Map901: Building Rich Interior Hazard Maps for First Responders

Lan Wang (PI), Eddie Jacobs (Co-PI)

University of Memphis

In collaboration with City of Memphis (Kimberly Bailey, Wendy Harris, Cynthia Halton)

Thomas Watson (Presenter)

Map901 Website: map901.memphis.edu

Disclaimer

- This presentation was produced by guest speaker(s) and presented for publication in the National Institute of Standards and Technology's PSCR 2021 The Digital Experience. The contents of this presentation do not necessarily reflect the views or policies of the National Institute of Standards and Technology or the U.S. Government.

- This work was performed under the following financial assistance award 70NANB18H247 from U.S. Department of Commerce, National Institute of Standards and Technology.

- Posted with Permission.

Overview

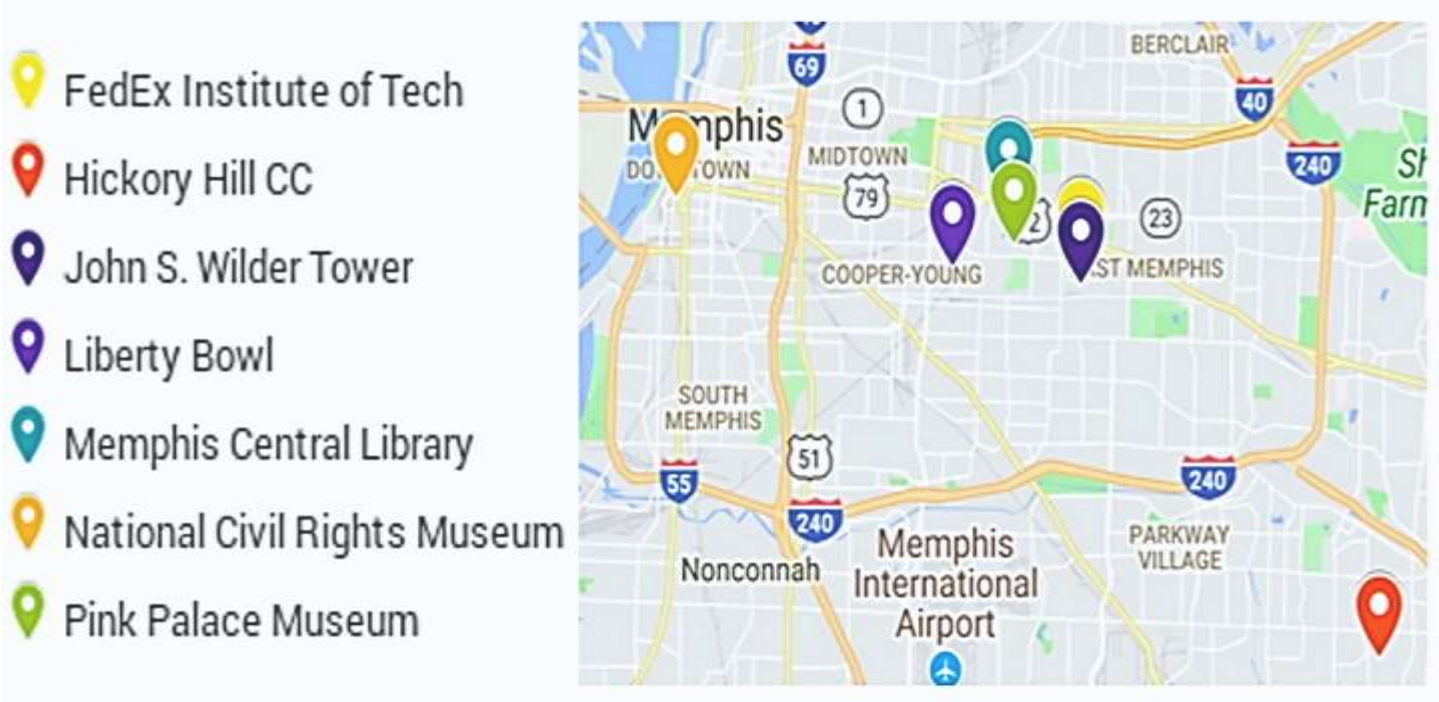
- Introduction and Motivation
- Methodology and Data Collection
- Data Representation and Findings
- Conclusion and Future Works

