Indoor Mapping

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Abstract

While orthophotos, lidar, and other remotely sensed imagery and data are readily available for outdoor areas at sub-meter resolution, our indoor spaces - where Americans spend nearly 80% of their time - remain largely unmapped. A well-structured mapping of these areas would increase the possibility of improved navigation within structures, deployment of robotic assistants for household and transportation tasks, aid in emergency response and the analysis of building use patterns. We present several new technologies and methodologies to address this gap, including mobile lidar, Structure from Motion (SfM) photogrammetry, building grid coordinate systems, and indoor positioning systems.

Background

Cartography and GIS have primarily focused on outdoor mapping with little attention to indoor spaces. Recent advances in cartography have the potential to make 3D indoor mapping a reality. Typically, indoor maps are tailored to specific needs in travel, retail, and industry but indoor mapping could have many more applications (Chen & Clarke, 2019).

There is a need to explore the Great Indoors, as their study can provide more insight on the human-environment relationship. Like outdoor spaces, indoor spaces are neither stable nor uniform, and they host a flow of energy, power, and technologies that create a political-ecological space (Day Biehler & Simon, 2010).

With the advancement of technology in mobile devices, an improvement in data acquisition in indoor mapping has increased (Otero *et al.*, 2020).

For example, mobile lidar technology is now readily available in consumer electronics such as the Apple iPhone and iPad, with similar performance to image-based Structure from Motion techniques (Luetzenburg *et al.*, 2021)

References

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Luetzenburg, G., Kroon, A., & Bjørk, A. (2021). Evaluation of the Apple iPhone 12 Pro LiDAR for an Application in Geosciences. Scientific Reports, 11(1). doi: 10.1038/s41598-021-01763-9

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Methods

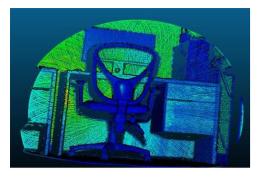
Mobile Lidar

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. Lidar units are generally more expensive than cameras and require specialized software to process the data.

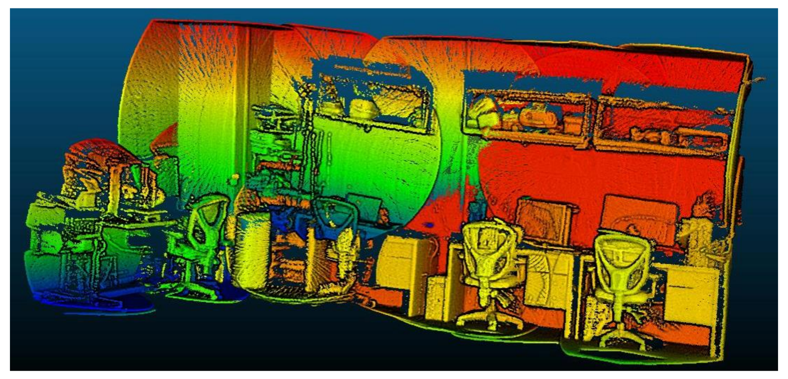
Livox Mid-40

The Livox Mid-40 Lidar Sensor is a mobile lidar sensor with a scan range of 260 meters, weight of 600 grams, circular FoV of 38.4 degrees and captures 100,000 points per second. We used the Livox Viewer to capture the scans with the Livox Mid-40. These scans from were manually arranged in CloudCompare using plane fitting, but SLAM algorithms will be used to automate the process.

