Multiple View Texture Mapping:

A Rendering Approach Designed for Driving Simulation

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Overview

- Background
- Contributions
- Projective Texture Mapping
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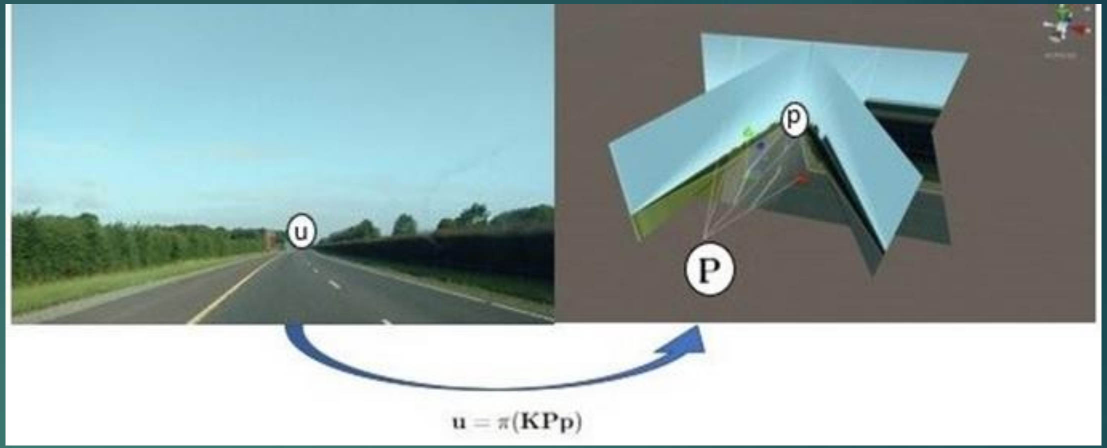