Introduction

- Firefighter deaths occur due navigation difficulties in smoky environments
- In 2019, 48 (averaged 65 deaths per year) firefighters and roughly 3,700 people lost their lives, and 16,600 people were injured
- High-quality 3D maps are a possible technological solution

Map901

- Collaboration between City of Memphis and University of Memphis
- Survey 7 facilities, 1.86 million square feet
- 3D point cloud, 360-degree camera images, other sensor data



3D Mapping Hardware for Colored Point Clouds

3D Mapping Hardware

Point cloud data

360-degree image data

GVI LiBackpack 50

Modified Green Valley International (GVI) Li-Backpack

Display shows low-resolution scan result in real time

Intel® RealSense™ T265 provides 3D world pose

Intel® RealSense™ D435 captures depth and color

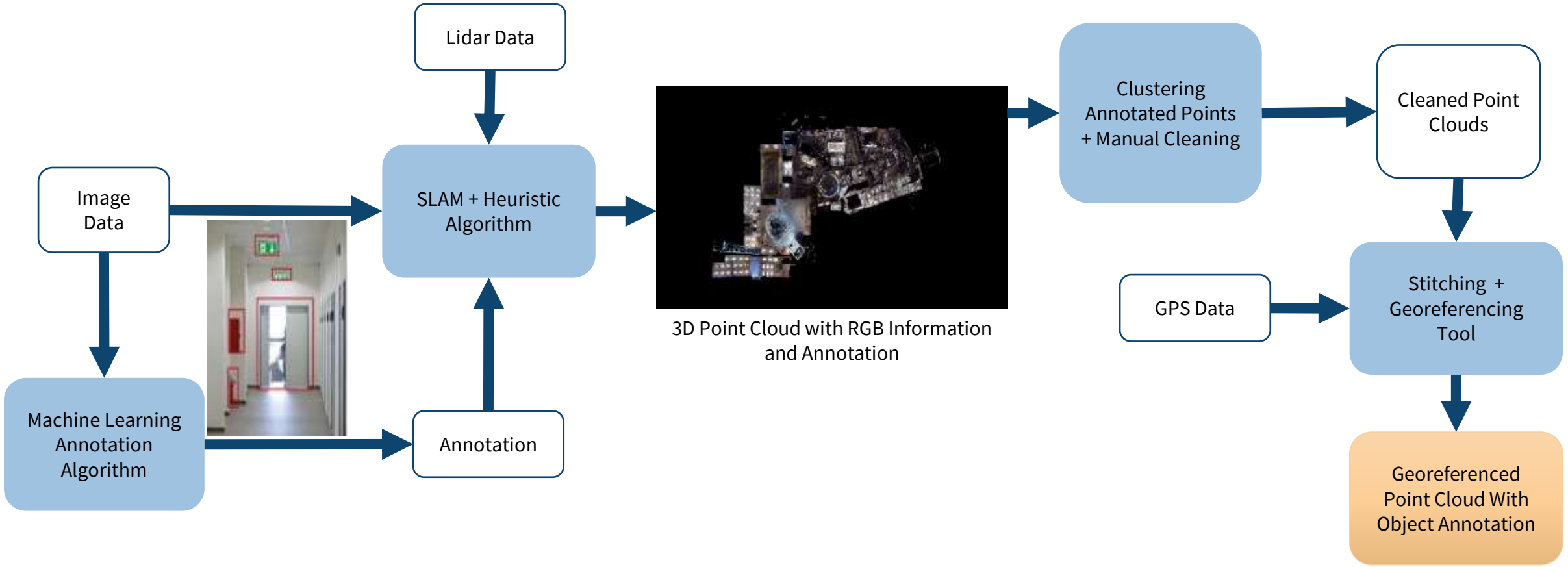
Signac Portable Scanner (Developed by Map901)

3D LiBackpack (Top) vs. Signac (Bottom)

