Aerial LIDAR surveys

Anglian Coastal Monitoring

April 2016
1.1

This document describes the coastal LIDAR (Light Detection & Ranging) surveys and data collected by the Anglian Coastal Monitoring project.

The Survey

How we collect LIDAR data

LIDAR is a method of measuring ground elevation as well as features such as buildings and trees. The Environment Agency have two aeroplanes equipped with Teledyne Optech ALTM Galaxy LIDAR systems.

To survey the east coast, the aircraft will fly a defined flight path consisting of a series of lines running along the shoreline. As the plane flys, the LIDAR unit scans the ground surface from side to side. The LIDAR uses a laser to emit pulses of near-infrared light which bounce off the surface and back to the sensor. Different surfaces reflect light differently based on the wavelength of the laser. The LIDAR sensor uses a 1064 nm wavelength or Near-Infrared. This is reflected off vegetation but absorbed by water, this wavelength also means the laser is not dangerous to the human eye. The ground surface area covered by the scan is called the swath. The instrument's swath width is a function of the programmable scan angle and the survey altitude of the aircraft.

Figure 1: LIDAR sensor mounted inside the aircraft

To calculate a ground elevation, first the LIDAR calculates the time it takes for a light pulse to reach the ground and return to the sensor, this is the 'return' signal. From this travel time, and using the speed of light the distance from the plane to the ground is calculated or ranged. The clocks in the waveform digitizers of the Optech sensors are capable of measuring to a precision of 1 nano second. Therefore they can accurately measure the travel time of an emitted pulse travelling at about 0.15 m per nano second.

The aircraft is also equipped with a 220 channel dual frequency Global Navigation Satellite System (GNSS) receiver. This allows us to track the planes x, y position and altitude. The position of GPS satellites is precise, and from the signal received by the on board GNSS the relative position of the plane to those satellites is known. For the highest accuracy the LIDAR requires a minimum of 6 satellites in lock (tracked by the receiver) throughout the survey and with the aircraft within 30 km of a GNSS base station on the ground. This also means that the location on Earth where the pulse hits is known, giving the return a ground position.

The LIDAR system also includes a Position and orientation system (POS) and Inertial Measurement Unit (IMU). This calculates the position of the plane in the air with regard to changes in pitch, roll and yaw. Although a relatively stable platform the plane is impacted by turbulence. The accelerometers and gyroscopes in the IMU measure this, and the tilt of the plane as it manoeuvres to achieve the designated flight path. The system also has a swath tracker and displays real-time x,y,z data in the aircraft. The altitude of the aircraft is subtracted from the distance travelled by the return signal to give a measure of ground elevation.

The system can vary the frequency of the pulses, but the LIDAR sensor generally emits 100,000 pulses per second. The pulse rate affects the data density and resolution of the final product. The millions of returns give us a large point cloud of data, each return signal containing ground position (x, y coordinates) and a ground elevation measurement. This comprehensive coverage of the ground from an airborne LIDAR survey allows us to create a detailed representation of the coastal topography and is one of major benefits of this type of survey in contrast to the ground topographic transect surveys.

Figure 2: The EA Geomatics aircraft in flight.

In addition to an elevation measurement the LIDAR also records the intensity of the signal return. This is the amount of light from the pulse that has made it back to the sensor. The reflectiveness of different surfaces such as saltmarsh, sand or wet sand varies. The intensity information can be plotted to provide information on the ground cover.