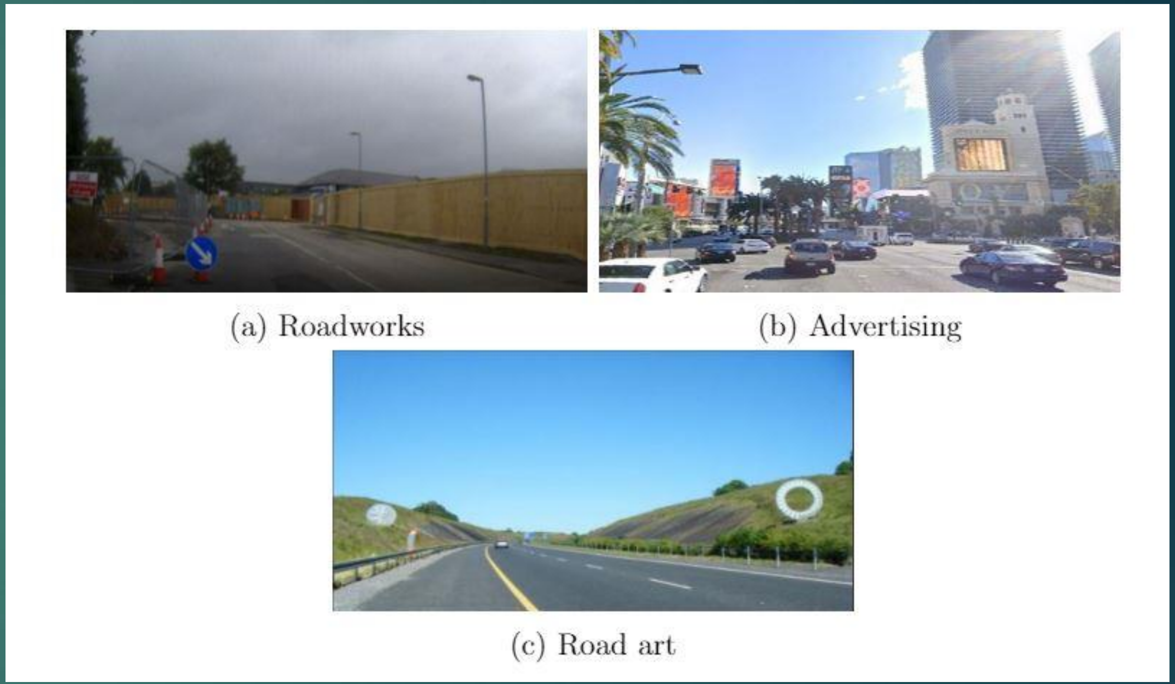
Road to model

Driving simulator

Unity Simulator

Background

- In 2015 a road engineer from TII suggested research into distraction on Irish roads.
- Special interest surrounded (a) road works, (b) advertisements, (c) roadside art.
- Standard equipment was identified as a constraint (i.e., cameras, vehicles, etc.)



(a) Roadworks (b) Advertising

(c) Road art

Contributions

Publications:

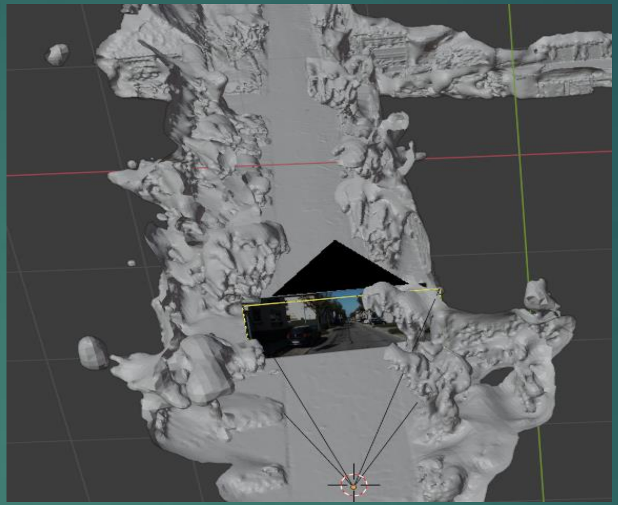
- William Clifford, Charles Markham, and Catherine Deegan. “Smart Detection of Driver Distraction Events”. In: European Conference of Eye Movement. European Group of Scientists active in Eye Movement Research. 2017
- William Clifford, Catherine Deegan, and Charles Markham. “High-speed reconstruction of a scene implemented through projective texture mapping”. In: Irish Machine Vision and Image Processing Conference Proceedings. The Irish Pattern Recognition & Classification Society. 2017, pp. 171–177
- William Clifford and Charles Markham. “Ghost Towns: Semantically Labelled Object Removal From Video”. In: Irish Machine Vision and Image Processing Conference Proceedings. The Irish Pattern Recognition & Classification Society. 2019, pp. 124–131
- William Clifford and Charles Markham. “Projective Texture Mapping on Reconstructed Scenes”. In: Irish Machine Vision and Image Processing Conference Proceedings. The Irish Pattern Recognition & Classification Society. 2020, pp. 101–104
- William Clifford et al. “Method to assess driver behaviour following distractions external to the vehicle”. In: 7th International Conference on Driver Distraction and Inattention. SAFER Vehicle, Traffic Safety Centre at Chalmers in Sweden, the Université Gustave Eiffel, France, and the University of New South Wales, Australia. 2021, pp. 48–50
- Yongxiang Wang et al. “Examination of driver visual and cognitive responses to billboard elicited passive distraction using eye-fixation related potential”. In: Sensors 21.4 (2021), p. 1471