Pink
Palace
Museum
Attic

Methodology and Data Collection

Data Processing Workflow



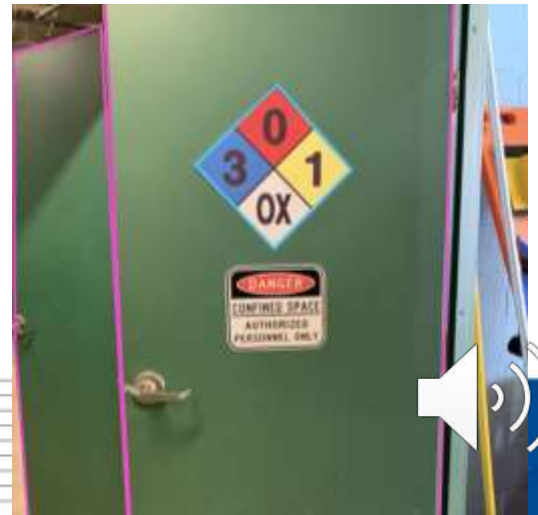
Data Collection

- Route is planned through space
- Operator walks through area, using tablet to start and stop recording
- Camera records 3840x1920 @ 30FPS equirectangular video
- Backpack records IMU and LiDAR data

AI-Driven Labeling of Public Safety Objects

Priority Objects

Priority	Label Class	Priority	Label Class	Priority	Label Class
5	hazmat	4.2	elevator	3.6	fire door
4.8	utility shut offs - electric	4	fire alarm	3.6	extinguisher
4.8	utility shut offs - gas	4	fire wall	3.6	sign exit
4.8	utility shut offs - water	4	mechanical equipment	3.2	emergency lighting
4.6	building entrance-exit	3.8	sprinkler	3.2	sign stop
4.6	door	3.8	sprinkler cover/escutcheon	3.2	smoke detector
4.6	fire hydrant	3.8	interior structural pillar	3	Automated External Defibrillators
4.4	fire escape access	3.8	standpipe connection	3	Individual First Aid Kit
4.4	roof access	3.8	window	2.4	server equipment
4.4	stairway	3.6	fire alarm switch	2	person



Annotating Images for Training Neural Network

- Manual annotation using LabelMe
- Crowd sourcing through contest
- Iterative process
  - Use trained Neural Network to label images
  - Select images with more annotated objects and errors
  - Manually correct the selected images to add to training data set
  - Retrain the Neural Network

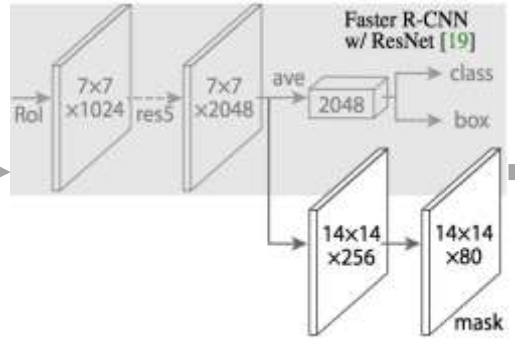
Map901 Image Dataset

Training Name	Date	Training	Validation	Testing	Total
Images from Other Sources (Google, MCIndoor20000 etc.)	2020/08/23	883	0	0	883
FedEx Institute of Technology (FIT)	2020/11/30	200	82	66	348
Hickory Hill Community Center (HHCC)	2020/05/05	262	92	76	430
Liberty Bowl Memorial Stadium (LB)	2020/09/08	132	43	46	221
Benjamin L. Hooks Central Library (MCL)	2020/12/16	101	51	33	185
National Civil Rights Museum (NCRM)	2020/08/23	206	76	64	346
Pink Palace Museum and Planetarium (PP)	2021/02/26	86	32	27	145
John S. Wilder Tower (WT)	2021/02/26	117	40	39	196
Contest (Equirectangular and Other Images)	2020/09/27	206	0	0	206
Total	2021/02/26	**2193**	**416**	**351**	**2960**
	5/5/2020	610	127	128	865
	2/13/2020	317	123	125	565