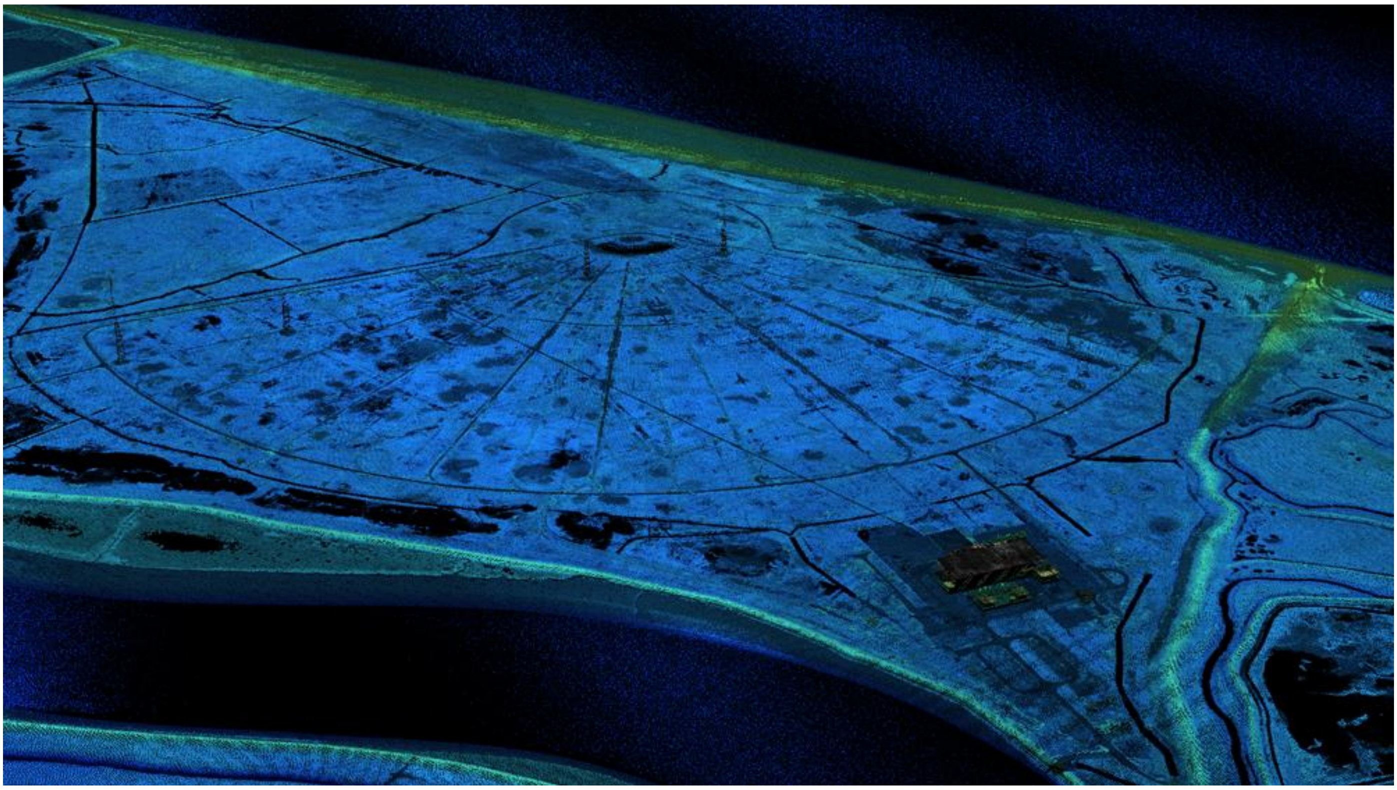

Figure 3: The point cloud output from a LIDAR survey over the Cobra Mist site at Orford Ness, Suffolk.

Furthermore an emitted pulse will not yield a single return. As the light reaches an object such as a tree, there may be an initial ‘1st return’ from the top of the tree or the highest point of an object. However some of the light will filter through the leaves and branches, some of these will be reflected and some will be absorbed by various surfaces until the light hits the ground and travels back through the tree further degrading the return intensity. The LIDAR sensor can detect 8 discrete returns from each pulse.

Specification

Surveys are conducted according to the latest version of the Environment Agency's *National Standard Contract and Specification For Surveying Services, Standard Technical Specificat*ions.

LIDAR systems are calibrated by comparing measurements to a ground survey, this is known as ground truthing and aims to ensure there is no systematic bias in the LIDAR data. These ground truth points may need to be accurately interpolated to the nearest LIDAR ground point observation. Ground truth test sites are ideally open flat areas, on the beach or within areas of saltmarsh and mudflat such sites are not common. Therefore on the coast all suitable sites such as roads and car parks are vital. Accounting for the systematic error is important as we assess the change in subsequent LIDAR surveys to understand the changes occurring on the beach such as a loss of sediment or the lowering of the beach elevation affecting wave impacts.

