Topics on Visual Augmented Reality

Otto Korkalo 8.10.2020

Content

1. Some definitions
2. Overview of visual tracking methods
3. Overview of display techniques
4. Some real-life examples and applications

SOME DEFINITIONS

Azuma's Definition of AR

1. **Combines real and virtual**

2. **Interactive in real-time**

3. **Registered in 3D**

Ronald T. Azuma *A Survey of Augmented Reality*
Presence: Teleoperators and Virtual Environments 1997 6:4, 355-385 (over 11k citations)

Milgram's MR continuum

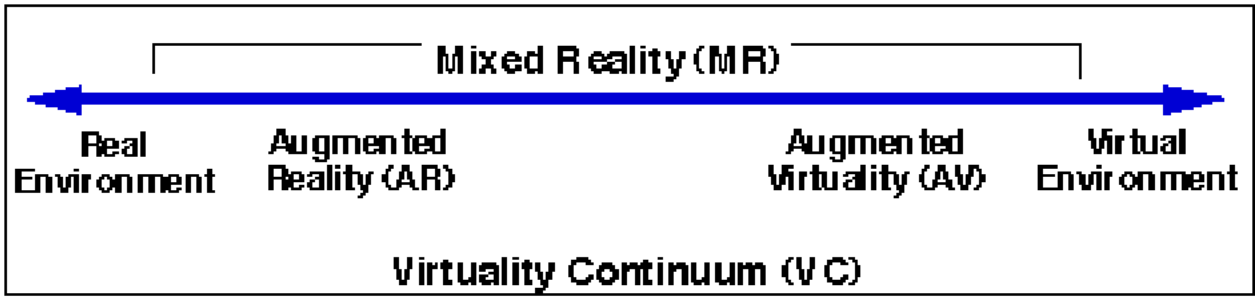


Figure 1: Simplified representation of a "virtuality continuum".

Milgram, P., Kishino, F. *A taxonomy of mixed reality visual displays* IEICE Trans. Inf. Syst. 77, 1321–1329, 1994 (over 5k citations)

Milgram's Taxonomy of Mixed Reality Displays

- **How much do we know about the world being displayed?**
- **How realistically are we able to display it?**
- **What is the extent of the illusion that the observer is present within that world?**

Milgram, P., Kishino, F. *A taxonomy of mixed reality visual displays* IEICE Trans. Inf. Syst. 77, 1321–1329, 1994 (over 5k citations)

How much do we know about the world being displayed?

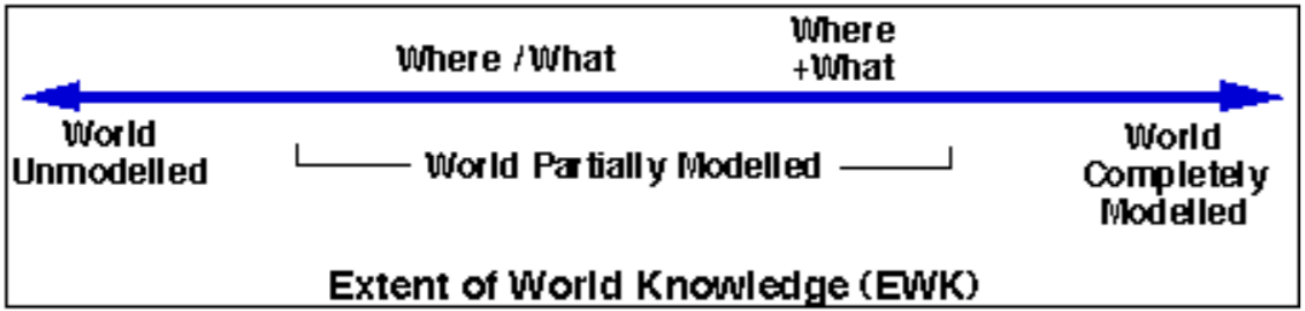


Figure 3: Extent of World Knowledge (EWK) dimension

Milgram, P., Kishino, F. *A taxonomy of mixed reality visual displays* IEICE Trans. Inf. Syst. 77, 1321–1329, 1994 (over 5k citations)

How much do we know about the world being displayed?

