Navigating the Indoor Frontier: Uncovering Movement and Occupancy Patterns with Terrestrial Lidar

Shashank Karki, Addison Flack, Dr. Thomas J. Pingel, and Dr. Timothy D. Baird

Near Earth Imaging Lab, Department of Geography, College of Natural Resources and Environment, Virginia Tech

Abstract

Indoor spaces have traditionally been difficult to map using conventional GIS and remote sensing-based methods: indoor spaces are not directly sensible with satellites and drones, and camera-based Structure from Motion (SfM) reconstructions are often of poor quality indoors. These methods also do not capture the dynamic nature of a shared space. We investigate how terrestrial lidar can be used to analyze movement activity in the lobby of the Creativity and Innovation District (CID) Building at VT, focusing primarily on the methodological aspects of collecting, visualizing, and analyzing the data.

We aggregate lidar data from 11 sensors into a single point cloud every second using a defined Building Reference Coordinate System, which we record as point clouds and orthographic images. We further process the orthographic images into animations and NetCDFs for spatiotemporal analysis. Additionally, using Percept, an object-tracking lidar perception software, we create line-based vectors containing both spatial and attribute data (including positional velocity, direction, and size).

Future work will apply these methods to answer research questions about how people use and move in the space, and how these patterns change in response to disturbance and affordances of resources.

Study Area: The Creativity and Innovation District

The study area for the research is the public spaces on the first floor of the Creativity and Innovation District (CID) at Virginia Tech (VT). CID is a residential and academic building with an area of 225,000 sq. feet. The building was opened for use in August 2021 and is currently being used by 596 undergraduate students as a dormitory building. Furthermore, the building is also a shared space for academic, research, and collaborative activities, including performing visual arts studios, maker spaces, classrooms, and student lounges. The lobby space is the building's main entrance, and houses chairs, desks, a large television, and study spaces - making it the perfect space for collaboration and interaction amongst residents.

Lobby space in the CID Building. Source: The Creativity and Innovation District | Living-Learning Programs | Virginia Tech (vt.edu)

References

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Methods – Data Preparation and Manipulation

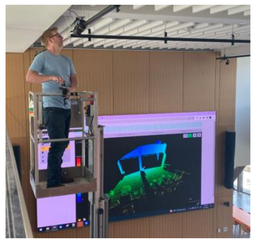
Blickfeld Cube

The Blickfeld Cube is a portable, forward-facing solid-state 3D lidar sensor with the capability of manual adjustment of field of view and configurable scan patterns. Blickfeld offers a UI-based interface to view and edit the configurations for scans from the Cube. The user interface is accessed through an internal web server, which enables users to change scan patterns, and fields of view, time synchronize the cube, check the status of the cube and enable data recording. The Cube has a port for power and another for ethernet through which it communicates with the user interface. Each sensor generates 155 GB of data per day.

Blickfeld Lidar Sensor

Terrestrial Lidar and the CID Building

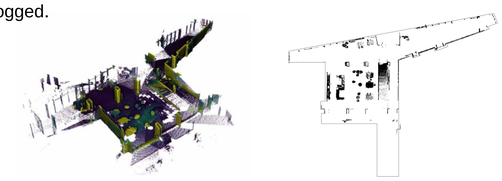
Lidar units emit pulses of light that are reflected off of surfaces to return an accurate point position in space. This process is repeated tens to hundreds of thousands of times per second to rapidly scan an area. In the lobby of the CID Building at Virginia Tech, we have installed 11 terrestrial lidar units to measure human movement patterns within the space. The lidar streams from all the sensors can be accessed through Blickfeld GUI. Also, using the Build Coordinate Reference System defined for the building, the lidar point clouds can be aggregated to form a single point cloud for the whole lobby space.



Lidar installation in CID Lobby

Point Clouds and Orthographic Images

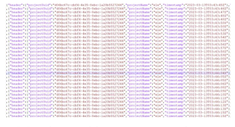
We reference and combine the point clouds from the 11 sensors together to produce orthographic images of the entire CID Lobby space. Generating one frame per second, we collect over 86,000 images of the CID space each day. 20 GB of data per day is logged.



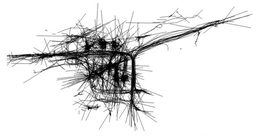
Point cloud generated viewed in CloudCompare for the shared space in CID building (left), and orthographic image (right)

Object-Tracking to Shapefiles

Blickfeld's Percept software is designed to fuse data from all the sensors and to track objects moving through the space. These logs are written out as JSON files, and contain not only positional information, but also attributes such as velocity and volume. We use Python to convert the JSON files into a Esri Shapefile feature class.