Number of HHCC images 2021/02/26 (430, 15%)
5/5/2020 (412, 47.6%), 2/13/2020 (225, 40%)

Image Annotation

Equirectangular Image



Mask R-CNN

Annotated Frame

- Goal: annotate image data with **public safety objects**, e.g., fire extinguishers, building control panels, utility shutoff, exits
  - Use Mask R-CNN [1] and ResNet-101 [2] (or Inception-ResNet-v2 [3]) to label objects
  - Store bounding boxes, polygon masks, and class labels in a JavaScript Object Notation (JSON) format and masks in a Portable Network Graphics (PNG) format
- Mask R-CNN provides pixel level segmentation with bounding boxes
- ResNet-101/Inception-ResNet-v2 architecture works as feature extractor and classifies objects

[1] K. He, G. Gkioxari, P. Dollr, R. Girshick, Mask R-CNN. ICCV 2017
[2] He, K., Zhang, X., Ren, S., & Sun, J. Deep residual learning for image recognition. CVPR 2016
[3] Szegedy, C., Ioffe, S., Vanhoucke, V., & Alemi, A. Inception-v4, inception-resnet and the impact of residual connections on learning. 2017

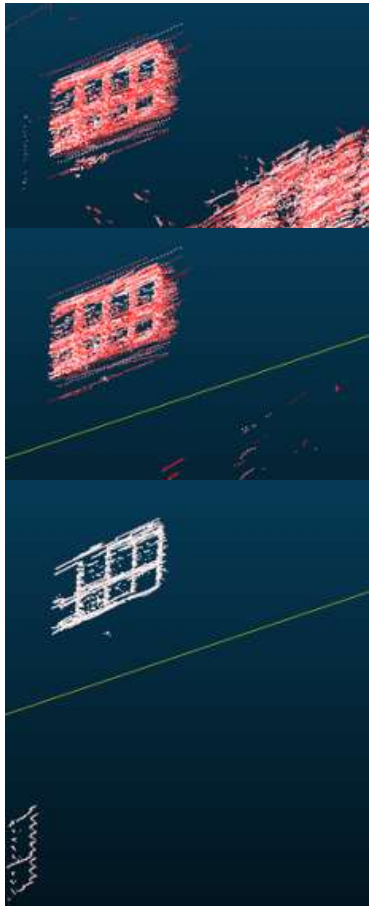
Fusing Point Clouds with Annotated Images

Color Fusion

- Fixed transformation enables color correspondence to be easily calculated
- Project LiDAR points before Simultaneous Localization and Mapping (SLAM) onto equirectangular image
- Time correspondence between LiDAR and camera is vital
- Internal clocks used for rough alignment
- IMU correlation used for fine alignment

