructure to a number of national and international research projects. The 25th annual Bulgarian Antarctic Expedition took place during the 2016/2017 austral summer. Widely known as the “Jubilee” expedition, it continued the tradition of geodetic and geospatial research activities on the island, commenced by Assoc. Prof. Dr. Eng. Borislav Alexandrov (UACEG) and Prof. DSc. Eng. Dimitar Dimitrov (BAS-NIGGG) in the season 1998/1999, and continued by others.

During the current expedition, one of the most advanced geospatial technologies – the terrestrial laser scanning (TLS) – was implemented on the island for the first time. This ongoing project is realized through a joint international cooperation between the University of Mining and Geology “St. Ivan Rilski” (UMG), the Bulgarian Antarctic Institute (BAI), the Association of Polar Early Career Scientists (APECS) – Bulgaria, and the Istanbul Technical University (ITU). The main objectives of the project are:

- Capturing of 3D geospatial data of the main buildings’ interior and exterior;
- Monitoring of the dynamics and volume variations of a local glacier;
- Development of web-based resources for 3D visualization and virtual reality access to all buildings, including the first SCAR historical site on the island – the Lame Dog hut, and the chapel “St. Ivan Rilski”.

Considering that the Station’s buildings are subject to constant extreme environmental conditions, with some infrastructure vanished under snow for many years, and other experiencing severe damage, obtaining in-situ information is a vital source for their future preservation and digital exhibition. On the other hand, the global warming effects are quite sensible on the Livingston Island. One of the glaciers – the Perunika Glacier, due to its proximity and ease of access, is rather feasible for TLS studies.

International Cooperation

The project ideology was initially outlined at the First APECS Balkan Meeting, which took place in the Bulgarian city of Kardzhali in October 2016. The Association of Polar Early Career Scientists (APECS) is an international and interdisciplinary organization for undergraduate and graduate students, postdoctoral researchers, early faculty members, educators and others with interests in Polar Regions and the wider cryosphere [6]. The meeting provided efficient communication platform between members of APECS International on the Balkan Peninsula: APECS Bulgaria, APECS Turkey/Turkish Polar Research Center and APECS Romania (via Skype call). The Chair of APECS International, Mrs. Gerlis Fugmann, connected to via Skype call as well. The national expedition operator – the Bulgarian Antarctic Institute, patronized and funded the meeting.

During the event, two of the participating parties – Bulgaria and Turkey – signed an official Memorandum of cooperation in the field of Antarctic science. Following this meeting, APECS Turkey decided to send two scientists in the upcoming 25th Bulgarian Antarctic Expedition – a marine biologist and a geomatics engineer from ITU, the latter becoming the senior LiDAR data processor for the project.

Figure 1. Participants in the First APECS Balkan Meeting (1-2 October 2016), supported and co-organized by the Bulgarian Antarctic Institute

Related Works

Most of the laser scanning projects performed in Antarctica are airborne, due to the larger area of coverage and time efficiency. Some notable examples are:

- A joint NASA/U.S. National Science Foundation/U.S. Geological Survey project for digital elevation model (DEM) extraction using airborne laser topographic mapping in the McMurdo Antarctic Station area on Ross Island [1, 2];
- SIPEX-II (Sea Ice Physics and Ecosystem eXperiment II) – a multidisciplinary project which includes airborne LiDAR remote sensing from a helicopter in combination with snow and ice depth measurements. The acquired DEM contributes to a three-dimensional picture of snow and ice thickness, and topography [3].

Although fewer, there are some quite intriguing TLS implementations as well, including:

- 3D white light/laser scanning of Scott's huts at Hut Point and Cape Evans and Shackleton's hut at Cape Royds on Ross Island, performed by the University of Waikato (New Zealand) in 2011. The resulting scan data supports multidisciplinary studies and development of 3D models for broader public interest to these heritage sites from the Heroic age of Antarctic exploration [4];
- A project for development of a high resolution DEM of the "Boulder Clay" moraine, adjacent to the Italian Research Station "Mario Zucchelli", intended to support the construction of two airplane runways [5].