Livox Mid-40



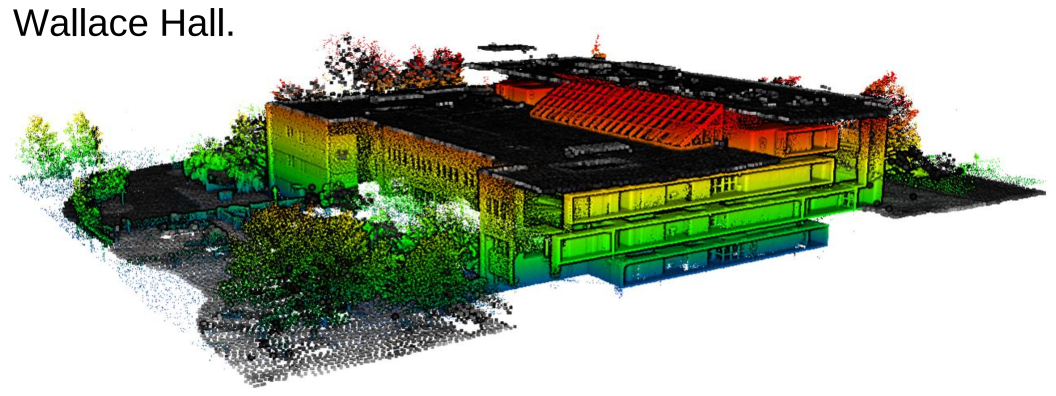
Single Scan



Multiple Livox scans assembled in CloudCompare

Velodyne

Velodyne has been a leader in mobile lidar for the past decade, and many of their sensors are used in autonomous vehicles, robots, and 3D mapping applications such as GeoSLAM handheld devices and YellowScan drone-mounted systems for environmental scanning, both in-use at Virginia Tech. We used both a single-sensor Velodyne VLP-16 Puck lidar unit and LidarView open-source SLAM software as well as a GeoSLAM unit to map portions of Wallace Hall.



Cutaway view of aerial (gray) and GeoSLAM (color) lidar, showing the detailed internal structure and improved facade model.

iPad/iPhone

Recent iPhone and iPads include a small (64 x 64 array) solid state lidar. In combination with its camera, it can generate point cloud and mesh models on the fly, without additional hardware. The resulting scans can be post-processed to reduce noise. We found these especially useful for the capture of single rooms, but difficult to stitch together larger areas. Through testing of many capture apps, we have found SiteScape and the 3D Scanner apps to produce models of the highest quality.

Scan of the Near Earth Imaging Lab using an iPhone 13 Pro and SiteScape.

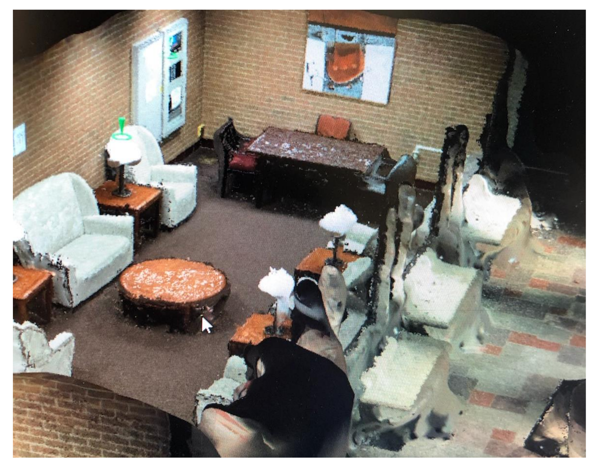
Structure from Motion (SfM)

Structure from Motion (SfM) is a photogrammetry technique that matches keypoints in sequential images to reconstruct the 3D environment. While often used with UAVs, SfM can be used indoors as well. We experimented with several approaches, including a "camera-on-a-stick" or pole photogrammetry method to collect high-overlap near-nadir images.

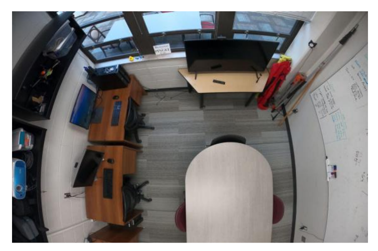
Pole Photogrammetry

We used a GoPro Hero8 Black, 12 MP fisheye camera outdoors and indoors to collect imagery. Indoors, the camera was mounted on a 3 meter pole. Ceiling tiles were used as markers allowing for fast and consistent placement. The camera was mounted slightly off-nadir to avoid capture of the photographer in the image, and when changes of direction were needed, the operator collected a second pass on the same tile row to ensure good overlap. A small set of manual tie points (MTPs) were used through the scene to assess and improve reconstruction quality. For the building's exterior, we walked in a circle around it, and took images every half second.