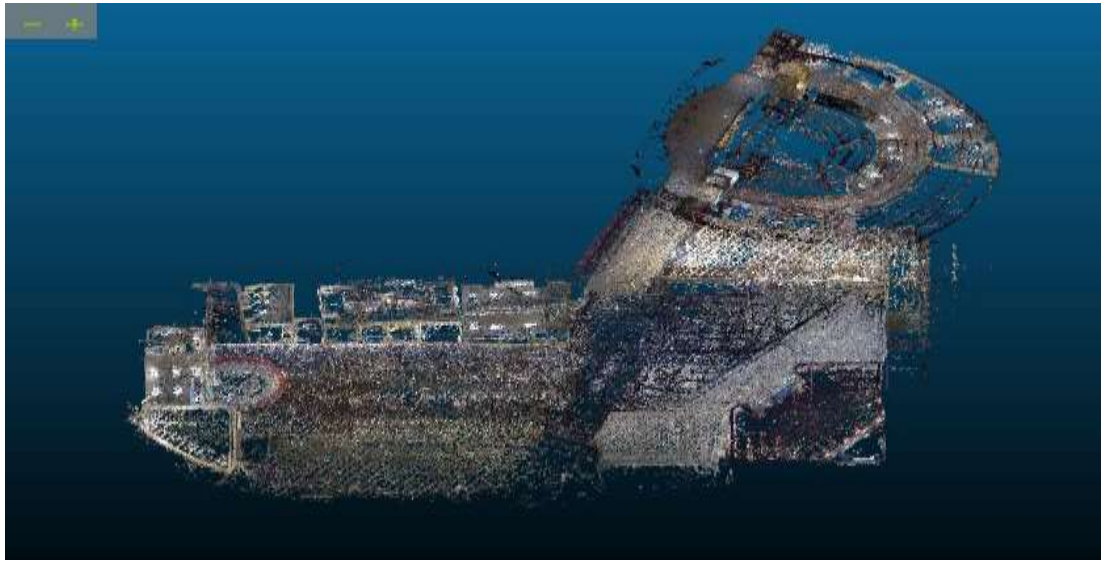
Label Fusion

- Labels are based on images, so theoretically can be fused like color
- Objects with holes are corrected for by limiting labeling to points close in depth
- Low-confidence labels are removed
- Multiple captures are corrected for by “expanding” labels to points <50mm away



Label Clustering and Manual Cleaning

- Interactive cleaning tool used to remove falsely labeled objects
- Users deal with only tens or hundreds of clusters instead of millions of points



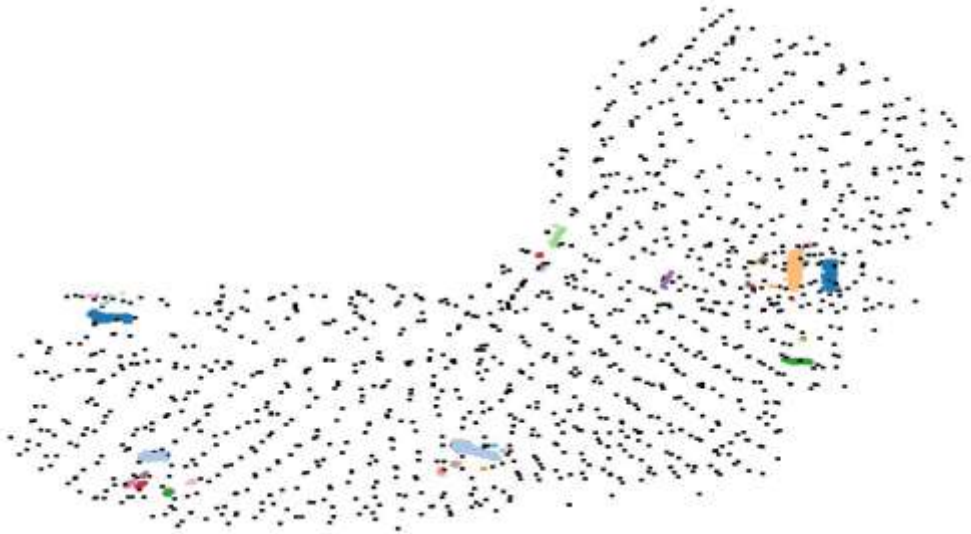
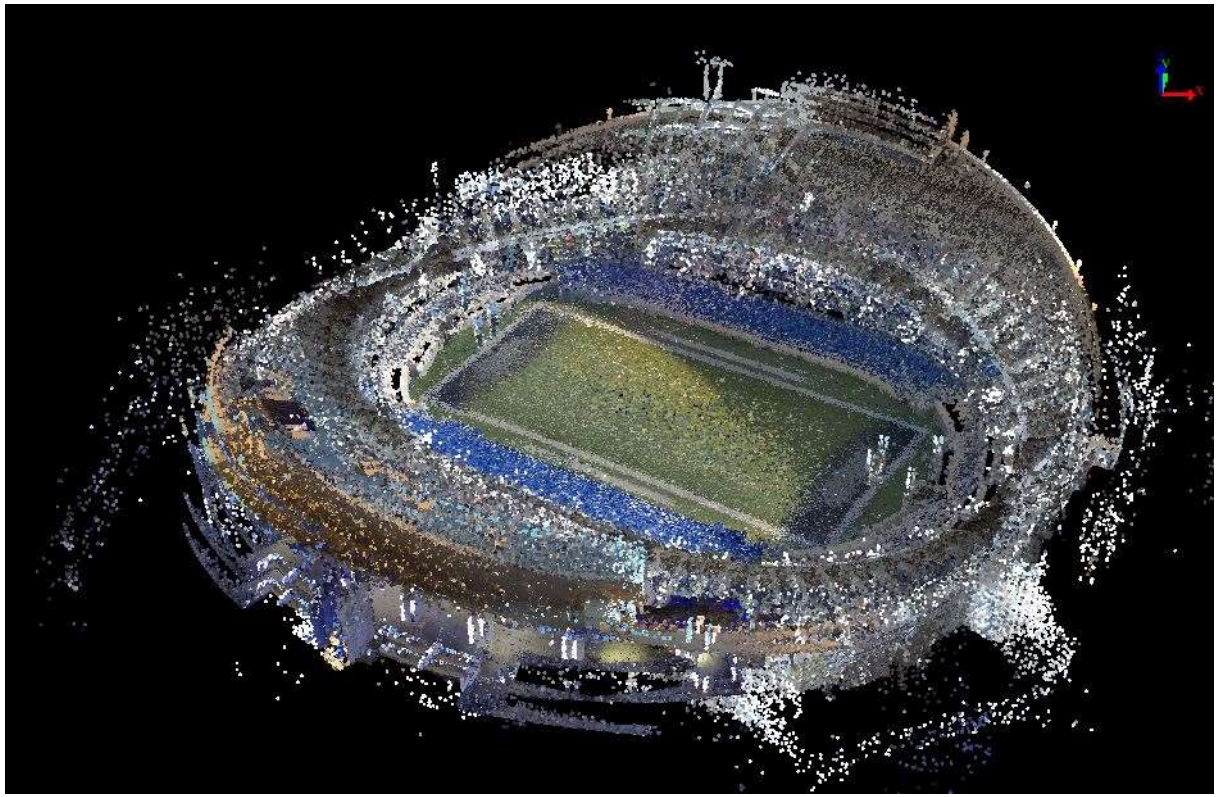


