Capturing 3D Environments using UAS Drone Technologies

Conservation, Forestry management, Flood alleviation

Contents

Introduction

With the advancement of lighter airborne scanning technologies, more data is becoming available for scientists and analysts to optimize workflows and assist in the alleviation of issues that may not have been previously conceptualized. The scanned environment can be processed remotely to extrapolate data from areas of interest by digitally replicating the physical world using unmanned aircraft systems (UAS) equipped with lidar sensors. When compared to manual techniques, AI assisted tree segmentation can achieve up to 98% accuracy, resulting in highly accurate bare earth scans. Utilizing these scans in simulated digital environments, we can simulate erosion, flooding, and other natural weathering forces that may occur on the landscape. Digital twinning provides a technological advantage in preserving real world environments that can be reviewed and made accessible later.

Data Collection

Sensor Hardware

Retro-fitted unnamed aircraft systems using lidar, high resolution cameras and FLIR sensors are now able to scan and reconstruct the physical landscape into digital formats. Remote sensing (RS) platforms used by UAS can be configured to produce a point cloud data set of an environment and the resulting digital twin can then be processed and further analyzed. Capture approaches utilizing different sensors vary based on expense and scanning requirements. Wherein each approach has its advantages and with processing algorithms improving, cheaper solutions to capturing depth information are becoming increasingly available.

Both scanning and flash lidar variants will use synchronized time-of-flight cameras to detect depth. Pulse-based approaches will use scanner less technologies and instead these high-powered optical pulses are emitted towards objects with nanosecond return delays that once processed capture depth information.

Single Photon LiDAR (SPL) provides an efficient approach to rapid, high-resolution 3D mapping. SPL requires only one detected photon per ranging measurement, as opposed to hundreds or thousands of detected photons per ranging measurement for conventional or Geiger Mode lidar.

Current airborne scanning trends use a combination of sensors; Lidar, FLIR for nighttime scanning and high-resolution cameras for daytime capture. An example of using other sensor units is the use of a navigation unit (GNSS) to record land prone to flooding and compare scans over time to this geographic location (1). Digital twin clones of land mass can allow for simulations of natural fire hazards due to the increased climate; High-definition resolution cameras are also applied with an inertial measurement unit (IMU) which is used to get the pitch and attitude of drones while scanning the environment. This allows for algorithms to consider the difference in UAS height when scanning to have a consistent 3D spatial scan. Frameworks have been established with the objective of understanding trends, overlaps and gaps between datasets (2).

Due to scanning and moving at speed, unlike traditional static lidar scanning it is frequent that pulses from the single photon laser are recording the terrain before the data has reflected to the sensor. An approach to aligning high fidelity scans could now be used with the advancement of graphical engines and their processing pipelines to render datasets in real time. Issues with algorithmically aligning datasets is related to the noise produced from scans typically prevents point cloud systems matching accurately.

Photogrammetry approaches to point cloud generation have outperformed lidar in reference to point cloud densities. At the cost of longer processing times, passive image-based depth approaches used in photogrammetry do not work well in darker or shadow-heavy environments. It is for this reason that height or distance estimation will use lidar systems. An example of the use of lidar based sensors for distance estimation can be found on the dragon crew capsule by SpaceX (3). Where computer vision and lidar are used together to confirm that the dragon capsule's position and velocity are accurate by comparing the lidar image with the thermal image depth map and fuse the depth maps for an accurate representation of distance. Unsupervised learning techniques have been studied to improve estimation accuracy of depth data using a single thermal image to tackle the low illumination issue (4). Issues involved include data generation which are restrictive due to the illumination conditions at the time of data capture. It is therefore still preferred to use a combination of lidar and thermal images to get accurate depth estimation in low light conditions. Synchronization between the lidar scanner and camera sensors, however, prove problematic during alignments of the different datasets. Without multispectral lidar sensors which are novel, accurate colour representation requires a camera to be used simultaneously or run into alignment issues if recorded at different times. A lidar scanner operating on a single wavelength will not be able to scan surface colour.

Terrestrial scanning (TLS) and mobile laser scanning (MLS)

Data Processing

Manual Processing

After point cloud data has been collected, visualization, segmentation, classification, filtering, transformations, gridding and further regression activities can be completed (5).

Segmentation, classification, filtering, and data transformations are used to support understanding lidar point cloud scans. Segmentation allows for areas of a scan to be separated based on intensity value, highlighting dense areas of foliage or highly reflective material alongside less dense and reflective materials. When used with classifiers, areas of scans can be further grouped into classes such as building, sign, and vegetation. Some classifiers are based on AI solutions and others use a processed library of values such as point intensity to estimate what the object is that the point originated from. Filtering this data further includes removing unwanted noise from scans or areas that are not relevant to the subject of the scan. A use case for this is to generate a bare earth scan and remove foliage, vegetation that may be occluding the earth's surface during satellite or drone scanning.