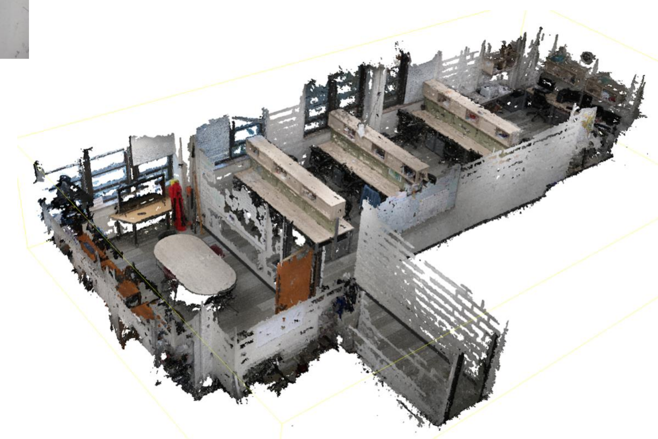
Collecting images with a GoPro mounted on a pole



3D reconstruction on entryway of Wallace Hall.



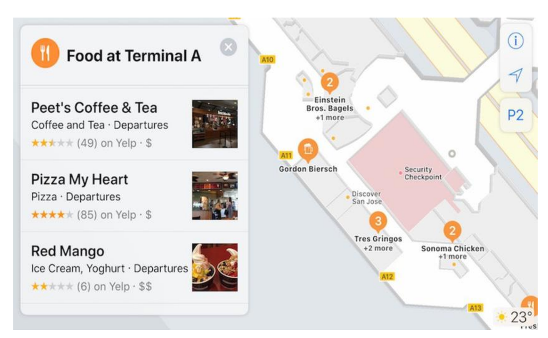
Sample image captured from the GoPro Hero8.



This SfM scan was constructed from 235 images, processed in Pix4D, and aligned to the Wallace BCRS using GCPs from the Pozyx Indoor Positioning System.

Apple Indoor Mapping

Apple and ESRI, among other companies, are developing their own indoor mapping capabilities. Apple's indoor mapping system is focused on organizing large indoor areas by categorizing features within them. For instance, each individual store in a shopping mall would be defined as an entity and mapped as one. Apple plans to solve the problem of coordinating these by using already existing WiFi networks without any additional hardware installation by measuring radio frequency patterns.



Apple's visualization of an indoor map.

Building Coordinate System

Chen (2018) defines a Building Coordinate Reference System to facilitate the mapping of indoor spaces. The critical element is the determination of a 4x4 affine matrix to transform local coordinates to a standard CRS. In this case, we have defined a Wallace Building CRS with an origin in the NEIL lab. The origin was selected as a corner of a wall (easily found via inspection of the point cloud or imagery) with a vertical zero corresponding to floor level as you walk in the building (easily determined via inspection of the point cloud histogram). The transformation matrix is shown here and includes elements of rotation and translation to project Wallace BCRS points to NAD83 (2011) UTM 17N.

$$\begin{pmatrix} -0.35313 & -0.93558 & 0 & 551086.013 \\ 0.93558 & -0.35313 & 0 & 4119762.487 \\ 0 & 0 & 1 & 633.475 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

The transformation matrix for Wallace BCRS to UTM 17N.

Indoor Positioning System

The Pozyx IPS can track real-time positions of various objects through Ultra-Wideband Technology. The system uses a mesh network of stationary *anchors* and mobile *tags* that track their location in reference to each other. Anchors can auto-generate an arbitrary coordinate system, but ours have been tied to the Building Coordinate Reference System in Wallace Hall, which streamlines the setup of anchor placement and calibration.

The Wallace Building Coordinate Reference System shown with a rendering of the 2nd floor and surrounding area.

A mobile Pozyx *tag*.

An *anchor* in Wallace Hall.

Conclusions

Off-the-shelf lidar systems such as the GeoSLAM unit allow for the fastest and easiest generation of indoor point clouds, but may be cost prohibitive for widespread use. In contrast, single-sensor lidar units paired with SLAM algorithms are relatively inexpensive ($1-3K) but require significantly more expertise to operate. Camera-based systems using SfM are even less expensive, use workflows similar to other outdoor SfM projects, and generate high point density but often noisy products. The use of a BCRS significantly aided the in the collection, processing, and management of data.