Apart from the high costs of the equipment and its insurance, some specific limitations, which hinder the implementation of LiDAR technologies in Antarctica, are the severe environment conditions (e.g. strong winds, low temperature and high humidity), which overpass the technical capabilities of many instruments, as well as the complicated logistics required to bring the equipment to the areas of interest.

Field Campaign

Logistics

Figure 2. The pier of King George Island, waiting for the transportation ship to Livingston Island

Figure 3. The area of the Bulgarian Antarctic Station "St. Kliment Ohridski"

The field campaign on Livingston Island lasted 30 days, spanning the period between 21 January and 21 February 2017. The two-way travel and transportation required 10 more days. The members of the geospatial engineering team, representing UMG and ITU, together with six other Bulgarian scientists assembled in the Chilean city Punta Arenas, from where an Antarctic Airlines regular flight took them to the island of King George – the largest of the South Shetland Archipelago. The group then boarded a Spanish oceanographic ship – “Sarmiento de Gamboa”, and after two nights of travel disembarked on the shores of Livingston Island. The geospatial equipment’s transportation boxes were carried as hand luggage at all times, as this was the requirement of the insurance policy.

Equipment

The following equipment was utilized for the project: a 3D laser scanner Stonex X300, a pair of dual-frequency GNSS receivers (Trimble R4-2 and Stonex S8+), a total station Zeiss Elta, tripod, survey rods and a variety of accessories.

Laser Scanner

Stonex X300 is a lightweight mid-range (1,6 – 300 m) laser scanner, able to receive color and intensity information alongside three-dimensional data (Tab. 1). Is has a 32 GB internal memory, capable of storing up to 50 scans at maximum resolution (~700 MB each). The instrument has a built-in Wi-Fi interface, which was used for field setup via Android smartphone.

Table 1. Technical parameters of the laser scanner (best mode)

Scan mode	***Value***
H. res. (360°)	*16000*
V. res. (90°)	*4000*
Total points	*64000000*
H. step (‘)	*1,350*
V. step (‘)	*1,350*
Time x 360°	*1 h 6 m 0 s*
Columns/sec.	*4*
Grid step at distance	
Distance (m)	***Grid step (Hz and V, mm)***
10	*3,9*
30	*11,8*
50	*19,6*
100	*39,3*
200	*7,8540*
Environmental and physical	
Operating temperature	*-10 °C to +50 °C*
Protection class	*IP65*
Weight (with battery)	*7 kg*

GNSS Receivers

The GNSS technology is utilized in the project with two main objectives:

- to provide georeference data for the 3D models via static relative GNSS positioning;
- to perform static campaign on the permanent GNSS station KOH2 (IERS DOMES number 66026M002) for various international scientific projects.

Two GNSS receivers with appropriate environmental durability specifications were transported to the island (Tab. 2).

Table 2. GNSS equipment specifications

Specifications	***Trimble R4-2*** 	***Stonex S8plus*** 
GNSS signals	• ***GPS****: L1C/A, L2E* • ***GLONASS:*** *L1C/A, L1P, L2C/A, L2P*	• ***GPS****: L1C/A, L2C* • ***GLONASS:*** *L1C/A, L1P, L2C/A, L2P* • ***BeiDou****: B1*
Channels	*72*	*120*
Accuracy in static mode (RMS, maximal values)	• *3 mm + 0,1 ppm (Hz)* • *3,5 mm + 0,4 ppm (V)*	• *5 mm + 0,5 ppm (Hz)* • *10 mm + 0,5 ppm (V)*
Internal memory	*11 MB*	*256 MB*
Field software and controller used	*Trimble GPS Configurator on Windows 7 laptop*	*Carlson SurvCE on Stonex S4 Windows Mobile 6.5 controller (806 MHz processor, 256 MB RAM, 4 GB internal storage, IP67)*
Communication used	*Bluetooth – setup and data download*	*Bluetooth – operation,* *7-pin Lemo – data download*
Operating temperature	*-40 °C to +65 °C*	*-30 °C to +65 °C*
Protection class	*IP67*	*IP67*
Weight (with battery)	*1,34 kg*	*1,2 kg*