Manual image registration, manual conversion.

AI Assisted Classification

Using machine learning to enhance understanding and interrogation of recorded data can support identifying and classifying relevant areas in shorter periods of time, reducing issues caused by human perception and cognition. A use case for this is to scan and then classify objects in the dataset to support in understanding what is included in the digital scan.

Hough space from lidar point clouds has been used with a convolutional neural network to classify 3D objects in point cloud space generated by a Lidar (6). The Hough space is rasterized into uniform grids where processing is then completed in a convolutional neural network. Additionally, the study used a semi-automatic 3D labelling tool which resulted in a library capable of identifying four objects: wall, bush, pedestrian, and tree. This technique of labelling will analyze and extract shape attributes to the classify by training a model (7). The CNN would then use this library to train the neural network through large amounts of offline datasets and resulted in object classification with accuracy of up to 93.3%.

Depth Estimation

A benefit of lidar is the conditions it can operate in without the need for further sensors to supplement the dataset retrieved. Passive images from RGB sensors such as high-resolution cameras are not suitable for dark environments but sensors such as FLIR are suitable. When the stereo pair are used together depth estimation algorithms are able to synthetically generate thermal images from their RGB counterpart (4), allowing for a significant increase in depth data available for FLIR sensors. Depth estimation is an important component of generating 3D environments from scans and is directly related to the field of computer vision. Many UAS and autonomous vehicles require a form of depth estimation to vectorize the world the sensor is in to make sense of it and provide the necessary steps to interact with the environment such as SLAM.

Supervised Learning

For neural nets to be trained using supervised learning, large quantities of dense point cloud datasets are required with high fidelity scans for clear object recognition, without noise or obfuscation. The labeling of these clouds needs to be accurate. Due to the unstructured distribution, the nature of point cloud datasets make it difficult to use techniques such as deep learning for classification, segmentation and object feature detection (8).

Unsupervised Classification

Synthetic data generation

Cluster analysis is used to categories areas of a point cloud or other dimensional dataset to assist in analyzing objects and their context within a scanned environment. Clustering algorithms are often used during the exploratory stage of data analysis and focus on analyzing points with their neighboring points. Two points close together within a specified value are likely to be clustered together and points far apart are not. Therefore, cluster shape is an important consideration when working with noisy datasets as inaccuracies can occur. By using Euclidean distance, the center point of a cluster can be calculated, and the homogeneity can be compared against another cluster's center point. By averaging the distance between points in each cluster we can then correctly group points to the correct cluster. Therefore, it is critical in unsupervised classification that separation and homogeneity are viewed as requirements for an accurate clustering system. To validate clusters generated, measuring the silhouette coefficient for given cluster points can support validating points within clusters.

Data Analysis

A clear challenge during analyzing and processing of point cloud datasets has been to streamline the ingestion process of data where multiple data types are being used. Previous data fusion techniques of multi-modal datasets have issues such as image registration and angular distance automation. Proprietary software packages are limited in their functionality and are often expensive to procure.

Referred to as data holidays, some return pulses from lidar sensors have interference preventing full data collection from the returned point. Overlapping the data points by repeating scans can help preserve the data but at the cost of increased and potentially redundant data points if the data was retrieved successfully. Dropouts of scanning can occur with specular materials such as water ripples where intersecting at an angle can cause data dropouts. Similarly, if the material is not specular and absorbs most light it is difficult to get a return photon to the lidar sensor causing dropouts of data.

Reflected objects such as birds can interfere with high scanning points such as tree canopies. The elevation data will be offset by the noise added by birds during a scan from a height. Low points can also have issues related to reflective materials in the surrounding environment. Similar issues occur during GPS tracking in urban environments where user's tracking can become obfuscated due to tall buildings

Issues related to uncertainty in understanding what is included in the data set with object characteristics.

Due to light absorption and sub surface scattering, Sub surface Lidar scanning has been notoriously difficult without post processing. Used by ROV pilots, the additional 3D Lidar representation of the surrounding environment is used for navigation, alignment during surveying and construction of sub-surface pipework (9).

Issues related to scaling of multi-dimensional systems and image registration. How the points are interpreted and work with other multi-modal data sets. Coordinate systems for various sensors are different. Need to transform dataset formats from WGS84 to UTM for example, where it is likely easier to convert any coordinate system to latitude and longitude so it is compatible with EXIF data which may be used from photogrammetry assets.