LIDAR surveys have an achievable horizontal accuracy of about 1/5500 x the flying altitude and a < 0.03 – 0.20 m RMSE (from 150 – 5000 m altitude) elevation accuracy. In addition ground truthing, or validation points are measured on different surfaces and substrate within the survey area, and on fixed flat surfaces of accurate known height. The EA Specification requires an accuracy of 0.15 m RMSE and a systematic bias of < $^{+}$- 0.10 m unless otherwise stated.

Survey timing

LIDAR surveys occur over the winter (October to March), when there is less vegetation and so providing a better return from the ground. Flights are carried out to coincide with the time of Low Water, usually on a Spring tide in order to achieve the required seaward extent and scan the maximum area or exposed beach.

The Data

Data outputs

The LIDAR product is a LAS point cloud of geographically registered data points, each containing x,y,z and intensity information. These data are available in a .las format and can be used in GIS and 3D visualisation software.

The point cloud data is quality checked and processed to produce a raster model of topography or Digital Elevation Model (DEM). The raster is an image file consisting of a grid of cells. Each cell contains position information as well as an elevation measurement. Because each cell is a single or averaged elevation measurement, cell size is important in how detailed the grid is in representing the Earth's surface (see the Resolution section). Shadows or hillshade on a raster or DEM helps us to display the relief of a landscape.

Figure 4: LIDAR survey of Blakeney Point, Norfolk

The DEM processing includes removing water bodies including the sea from the data. There are two DEM products created, firstly a Digital Surface Model (DSM). This is an unfiltered representation of the surface, and contains buildings and vegetation as well as open terrain. We also filter out buildings, vegetation and structures such as beach huts and piers to create a 'bare earth' surface model called a Digital Terrain Model (DTM). The data density is key to how effectively a DTM can be filtered from a DSM.

Resolution

The coastal LIDAR has a 1 m spatial resolution, this means an elevation measurement every metre on the ground. The spatial resolution defines the how often there needs to be an xyz measurement on the surface being surveyed. As the LIDAR scans from side to side in a saw tooth pattern, the forward distribution of points can change, with more returns being collected from directly under the plane (in Nadir) than towards the edge of the swath or when scanning at an angle (off Nadir). A 1 m resolution dataset requires a minimum of 1 measurements every 1 m², in additional to accurate ground validation. 25 cm resolution data needs at least 16 points every m².

The different resolutions of data capture are achieved by changing the capture parameters of the LIDAR sensor. The scan angle determines the swath width. The scan frequency determines how many times a second the instrument completes a full scan, from Nadir to full left then full right and back to centre. The laser repetition frequency sets how often the pulses are emitted, this can be up to 550,000 times per second with the current Optech sensor. To a lesser extent we can also adjust the flying height. The flight lines are also programmed to ensure an overlap in swath paths, in reality there will be usually be more than the number of required returns. The higher the data point density/resolution we want to achieve the narrower the swath and the higher the scan frequency and laser frequency we use. Typically 25 cm resolution data is captured at 850 m flying height above ground and 1 m resolution is captured at 1000 m above ground. 1 m resolution surveys can be captured at higher altitudes but the height of cloud cover tends to restrict this.