Data Collection

Terrestrial Laser Scanning

Due to the unpredictable outside weather conditions and the exploitation of the buildings by the expedition's both scientific and technical crews, data collection was scheduled with an opportunistic manner, by overlapping several data acquisition target groups and carrying out surveys whenever and wherever possible. A total of 82 point clouds were collected, equivalent to more than 100 working hours of the scanner.

The main building's interior was scanned mostly during nighttime, when it was possible to place the scanner at all desired locations. The chapel interior, due to the lack of electricity inside, was scanned either with open doors at bright sunny days or with artificial light during the rest of the time. The aim of both main building and chapel scans is to obtain in-situ 3D models of their current condition and transfer it to a virtual environment where it can be analyzed and altered according to the necessities should they arise.

Figure 4. Instrument setup during 3D data collection of the main buildings' exterior

The Perunika Glacier was monitored periodically through a 5-day gap.

All data was being downloaded on a daily basis and backed up on several external hard drives. Sequential cloud-to-cloud registration, georeference, 3D mesh, and cross section extraction were performed on site through a 30-day demo version of the JRC (Stonex) 3D Reconstructor software.

GNSS

Figure 5. *a*) Base receiver set up on the permanent GNSS marker KOH2; *b*) Rover receiver measuring the chapel's roof corners for TLS data georeferencing

All GNSS observations were performed in static relative mode.

The GNSS base receiver (Trimble R4-2) was set up on the permanent geodetic marker KOH2, established in the season 2015/2016 in the framework of a project headed by the National Institute of Geodesy, Geophysics and Geography (Fig. 5*a*). Twenty-three daily datasets were acquired in the period January 21 – February 13, 2017. The receiver was powered through a solar panel, which proved to be a great advantage considering the fast battery drainage in cold weather conditions. The raw observations are recorded in 1 sec interval, converted to RINEX format and subsequently decimated to 15 sec interval via the open source tool GPSTk. As a project follow-on, the data is exchanged with the Spanish GNSS Research Group from the Cadiz University, supporting a seasonal GNSS station on the same island. GNSS data from the KOH2 point is also sent to the SCAR GNSS database [7] for participation in the GIANT-REGAIN [8] and other international projects.

The rover receiver (Stonex S8+) was used for positioning of the buildings' roof corners and other characteristic objects, aimed for georeferencing of the TLS data (Fig. 5*b*). All points are measured in 15 min sessions with 1 sec sampling interval. Additionally, the GNSS geodetic network, established in the vicinity of the Bulgarian Antarctic Station in the season 2012/2013 by a team UMG "St. Ivan Rilski" [9], was re-measured for data comparison studies.

Data Processing

Data Import

The field data collection campaign produced large point cloud datasets, recorded in proprietary Stonex .x3a format. They are subsequently exported via the Stonex 3D Reconstructor software to standard text XYZRGBI format ("XYZ" stands for the coordinate portion of the data, "I" is the intensity of the returning signal strength from target to the instrument, "RGB" stands for Red-Green-Blue color format). Thus all coordinate, reflectivity and color information from the raw data was obtained (Fig. 6).

Figure 6. 3D point cloud view of the chapel's altar

Eventually the project data exceeded a billion points, which required significant workload and processing power. For that purpose, the Department of Geomatics Engineering at ITU dedicated a powerful workstation running an edition of the Leica Cyclone software. There the data was sorted, preprocessed and classified as areas of interest, and separated in three main groups and several subgroups:

- Chapel (interior and exterior);

- Main Base Building Area (main building, auxiliary buildings – interior and exterior, critical infrastructure);
- Perunika Glacier.