Plain video overlay

Marker-based AR

Real-time SLAM

+ Object detection & localization

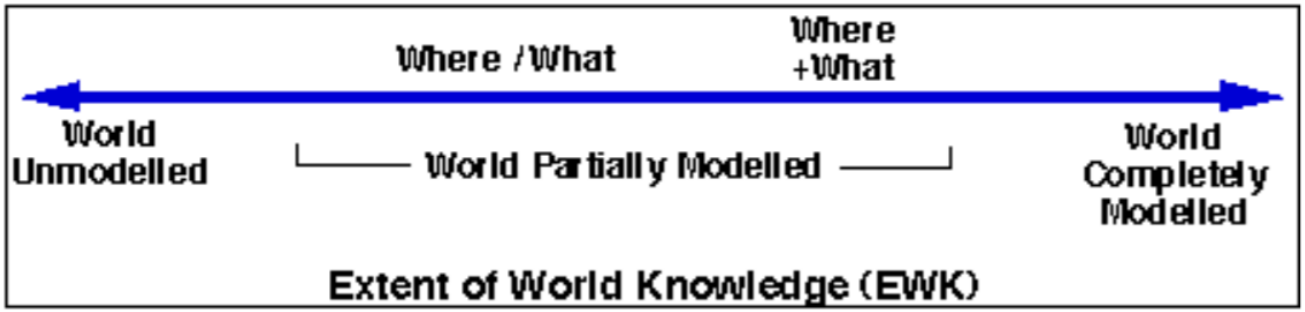


Figure 3: Extent of World Knowledge (EWK) dimension

Milgram, P., Kishino, F. *A taxonomy of mixed reality visual displays* IEICE Trans. Inf. Syst. 77, 1321–1329, 1994 (over 5k citations)

How realistically are we able to display it?

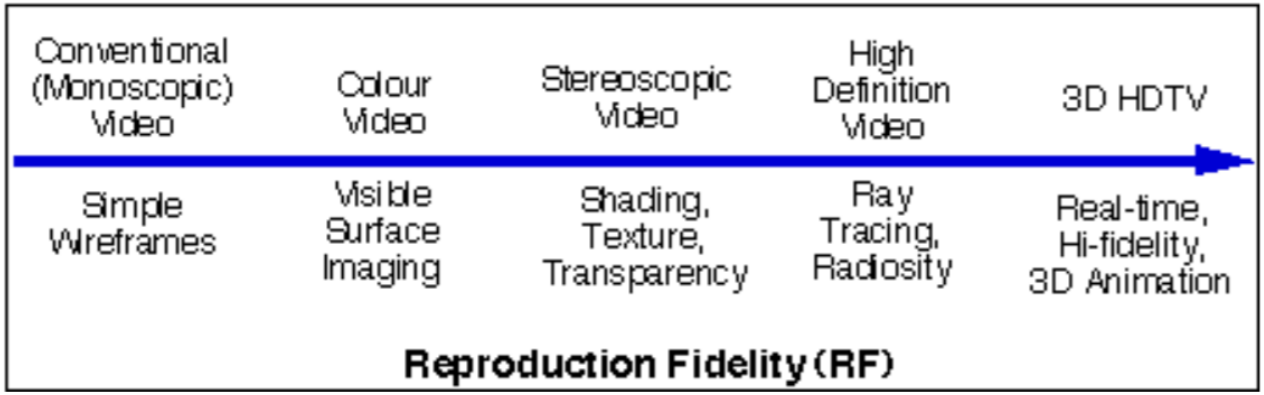
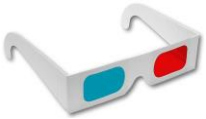


Figure 4: Reproduction Fidelity (RF) dimension.

Milgram, P., Kishino, F. *A taxonomy of mixed reality visual displays* IEICE Trans. Inf. Syst. 77, 1321–1329, 1994 (over 5k citations)

How realistically are we able to display it?