Issues related to scanning colored textures in low lit environments. We can conclude from this that for accurate passive image-based depth information, point colour exclusively from images will not work in darker environments.

By taking into consideration the above issues, the processes available for visualizing high density point clouds can become available for real time modification and playback by using game engine technologies. A clear problem for depth-related data is losing data during data format conversion during loading to proprietary software products or ASCII in which crucial header information is lost.

Data Visualization

Most 3D points recorded by lidar are stored in the form of a vector coordinate system and saved to a file type that is suited for the processing application that is used. The x,y,z points are referenced collectively after scanning, to produce a point cloud space.
ASCII formats end the file extension with *.txt, *.xyz or similar, and traditionally store the vector coordinates in 3 columns, representing a single point per line. Reading a single point would take one line read which will add additional computation time when reading the points out to a buffer or rendering system and take up system memory.

Additional file formats are now more accepted due to the increased meta information that can be gathered about points. A smaller file size is also available due to the binary format type which in turn increases read time efficiency. Unlike ASCII, the LAS format has a header which contains more metadata about the scan such as the number of total points, data extents (how much continuous area of storage required for the file in memory), flight date, flight time, number of returned points, offset values and scale values. Each lidar pulse contained in the binary body includes the x,y,z location of the point, GPS time, return number, intensity value, point classification value, scan angle, RGB values, scan direction, edge of flight line, user data point ID and waveform information.

The LAZ format is the same as LAS but uses optimized compression and is also open source. Additionally, the zLAS format also compresses the binary file however due to its closed access by ESRI government and private sector agencies are hesitant to use it.

Tiles are used in the LAS data format to improve loading times of desired areas of point cloud data (10). It works similarly to a voxel chunk engine and tiles of points are loaded based on the LAS file header attributes, allowing for correct identification of scanned land areas and therefore more appropriate loading of land mass. By combining with multi-threading applications, tiles can be asynchronously loaded alongside other tiles allowing for volumes of data to be loaded concurrently.

Proprietary processing software such as Autodesk ReCap converts raw scan data to scan files (RCS files), and project files (RCP files) that reference multiple RCS files. Both these formats can be attached to an AutoCAD drawing. This approach is not open and requires software licensing.

Storing Point Cloud with Images

3D lidar recording for playback has the advantage of anonymity during data processing tasks. Applications for such a feature can include site security and counting people entering a venue. Playback of the captured recordings can be completed using proprietary point cloud graphics engines, however game engines such as Unity and Unreal are becoming more favorable for real time graphics processing in multimodal data representation. A framework for storing lidar scans for playback and further analysis involves converting lidar scanned values to 16 bit colour EXR images and playing the X,Y,Z positions stored in the RGB values back over time.

Optimization techniques involved in this include pooling the points for the images to prevent memory spikes, then passing the vector 3 coordinates to the points for representation. Point cloud datasets may not align due to sensors being in different locations during recording; if a long duration is in between scans, this issue can be directly related to image registration. Playback of lidar scans over time can be beneficial for conservation and delta analysis of changes. Image registration techniques can be adopted to ensure the datasets location in 3D space is consistent with each point. By manually assigning datasets for each frame, it may be tedious, however with technologies such as virtual reality and point classification, this process is becoming ever more streamlined. During playback of lidar images, interpolation can be used to support masking of gaps between scan rotations.

Microsoft's Azure Kinect supports scanning using numerous sensors simultaneously and is recorded to a .mkv binary format. Each recorded data type can then be accessed by deserializing the .mkv file type to play back desired data over time as it is not a static scan but a scan over time format. Due to hardware still being in its infancy to the research and development market, this solution allows for access to large multi fusion datasets in one recording.

Further optimization steps can be completed during playback of the recorded data such as 2x2 binning where diagonal pixels are merged into one, resulting in the resolution being quartered. A side effect of this, however, is doubling the signal to noise ratio on the output. Depth delay during playback of a recording is another option. By delaying the depth for high density clouds we can assign vector3 positions of the depth values before the colour values have been read. This approach allows for pooling point positions before colour textures have been assigned.

If points are not linear after scanning due to unstructured distribution of points during the scan. By using an image storage approach, cropping the image used to store the points would reduce the image size buffer for reading and the total amount of points being rendered on screen for further optimization.

Mention here how .mkv file type is used to embed multiple data formats in azure kinect.

Visualization Techniques
3D Visualization tools are classified by 3 points, data type, visualisation technique and interoperability (11).

An approach to visualizing and modifying point-cloud datasets using game engine technologies.