Figure 1 (left) shows the first floor of FIT in CloudCompare
Figure 2 (right) shows the simplified area in the cleaning tool

Stitching Point Clouds

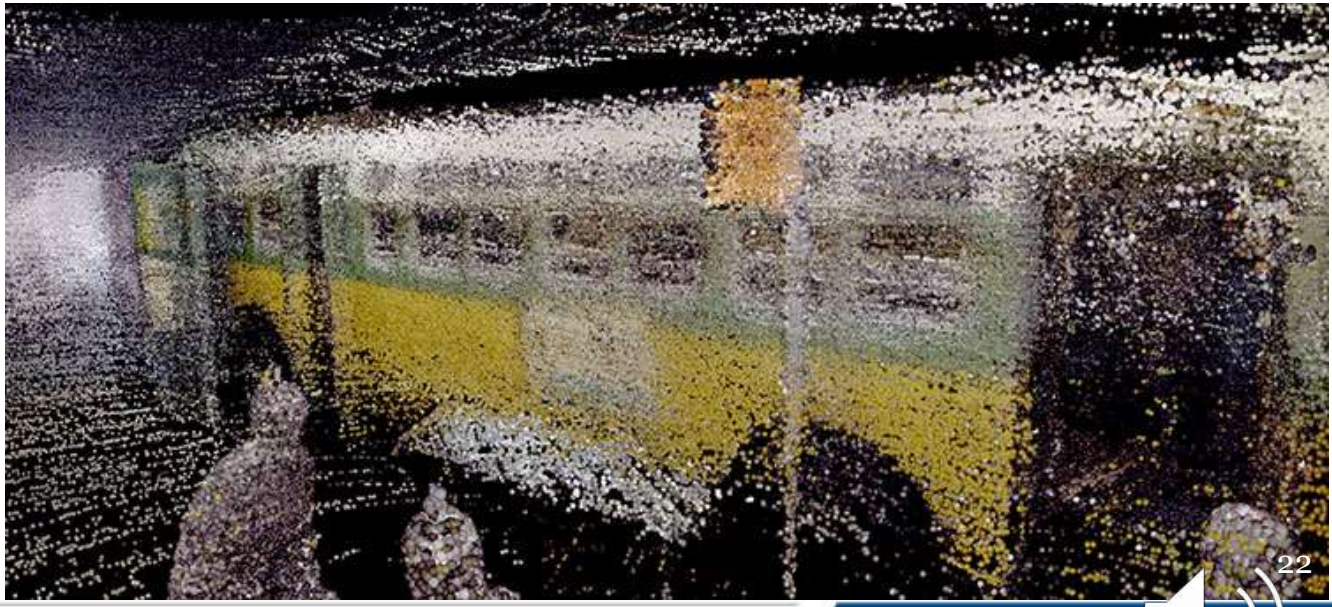
- Buildings cannot be finished in a single scan.
- How to stitch multiple scans into one building?
  - Set one of the point clouds as the reference
  - Use Cloud Compare's Manual Registration to add a neighboring point cloud to the reference
  - Continue until all the point clouds are added
- Future Work
  - Automate the stitching process