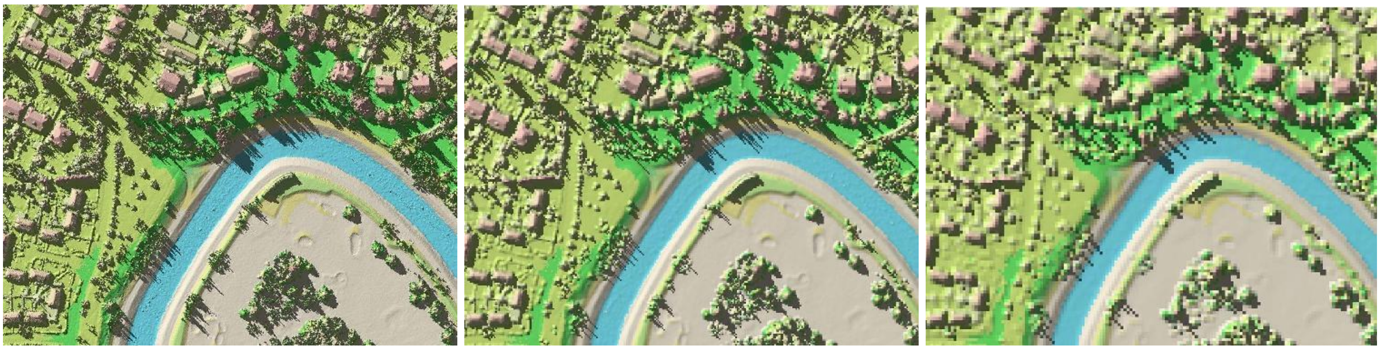

Figure 5: Examples of LIDAR resolutions at: 25 cm (left), 1 m (middle) and 2 m resolution (right)..

Analysis

The LIDAR survey data provides a topographic model, a snapshot of the geomorphology and how this has changed from previous observations. It also provides us with a base model from which to model changes and forcing factors such as flow rates in rivers or erosion rates of the shoreline.

A useful analytical technique to assess coastal change is our 'LIDAR elevation change analysis' or difference modelling. Whereby one raster DEM is subtracted from a DEM of a previous survey. The output difference model shows the change between the two LIDAR surveys. To account for systematic errors, as well as we can, the data will be normalised. This means the first survey is used as a baseline to validate points on the second dataset in areas where we know, usually through the ground truth surveys, there has been no change in elevation, for example concrete surfaces such as car parks and promenades. Any corrections made to these points is used to normalise the whole dataset before it is subtracted from the initial baseline dataset.

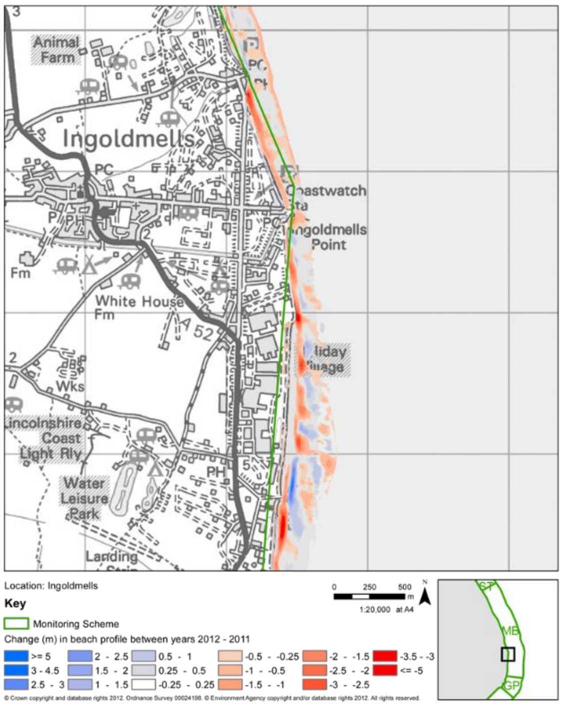

Figure 6: Elevation change analysis and difference model of the beach at Ingoldmells, Lincolnshire

We also extract profiles from the raster data, these extracted lines of data match our topographic survey transects The extracted data provides a cross section or beach profile, and allows us to compare both survey types, increasing the information we have about the changes that have occurred on that beach. The LIDAR data do not have the same accuracy as the topographic ground surveys, but they do have a greater data density and usually provide more observations along a transect line and giving a more detailed profile.

Data use considerations

LIDAR surveys provide a high density of data, especially the cloud point datasets. The benefit of which is a high level of detail in describing the coastal terrain, but the high number of points means large file sizes and large datasets to handle. The cell size of the raster and the resolution of the data are key for the required level of detail for the surface you are representing and the use of the data.

LIDAR data and topographic ground survey data are complementary and can be used together to increase our understanding of changes, however they are different datasets. The two survey techniques have different accuracies and errors which need to be considered.