Application Uses

Areas that have a demand for interactive visualizations of point cloud datasets vary from static scanning to develop a digital twin of historical sites, to real time visualization of forestry for remote sensing. Industry has used Lidar UAV for applications related to forestry, habitat monitoring to stockpile recording and digital twinning. By combining 3D datasets of bare-earth scans or raw earth scans we can see how point cloud scanning technologies can be used to reconstruct a digital twin of the environment to support in simulation and area understanding.

Search and Rescue

Mountain regions, hard to access, small drones at base camps to help locate mountaineers

Geomatics & Conservation

Environmental monitoring (12) such as glaciers where two drones are used (13). One with FLIR and the other with lidar scanning, once overlaid, demonstrate how the glacier surface is changing and apply more current thermal imagery to gain a greater understanding about the debris cover and melt rate.
The use of drone scanning technology has allowed for dense data capture of historical sites which can be used to explain and highlight areas of historical interest while also uncovering unknown stories to tell. An example of this is the use of UAV drones equipped with lidar

Lidar has been used for archaeological surveying

Revealed long-lost Maya and Olmec ceremonial sights in southern Mexico.

Digital Twinning

By digitally replicating the physical world, more data becomes available for scientists and analysts to optimize workflows and support in alleviating issues that may not have been previously conceptualized.
Digital twinning projects can include simulating a virtual entity such as a business, allowing for predictive analysis on changes to operations simulated to support in alleviating issues should the changes move to the real business model. Additionally, 3D models are also forms of digital twins and allow for areas as large as cities to be scanned and digitally constructed for further analysis. These high-resolution datasets can then be used to simulate scenarios such as flooding, analyze areas of land mass that otherwise would require onsite presence or an entire city providing data about infrastructure, businesses, and movement of people.

Historical Preservation
City planning

https://geo-matching.com/content/using-mobile-mapping-and-airborne-lidar-scanning-to-create-digital-twins

Security and Hazard Avoidance

Lidar sensors' advantages over traditional video surveillance systems include increased privacy when tracking users in a specific field of view. Issues using video surveillance systems can arise during tracking where persons are occluded, failing to accurately track personnel count and privacy storage when tracking with faces visible. With the addition of recording in colourless 3D, lidar tracking systems for monitoring personnel count at venues such as concerts, conferences and areas with large gatherings of people can be private. Identifiable features on a person such as their face will not be of sufficient fidelity using such a system at range. This provides an element of privacy built from the data collection stage of the process. By having anonymous data from the start in real time processing, there would be no further anonymization processing required.
Autonomous drones have also been used for patrolling a site 24 hours a day 7 days a week. Battery life varies from 3 minutes to larger commercial use drones reaching 30 minutes. Due to the technology being so novel, there has not been mass adoption of this process of surveillance of drones automatically docking to a charging system while another drone takes its place.

Remote Sensing of Forestry, Glacier and Ocean

Climate smart forestry preservation techniques have been used to focus on more sustainable solutions to forestry management. An example is using an AI platform to identify log density accurately allowing for increasingly accurate logging stockpile predictions which can further support in understanding the environmental impact such as soil densities, erosion used by trees in the area if they are ready to be logged. By creating a digital twin of a forest, segmentation algorithms can ben be used to extract individual trees and branches with 95-98% accuracy (14). Furthermore once the environment has been scanned and the trees segmented, the bare earth scan can be isolated to support in simulation of erosion, flooding, and other natural weathering forces.

An industry taking advantage of digital twinning is climate-smart forestry, focusing on sustainable forestry development in response to climate change and reducing greenhouse emissions while additionally capturing carbon from the atmosphere. With conifers reaching 30m in height, it has been technically difficult to scan between the different layers of forestry with spotty shrub layers and dense mosses and lichen layered ground. Accurately recording the variations in scanned forestry has been difficult for this reason, with a variety of species living in the different forestry layers.

For forest inventory management, terrestrial lidar scanners (TLS) allow for mass digitization of large areas quickly, with post processing, further classification and segmentation completed at a later stage. Manual measurements are not required when using this approach, therefore data collection speed is increased and has the opportunity for using AI methods to increase accuracy of the data. Classical methods for calculating tree area involve collecting diameter at breast height (DBH) which is affected by an error rate of around 5.6%. There has also been bias to the DBH collection approach of up to 26%, this is another clear indicator that traditional approaches are not suitable for accurate information retrieval or estimation. During digital twinning of forestry using the VirtSilv platform, a novel software that takes into the exact shape and measurements from trees not just a more general sphere shape in which a DBH formula can be applied, it uses the unique shape of each tree for its calculations.

Coral reef remote sensing (15).