Stitched Liberty Bowl Stadium Point Cloud

Uses

- VR visualization enables problems to be identified and results to be communicated to stakeholders
- Maps enable pre-incident planning
- Maps can be used in 3D simulations to reduce training costs
- Maps can be used during incidents for indoor localization and navigation



Performance Evaluation of Object Detection and Instance Segmentation

Average Precision of latest Model

Model	Building	AP	AP_{50}	AP_{75}	AP_S	AP_M	AP_L
Mask R-CNN Inception ResNet V2	FIT	0.286	0.472	0.277	0.067	0.228	0.399
	HHCC	0.214	0.357	0.238	0.149	0.193	0.338
	LB	0.230	0.362	0.251	0.034	0.192	0.391
	MCL	0.229	0.365	0.235	0.008	0.180	0.392
	NCRM	0.278	0.437	0.297	0.044	0.327	0.340
	PP	0.270	0.432	0.279	0.036	0.236	0.351
	WT	0.287	0.508	0.293	0.027	0.209	0.500
	All Buildings Combined	0.196	0.328	0.198	0.030	0.197	0.281

Average Recall of latest Model

Model	Building	AR_1	AR_{10}	AR_{100}	AR_S	AR_M	AR_L
Mask R-CNN Inception ResNet V2	FIT	0.224	0.327	0.327	0.096	0.276	0.444
	HHCC	0.190	0.265	0.265	0.173	0.250	0.369
	LB	0.213	0.251	0.254	0.043	0.207	0.421
	MCL	0.151	0.270	0.270	0.015	0.251	0.431
	NCRM	0.230	0.310	0.310	0.053	0.351	0.370
	PP	0.235	0.329	0.329	0.068	0.285	0.410
	WT	0.220	0.325	0.325	0.043	0.276	0.532
	All Buildings Combined	0.173	0.247	0.248	0.051	0.260	0.315

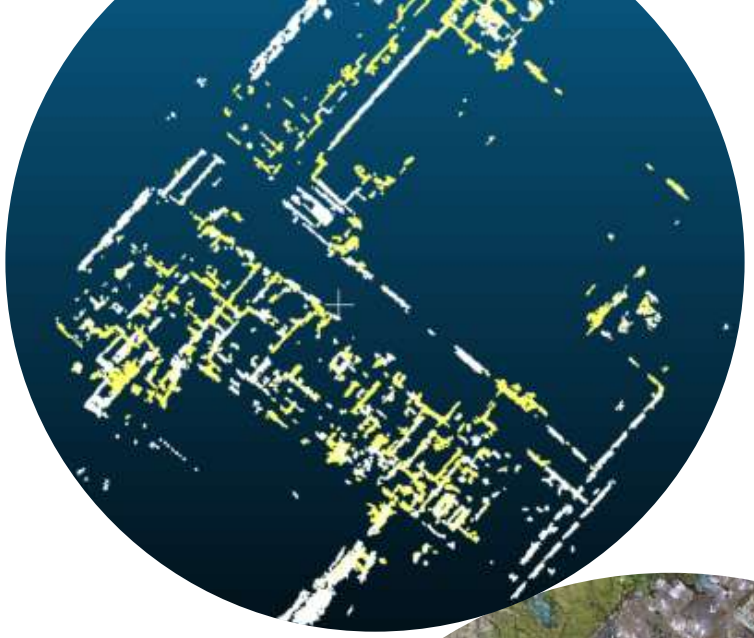
Individual Objects Performance of Object Detection (FIT 1st floor)