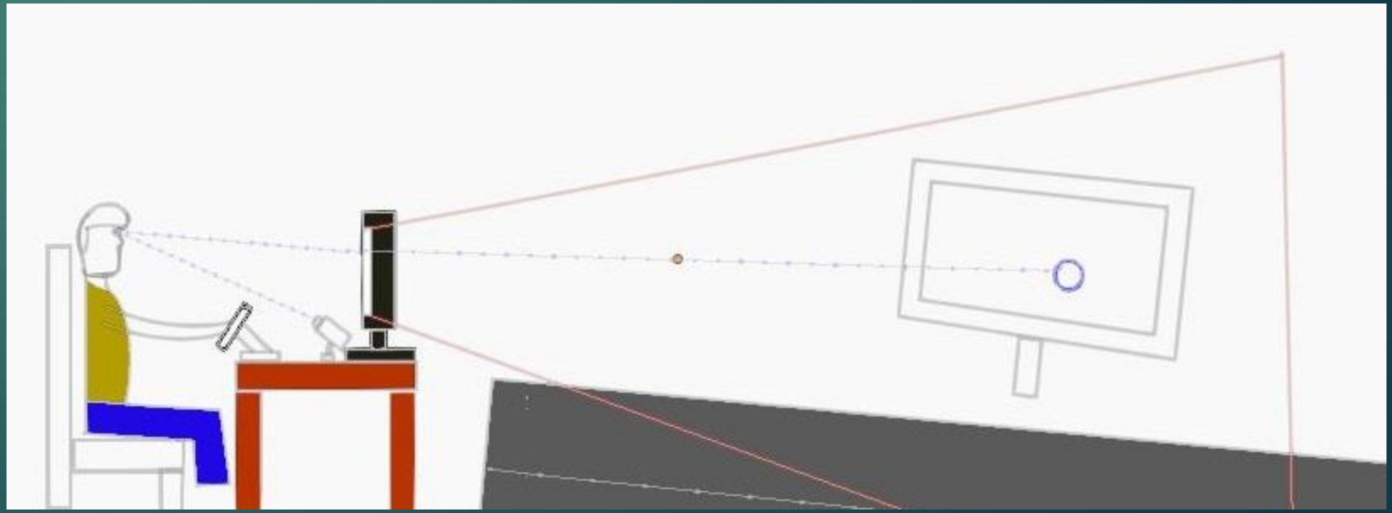
Software:

- An implementation of PTM written in GLSL.
- Extensions to PTM
- Hybrid rendering models for vertex colours and PTM for single models.
- An interface for machine vision camera models in openGL.
- COLMAP and elastic fusion odometry file parsers.
- A multi-threaded graph-connected set of 3D models.
- Camera motion models for OpenGL.
- KD-Tree implementation for selecting rendering cameras based on their coordinates.
- An Open3D implementation of depth map to 3D mesh alignment using ICP.
- ORBSLAM2 to COLMAP parsers.
- Python scripts to automate 3D reconstruction of 3D models.
- Labelling tool for images selected from video sequences.
- An implementation of the Tobii –IVT eye tracking filter.