The subsequent co-registration and geo-registration of the data required creation of a database, which structure is according to the aforementioned dataset grouping (Fig. 7). The size of the data in the database exceeds 290 GB, resulting in time-consuming import process due to the “normal computation process”.

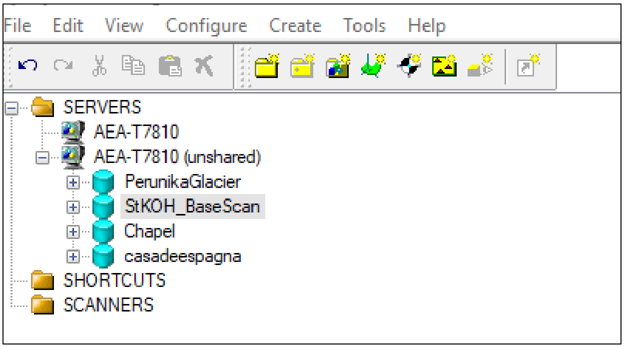

Figure 7. Project database structure in the Leica Cyclone software

Cleanup

Cleanup is a sensitive and time consuming but necessary step, implemented in the project for:

- elimination of unnecessary data which burdens the database, clogs the process and consumes computing resources;
- removal of irrelevant areas that can interfere with the actual area of interest.

The data was “cleaned” automatically and – where it fails – manually. This was carried out using a statistical outlier removal (SOR) filter based on k-means clustering. Generally, this algorithm “clusters” point clouds and removes “outliers” which does not fit into the group statistically [10]. However, because this method frequently deletes necessary parts as outliers, it was supervised and optimized with utmost care. A manual cleaning was also required in order to intervene to the more information sensitive areas.

Registration

The process of registration involved two main steps – co-registration and geo-registration. Both were performed over common points from overlapping point cloud models (Fig. 8). For proper subsequent co-registration of the point clouds, certain amount of overlap was ensured during the data collection. By marking the common points (Fig. 9) in the overlap areas, the software performs statistical evaluation of all neighboring points and deduces 3D 7-parameter transformation parameters between the point clouds (three rotations, three origin center shifts and a scale) [11]. This co-registrations accuracy is dependent on the overlap quality, scan resolution and proper selection of tie points between point clouds.