- Model's performance on test dataset and 3D point cloud result

Cat.ID	Name	HHCC Image	All Buildings Combined Image	HHCC Point Cloud		
		Precision	Precision	Precision	Recall	F1-score
5	Building entrance-exit	0.595	0.317	0.118	1.000	0.211
10	Door	0.577	0.356	0.356	1.000	0.525
11	Elevator	0.632	0.347	0.136	1.000	0.240
13	Fire alarm	0.353	0.260	0.284	0.905	0.432
14	Fire alarm switch	0.336	0.227	0.167	0.667	0.267
18	Fire suppression systems – extinguisher	0.514	0.372	0.214	1.000	0.353
37	Sign exit	0.542	0.398	0.493	1.000	0.661
46	Utility shut offs - electric	0.469	0.415	0.778	1.000	0.875

Publication and Dataset

- We have published our paper in 10th International Conference on Smart Cities and Green ICT Systems (SMARTGREENS 2021)
  - Hossain, M., Ma, T., Watson, T., Simmers, B., Khan, J. A., Jacobs, E., & Wang, L. “Building Indoor Point Cloud Datasets with Object Annotation for Public Safety”
- Public 3D point cloud dataset is available for request
  - https://www.memphistn.gov/government/information-technology/map901/

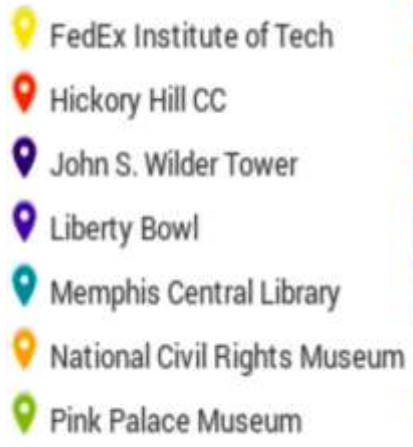


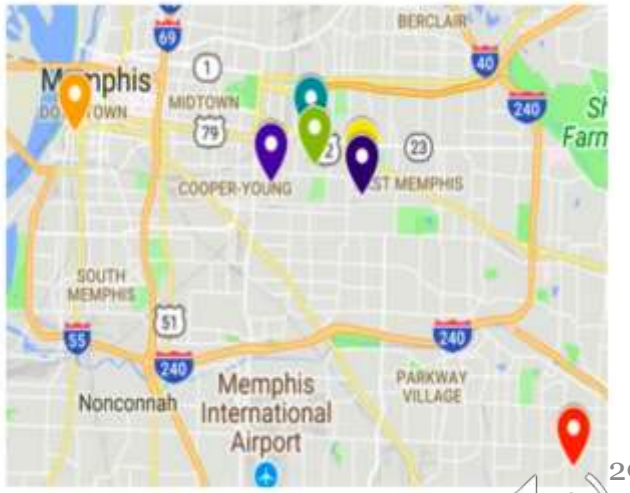
Summary

- Documentation of encountered challenges
- Description of complete data collection and processing workflow
- Case study to show evaluation results
- Public 3D point cloud dataset
- Segmented indoor public safety object image dataset

Conclusion and Future Work

- Developed a system to collect and annotate indoor point clouds
- Annotation performance is encouraging despite limited training dataset
- Future Work
  - Increase the number of annotated images for the rare objects
  - Improve the recognition accuracy of small objects
  - Finish auto annotating all the buildings
  - Apply machine learning models directly to point clouds
- Dataset: https://www.memphistn.gov/government/information-technology/map901
- Contact Information
  - lanwang@memphis.edu
  - Map901 Website: map901.memphis.edu





Thank you