The Idea

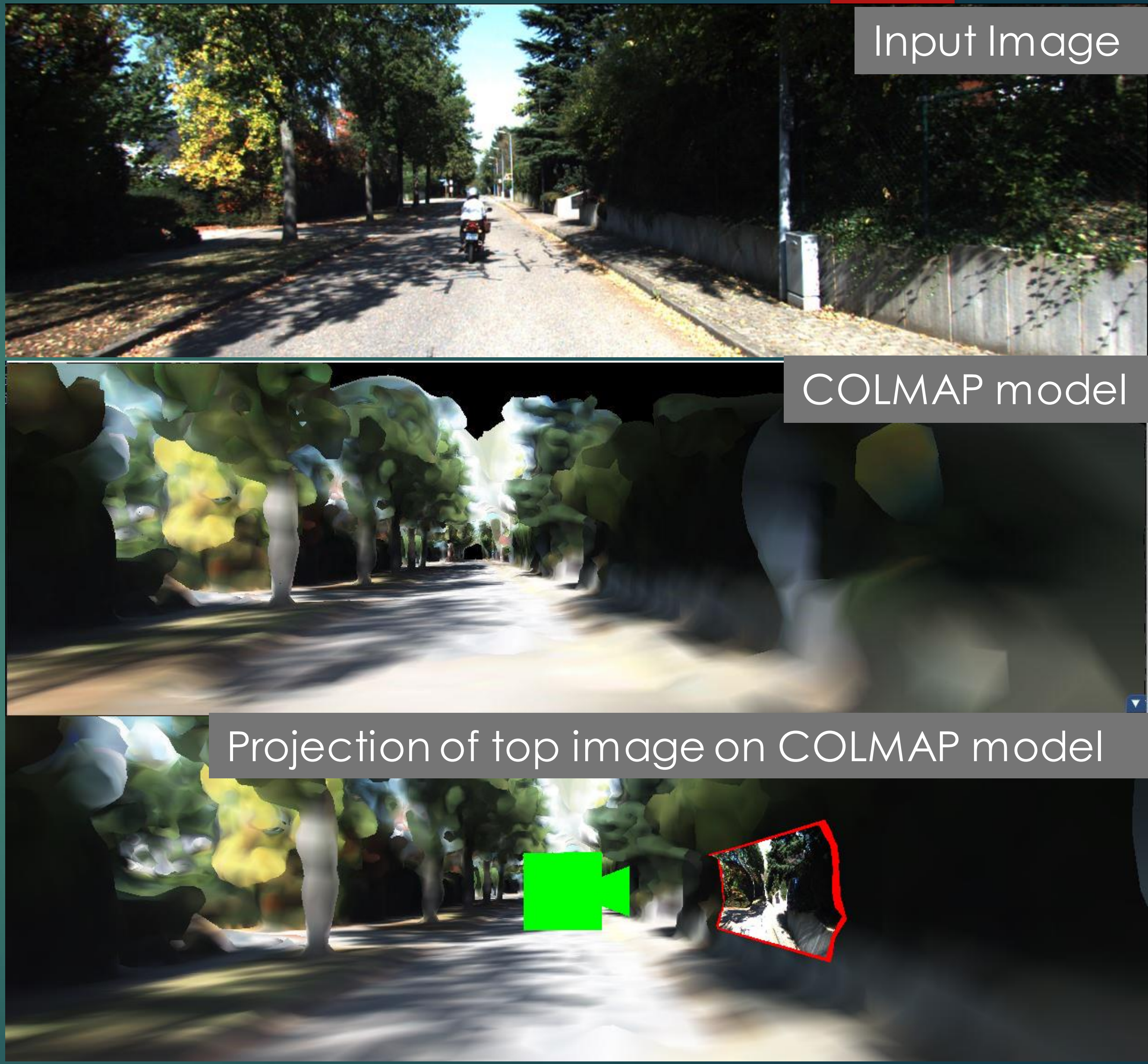
- Reconstruct a 3D model from image features using a structure from motion algorithm.
- Use a process known as projective texture mapping to make the models look photo-realistic.
- Allow a user to drive within this environment for experimentation.





Projective Texture Mapping

- Given the odometry from COLMAP, a pose of the camera was acquired.
- This pose was used as a projector position and orientation.
- The image corresponding to that pose was projected to all the 3D points in front of that camera. Region inside red is the projection and outside are COLMAP vertex colours.



Projective Texture Mapping Challenges

- Occluded parts of the scene caused by moving objects result in distortions/visual artefacts.
- A projection onto all surfaces in front of the projector (not just the first one).
- PTM causes a forward and reverse projection.

Projective Texture Mapping Challenges

Challenge:

- Occluded parts of the scene caused by moving objects result in distortions/visual artifacts.

Solution:

- Using two projections (one with a foreground object and another without). The projections can be blended to remove the vehicle.

Projective Texture Mapping Challenges

Challenge:

- A projection onto all surfaces in front of the projector (not just the first one).

Solution:

- Capturing a depth map from the perspective of the projector and rendering from the perspective of the rendering camera.
- These warped values can be used to tell us of the front most facing depths.

Projective Texture Mapping Challenges

Challenge:

- PTM uses causes a forward and reverse projection.

Solution

- While using PTM the 3D points can be represented in eye space of the projector. Limiting the projection to positive z-values in this space prevents reverse projection.