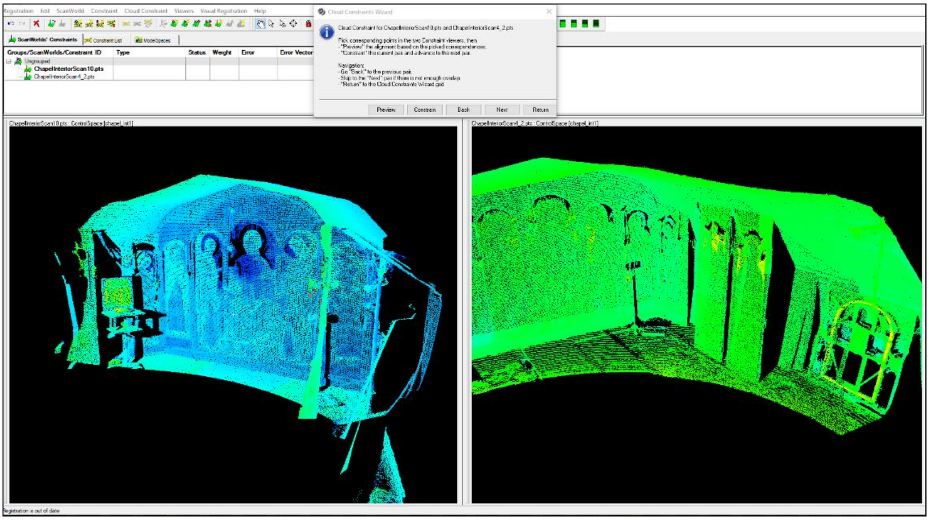

Figure 8. Overlapping scans of the chapel interior

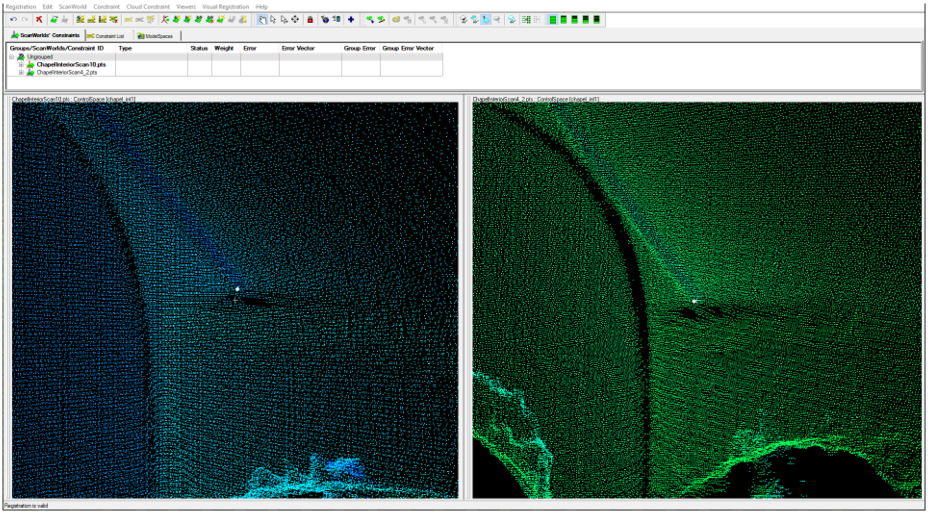

Figure 9. Co-registration points in the chapel interior corners

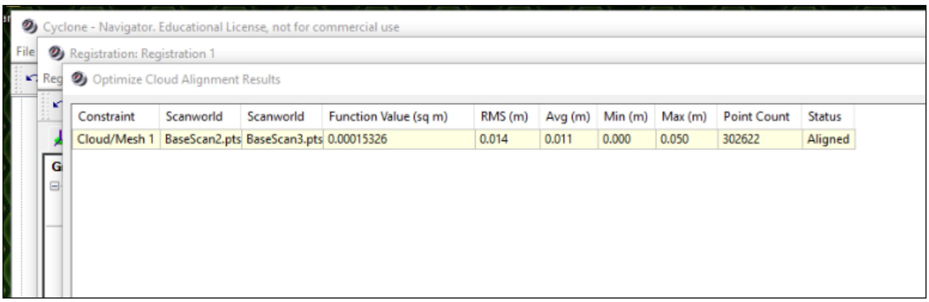

Figure 10. Model accuracy sample for two of the main building point clouds

The geo-registration process was carried out by converting the local coordinates of the co-registered point clouds (received from the scanner itself) to ITRF2008 coordinates, received from the GNSS campaign data processing. The average co-registration error vector, computed from all datasets, is 8 mm (Fig. 10), and the final geo-registration accuracy – 15 mm.

3D Mesh Modelling

After the end of the project, several types of geoformation products will be available, aimed for both professional and academic community, as well as for wired audience, interested in the Bulgarian Antarctic Station and the Antarctic Region in general. These will include, among others:

- A virtual reality model of the base;
- 3D models, ready for printouts at different scales;
- Web-based interactive environment;
- Glacier movement dynamic model.

Figure 11. Mesh model of the handmade Jesus Christ icon inside the chapel

Since the project is ongoing and extremely time-consuming, up to the deadline of the paper submission only a limited amount of geoformation products are ready: a mesh model and a 3D printout model of the chapel (Fig. 11) and the base building area (Fig. 12).