1. Eeckhaut M v, Poesen J, Verstraeten G, Vanacker V, Nyssen J, Moeyersons J, et al. Use of LIDAR-derived images for mapping old landslides under forest. Earth Surface Processes and Landforms; Earth SurfProcessLandforms. 2007;32(5):754–69.
2. Feng Q, Liu J, Gong J. Urban Flood Mapping Based on Unmanned Aerial Vehicle Remote Sensing and Random Forest Classifier—A Case of Yuyao, China. Water (Basel). 2015;7(12):1437–55.
3. Nasa S. Spacex CRS-6 Mission. 2015.
4. Lu Y, Lu G. An Alternative of LiDAR in Nighttime: Unsupervised Depth Estimation Based on Single Thermal Image. In IEEE; 2021. p. 3832–42.
5. Fernandez-Diaz Juan & Singhanic E al. An overview of lidar point cloud processing software. 2008.
6. Song W, Zhang L, Tian Y, Fong S, Liu J, Gozho A. CNN-based 3D object classification using Hough space of LiDAR point clouds. Human-centric Computing and Information Sciences [Internet]. 2020 Dec 1 [cited 2022 Jan 18];10(1):1–14. Available from: https://hcis-journal.springeropen.com/articles/10.1186/s13673-020-00228-8
7. Guo Y, Bennamoun M, Sohel F, Lu M, Wan J. 3D Object Recognition in Cluttered Scenes with Local Surface Features: A Survey. IEEE Transactions on Pattern Analysis and Machine Intelligence; IEEE Trans Pattern Anal Mach Intell. 2014;36(11):2270–87.
8. Bello SA, Yu S, Wang C. Review: deep learning on 3D point clouds. 2020;
9. Evans P.M. KJO, Bjarnar ML. New technology for subsea laser imaging and ranging system for ispection and mapping. Sensor Review. 1998;18(2):97–107.
10. USNA. LAS Point Cloud Format. 2021.
11. Olshannikova E, Ometov A, Koucheryavy Y, Olsson T. Visualizing Big Data with augmented and virtual reality: challenges and research agenda. Journal of Big Data [Internet]. 2015 Dec 1 [cited 2022 Jan 18];2(1):1–27. Available from: https://journalofbigdata.springeropen.com/articles/10.1186/s40537-015-0031-2
12. Kaufmann Viktor Kellerer-Pirklbauer Andreas SG. Conventional and UAV-Based Aerial Surveys for Long-Term Monitoring (1954–2020) of a Highly Active Rock Glacier in Austria. Frontiers in Remote Sensing. 2021;2(https://www.frontiersin.org/article/10.3389/frsen.2021.732744).
13. Bisset RR, Dehecq A, Goldberg DN, Huss M, Bingham RG, Gourmelen N. Reversed Surface-Mass-Balance Gradients on Himalayan Debris-Covered Glaciers Inferred from Remote Sensing. Remote Sensing 2020, Vol 12, Page 1563 [Internet]. 2020 May 14 [cited 2022 Jan 18];12(10):1563. Available from: https://www.mdpi.com/2072-4292/12/10/1563/htm
14. Niță MD. Testing Forestry Digital Twinning Workflow Based on Mobile LiDAR Scanner and AI Platform. Forests. 2021;12(11):1576.
15. Foo Shawna A. AGP. Scaling Up Coral Reef Restoration Using Remote Sensing Technology. Frontiers in Marine Science. 2019;6:79.

Funding Opportunities:

1. NERC possible funding routes:
   a. Future of UK Treescapes programme, Closing Date: 14th January 2022, Maximum award £625,000: https://www.ukri.org/opportunity/research-solutions-for-uk-treescape-expansion-and-resilience/
   b. NERC large grant to tackle big environmental science questions, Deadline: 08/03/2022, Award range: £1.2m - £3.7m: https://www.ukri.org/opportunity/nerc-large-grant-to-tackle-big-environmental-science-questions/
   c. Develop basic technologies in sensing and imaging, Deadline 03/03/2022, Award: £225,000: Develop basic technologies in sensing and imaging – UKRI
2. EPSRC possible funding information:
   a. **Build a network to enable resilient solutions for future UK systems, EPSRC co-fund with Defence Science and Technology (DST works under the direction of the Ministry of Defence's Chief Scientific Adviser to maximise the impact of science and technology for the defence and security of the UK.), Deadline: 01/02/2022, Award: £2,250,000 (can explore all technology discussed): https://www.ukri.org/opportunity/build-a-network-to-enable-resilient-solutions-for-future-uk9-systems/**
3. Other: Datalab, KTP