Experiment

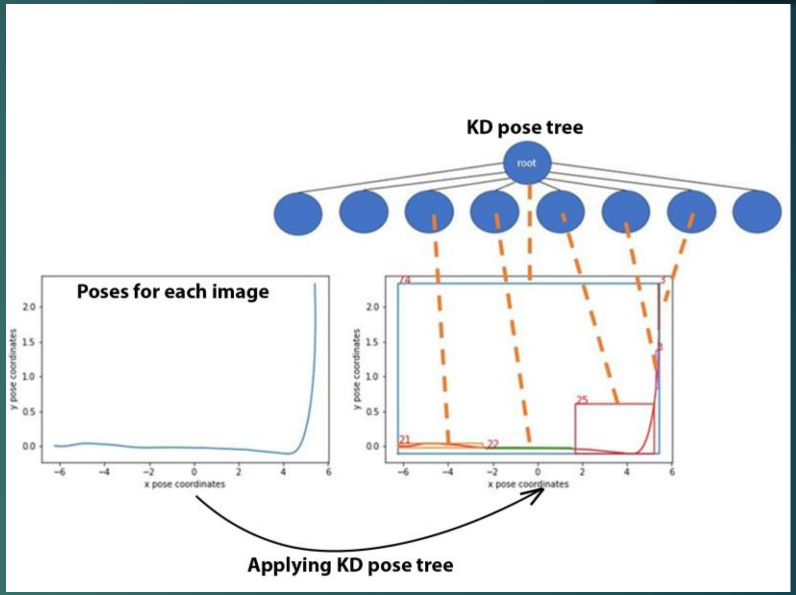
To test the removal of foreground objects using PTM the following test was used:

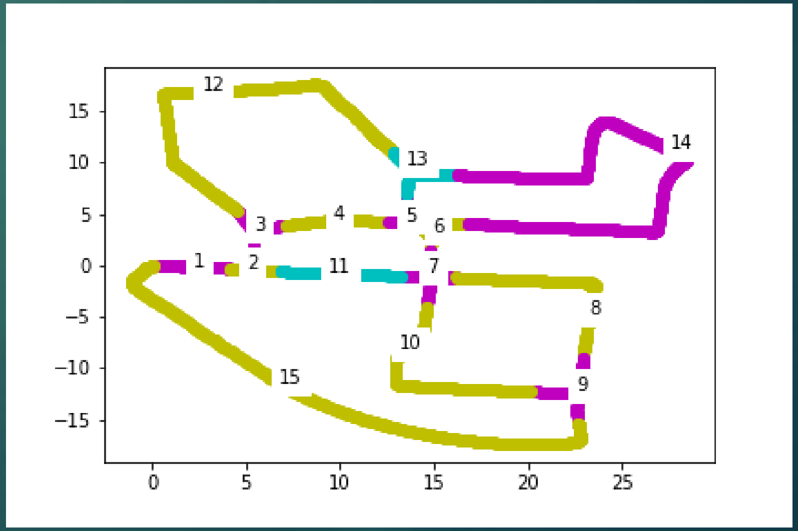
- Images from the KITTI benchmark were used on roads where the camera re-ran the same road segment.
- The clear road with no vehicles was used as ground truth.
- The sequence containing vehicles was inpainted using PTM.
- Photo-consistency metrics were measured before the removal of the vehicles and afterward (structure similarity index metric, root mean squared error, cross-correlation)

Inpainted	SSIM	RMSE	CCORR
Yes	0.52	46.37	0.83
No	0.42	57.55	0.75
Vertex Colours	0.32	60.94	0.73

Supporting Implementations

- KD-Tree to search for possible projections given odometry for a set of images and a 3D model.
- Graph worker implementation to support the loading of 3D models as users progress through the simulation.
- A basic arc-ball motion model to support movement within the simulation.





Future Work

- Experiments within this environment would be an exciting avenue:
  - User experience
  - Distraction and eye tracking
  - 3D ray picking and eye tracking using the common frame of reference
  - Including augmented objects in the simulation to allow for greater experimental controls and testing.