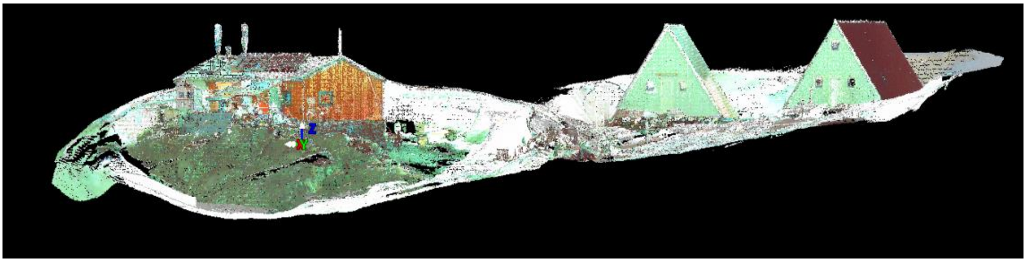

Figure 12. Main buildings and near vicinity

Conclusions and Future Work

The terrestrial laser scanning campaign at the Bulgarian Antarctic Station "St. Kliment Ohridski" provided a unique experience for geospatial research and production in extreme conditions. Some unique and diverse LiDAR and GNSS datasets, feasible for implementation in various interdisciplinary fields (e.g. historical documentation, Virtual Reality, GIS, civil engineering, architecture, geodesy a.m.) were acquired for the first time on Livingston Island. Within this project several important buildings (the main living quarters, the orthodox chapel, and the oldest standing building in Livingston island – "the Lame Dog Hut", were scanned and documented. In addition, the Perunika Glacier's movement was also observed and modeled.

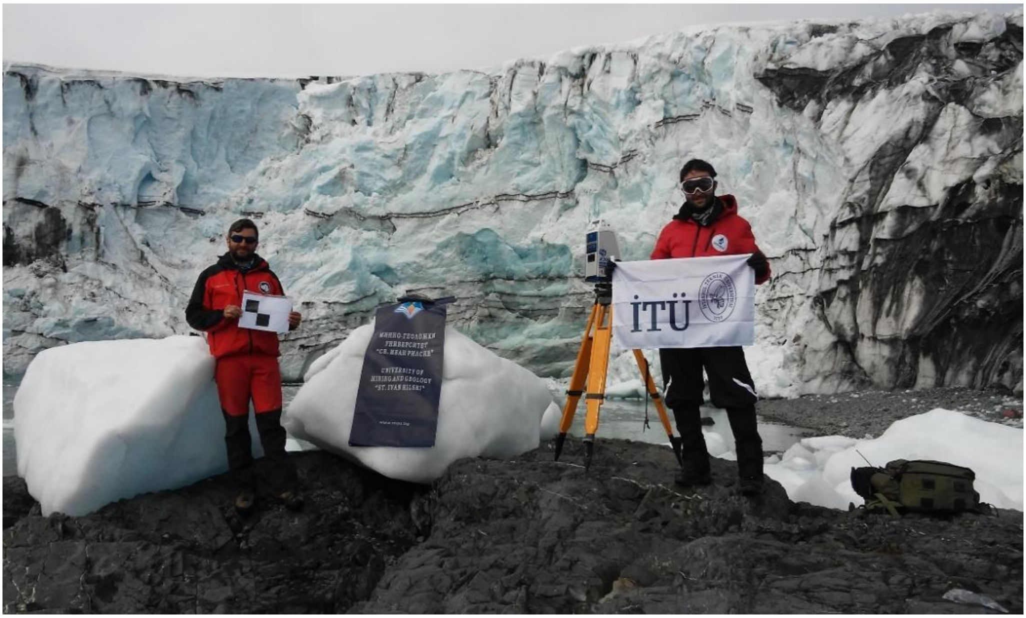

Figure 13. The team in front of the Perunika Glacier's face

However, much of the processing effort is yet to be performed, and will be published in time. Ultimately, a virtual 3D model of the whole station will be created, which will allow the end users to analyze and manipulate its configuration without altering anything physically. The project may also influence extensive geospatial documentation of other buildings with historical and artistic value over the whole Livingston Island. Furthermore, since the base buildings are under constant extreme weather conditions and snow load, they should be checked periodically for deformation, including via TLS technology, in order to preemptively repair any deformation and extend the longevity of the base both physically and economically, removing any structure-caused hazards along the way.

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