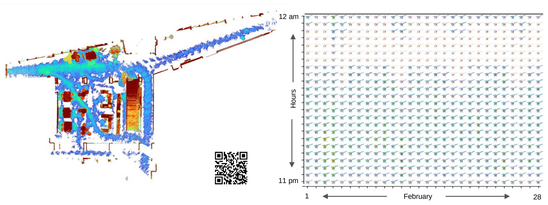
JSON logged by Percept software



Tracks generated from the JSON file

Analysis and Visualization

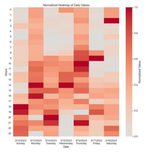
Visualizing: Animations and Small Multiples



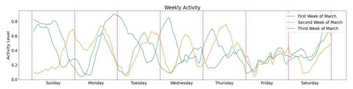
Activity patterns are visualized with daily animations, hourly composites, and monthly small multiples (Feb shown). Red shows non-moving objects (walls, furniture) and blue/green shows activity. A representative animation is linked with the QR Code.

Daily Activity Analysis

We use overall intensity values provided by a combination of 11 sensors to represent the overall amount of occupation within the CID space - doing this for one hour at a time allows us to see the total occupation and movement within the lobby space at a specific time.



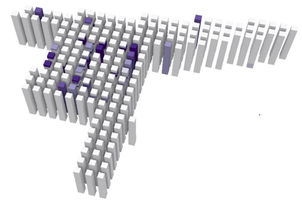
Heatmap showing activity level fluctuations for a week in March



Line Plot showing the activity in the CID lobby for the first three weeks of March

Space Time Cube Analysis

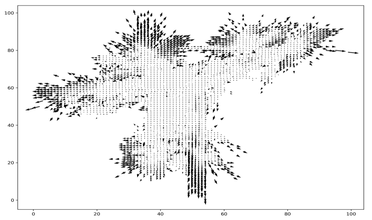
Esri's Space Time Cube and Space Time Mining toolbox provides advanced spatiotemporal analysis and visualization. Data at the hourly and daily levels are particularly useful for Space Time Cube analysis, as they permit us to view and analyze data in larger time-slices. Larger spatio-temporal trends can be drawn using this data, such as the intensity and frequency of movement in different spaces in the CID space at different times. Additionally, local outliers with regards to both space and time can be drawn out and recognized.



A 3D Visualization of a Space Time Cube charting the CID Building Space - There are 24 time slices representing the average movement over each hour of one day.

Percept Vector Flow

The Percept data logs the position of each object detected in the lidar stream along with attribute information such as size, velocity and orientation of the detected object. The information about the velocity and the orientation of the object gives an idea of how people are moving in the area. A quiver plot was made by generating average velocity and direction in bins for the whole space. The vector flow shows how people prefer to move across the space.



Vector Flow showing movement activity across the CID space as a Quiver Plot- The direction of the arrows show where the average orientation points and the magnitude is defined by the size of the arrow

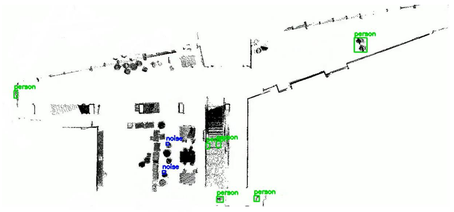
Accomplishments

Georeferencing Indoor Data

Within the CID space, the origin for a local coordinate system was selected as a corner of a wall which could be easily found via inspection of the point cloud or imagery. The vertical zero was defined by the ground floor. The coordinate system is tied to geocoordinates by defining an oblique Mercator projection defined by the latitude and longitude of the zero coordinate, and a rotation. These were obtained from inspection with orthoimagery and the georeferenced GeoSLAM lidar scan of the building.

Computer Vision for Object Detection

We use animations generated with OpenCV method to assess object detection and positional data from Blickfeld's Percept, which is built-in to the data collection.



A frame showing people and noise being detected using OpenCV methods in the animations of the lidar stream. The green boxes represent people and the blue boxes represents noise

Noise Detection and Cleaning

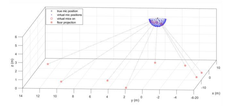
Image showing noise paths that are passing through walls in yellow

Data collected from lidar sensors are prone to noise and many of the objects detected by Percept are noise features that are reflections from shiny surfaces. Detection of noise and data cleaning was an important process. The data was cleaned using logical approaches such as objects should not pass an impenetrable wall. Additional statistical and machine learning approaches aid in noise classification as well.

Future Work

Sound

Our next steps in the CID space include the implementation of sound data into the project. Multi-directional microphones will be placed throughout the CID space, and transformations will be done to position the sound's origin on the CID orthographic images, allowing us to compare sound and visual data.



Sound data from a collection of microphones can be triangulated into position on a raster surface - Figure by Dr. Nicole Abaid

ArcGIS Indoors

We are in the process of building an ArcGIS Enterprise Base Deployment to host an ArcGIS Indoors server, giving us access to better floor-plan functionality, as well as improved indoor-based visualizations for the CID Space.

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