- Development of a probabilistic model to select views for perspective projection rather than a database form of retrieval.

- Using Semantic labels to inform AOI eye-tracking analysis in driving simulator experiments.

- Submission of the driving simulator engineering and commissioning to the Transport Research Record Journal.

Conclusions

- Real environments may now be created for simulation-based trials so long as they can be recorded on camera.

- Driving simulation has come full circle from video-based driving simulators to digital environments, and now back to video-based simulators.

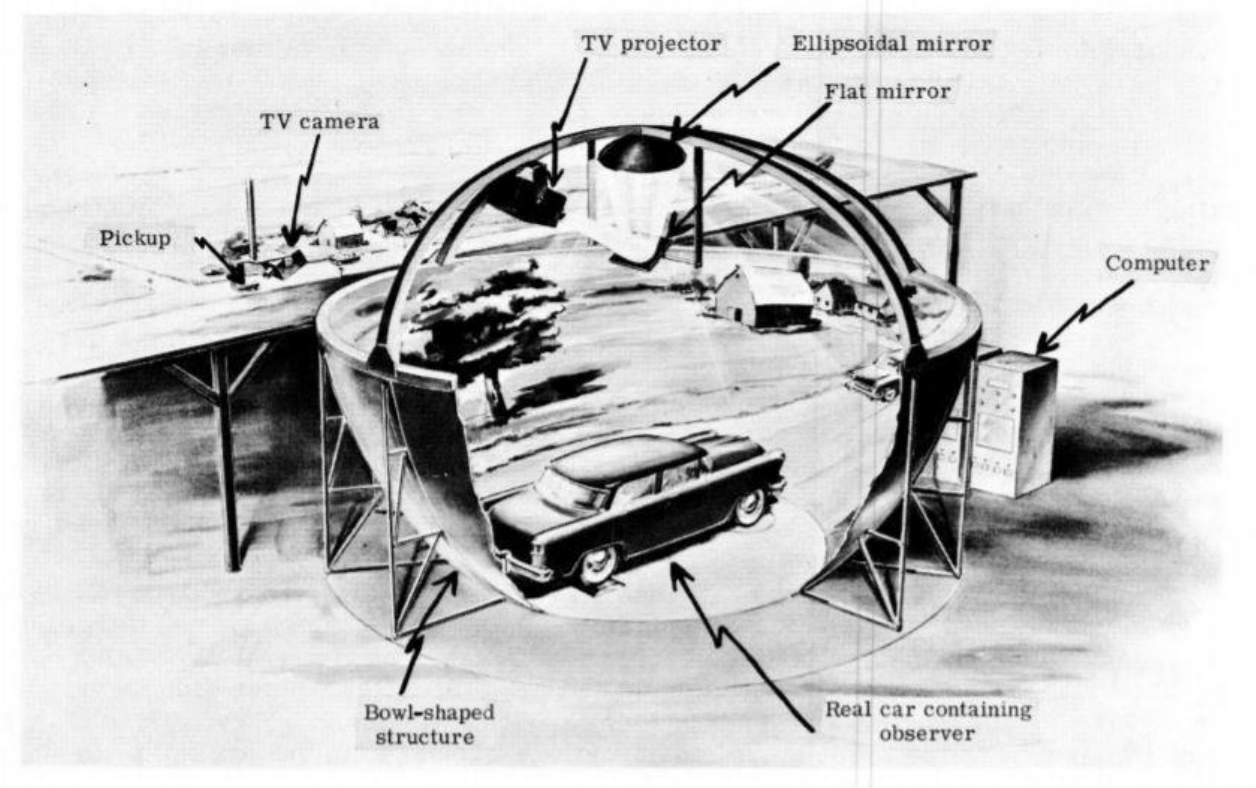
- PTM rendering problems have been addressed and pose a realistic solution to view synthesis of real environments.

