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Terrestrial laser scanning of the landscape around Stonhage

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The landscape of Stonehenge became the first and so far the largest case study for developing and testing highly accurate and efficient methods of archaeological geophysical prospection and remote sensing, applied at the landscape level by the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology. The University of Birmingham (UK) and the LBI ArchPro (Austria) started the Stonehenge Hidden Landscape Project and has run annual campaigns since 2010, focusing on high-resolution magnetic and ground penetrating radar (GPR) prospection to investigate the *terra incognita* around the iconic stone monument (Gaffney *et al.* 2013; Löcker *et al.* 2013; Gaffney *et al.* 2012). An area of approximately 8 km^2 within the view shed of the stone monument, the so called Stonehenge Envelope, has been covered so far, applying the latest technology developed by LBI ArchPro and its international partners. The surveys revealed in unprecedented detail and scope a variety of new monuments, features and detailed information on monuments in the surrounding landscape of Stonehenge.

A highly accurate topographic model was needed for a detailed 3D analysis of the data. Airborne laser scanning was not an option owing to the presence of Royal Air Force units nearby, hence the decision to implement a terrestrial laser scanning (TLS) survey, accompanying the geophysical prospection.

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Fig. 1. DTM of the landscape of Stonehenge derived from terrestrial laser scanning

The initial plans, which were based on a decade of experience in the documentation of archaeological sites and landscapes using TLS, were quite traditional. Challenges facing the project included :

- more or less flat topography, which had to be scanned with high resolution over more than 10 km^2;
- part agricultural use of large fields and limited permissions necessitated the breaking down of the work into several individual surveys with varying vegetation;
- every scan position required the registration of several retro reflectors by means of a total station, slowing down the work significantly.

A Riegl LMS Z420i scanner using a well approved workflow was applied for the first three surveys. For each scan position, a set of 8 to 12 cylindrical retro reflectors was put in place and registered with a total station. Using a mobile scanning platform 6 m high, the scan positions were set out at an average distance of 150 m to 200 m. The scan positions were registered using global coordinates and Multi Station Adjustment (MSA) was applied for better alignment. This procedure allowed for a maximum of 10 to 12 scan positions to be completed per day. After three seasons, 105 scan positions were in place, covering most of the Stonehenge Envelope.

Recent surveys with a Riegl LMS VZ400 scanner and on-board GPS promised the development of a faster long range TLS workflow. Additionally, Riegl LMS provided a *beta* license for testing the new software RiSOLVE, which was designed for connecting scan positions easily without using retro reflectors. The last survey at Stonehenge took place in September 2013, operating a Riegl LMS VZ400 on a tripod approximately 2 m high. A few "core" positions were used, setting up reflectors and measuring them with a total station. These positions were later used for georeferencing the surface model. All other positions were roughly located using the on-board GPS. When no reflectors were being used, the scanner was operated by one person. A lightweight tripod and an additional battery pack proved sufficient and comfortable for a day's work.

After removing the vegetation with different filters, this procedure resulted in a high density and georeferenced DTM (Digital Terrain Model). Applying the initial workflow with the Riegl LMS Z420i scanner operated by three persons, it was possible to complete 10 to 12 scan positions per day. The new workflow, using the Riegl LMS VZ400 in combination with RiSOLVE, made it possible for just one person to complete 30 to 40 positions per day, increasing dramatically efficiency while providing higher data quality.

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