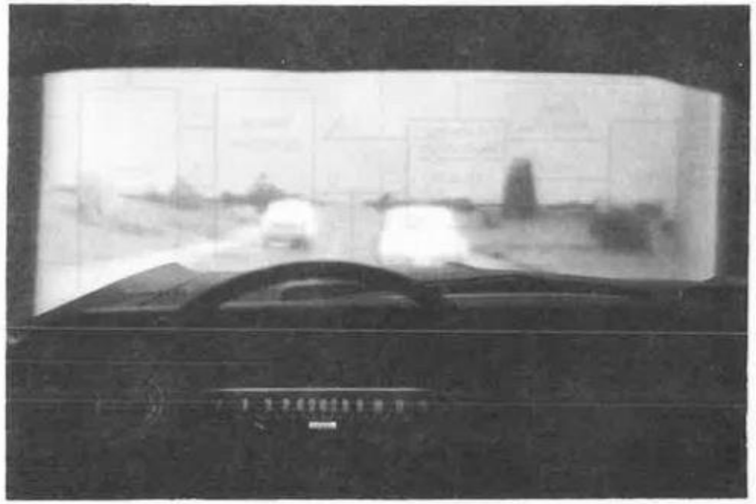
Thank you

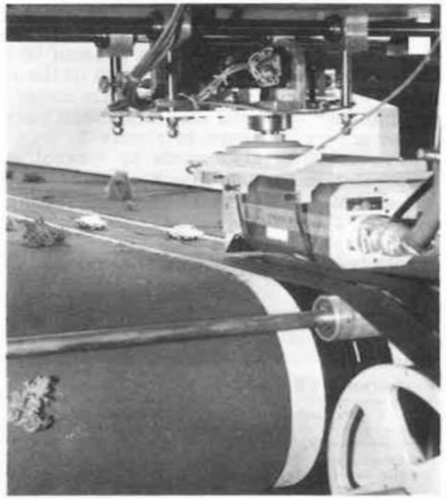
Driving Simulation

Video Based Driving Simulation:

- 1958 Hutchinson describes a driving simulator that uses video footage of previously driven roads
- 1971 Weir develops a driving simulator connected to a scale model on a conveyor belt.

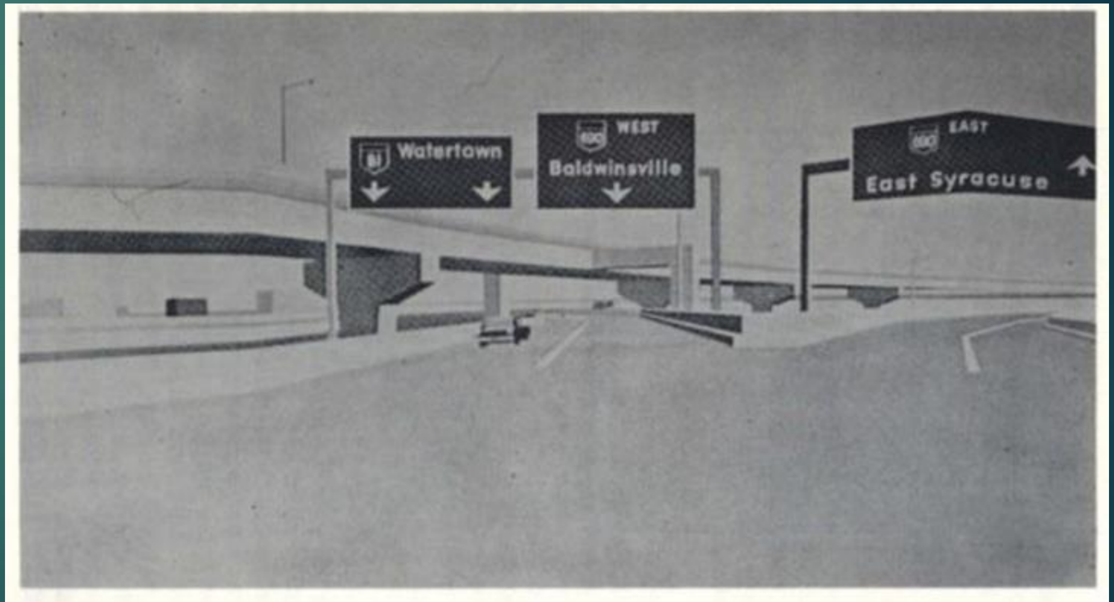






Driving Simulation

- Driving simulation then began to transition to a more computer based build rather than using cameras.
- Starting with analogue based setups.
- Then graduating to digital simulators in the 1970's.
- The reliance on digital displays would grow as it enabled fast creation of environments and it was easy to control.



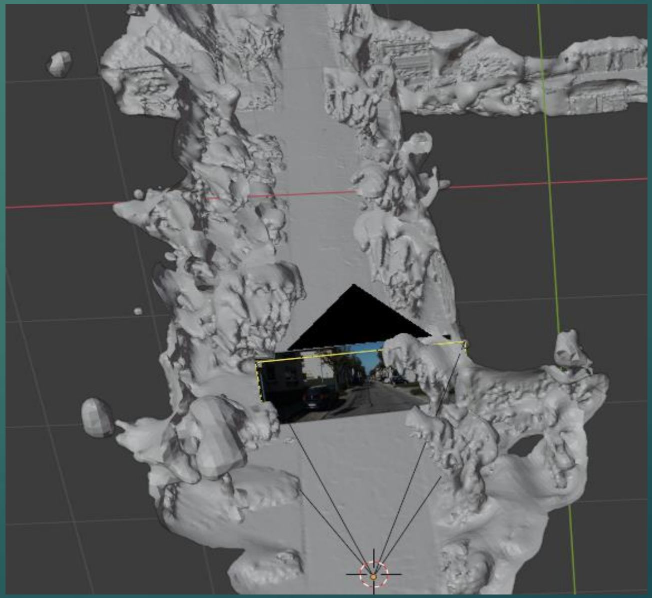
Driving Simulation

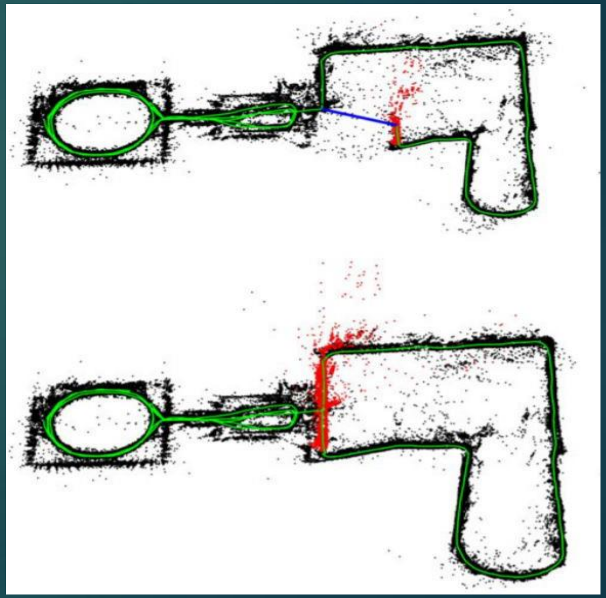
- 3D models of driving simulators got more detailed and eventually included light reflection and a good feel of depth.

- As graphics got better the attention in research shifted to tactile responses using large capsuled environments.

3D reconstruction

- Over the last 20 years there has been a lot of development in scene representation and understanding of visual perception.
- Using many images of the same scene we can reconstruct 3D models of that scene. This is called structure-from-motion.





Requirements Gathering

Findings of each:

1. Video based:
   - The inclusion of steering may increase participant engagement.
   - Eye tracking requires fixation based analysis and AOI’s to measure against.
   - Labelled images are required for AOI analysis.
2. Asset Based:
   - Lab Streaming Layer was invaluable in synchronizing sensors and should be considered for future experiments
   - Distractors in a basic environment elicits weak signalling of distraction.
   - Validation of eye tracking data before and after the experiments resulted in superior analysis.