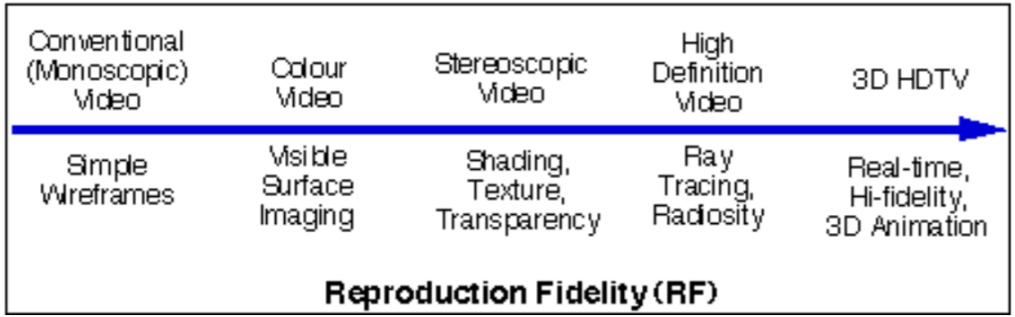


Figure 4: Reproduction Fidelity (RF) dimension.

Realistic rendering is not always the goal!

Milgram, P., Kishino, F. *A taxonomy of mixed reality visual displays* IEICE Trans. Inf. Syst. 77, 1321–1329, 1994 (over 5k citations)

What is the extent of the illusion that the observer is present within that world?

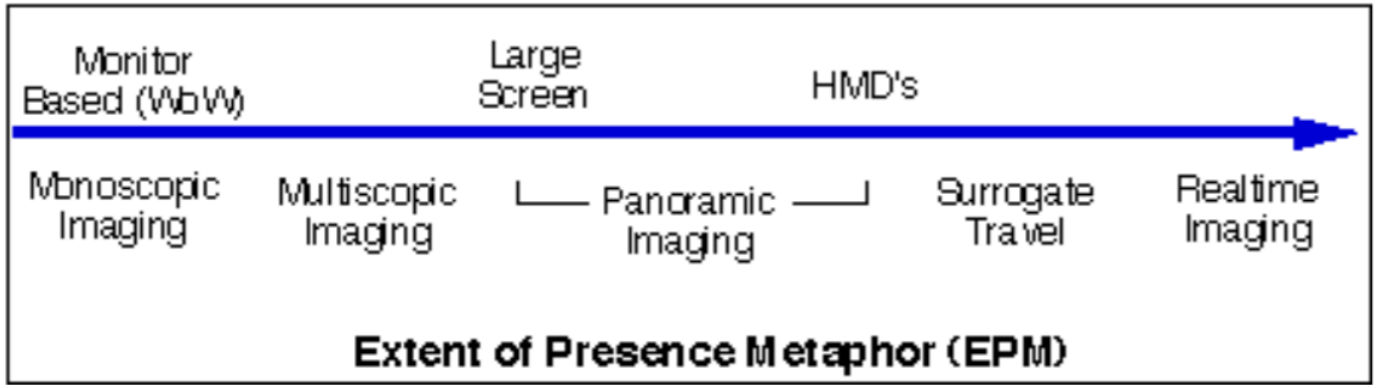


Figure 5: Extent of Presence Metaphor (EPM) dimension

Milgram, P., Kishino, F. *A taxonomy of mixed reality visual displays* IEICE Trans. Inf. Syst. 77, 1321–1329, 1994 (over 5k citations)

(VISUAL) TRACKING

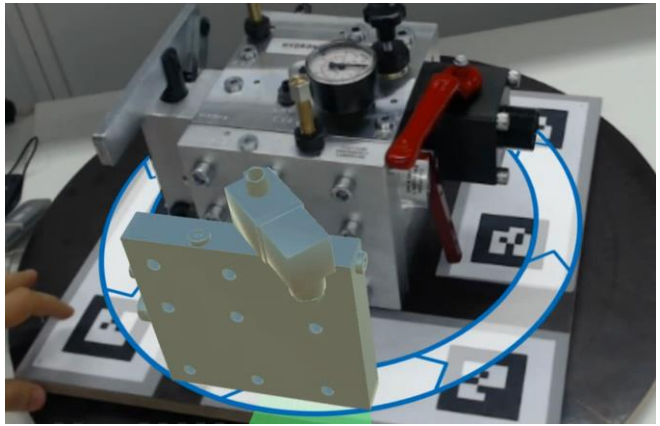
Tracking

- **Real-time registration of the display and the real world**
- Cameras, 3D cameras, IMUs, GNSS, …
- In AR, camera-based tracking is the most common approach
- 3D computer vision and sensor fusion are the key technologies

Simplified AR pipeline

1. Take picture from scene
2. **Determine what is camera's pose wrt. target object(s)**
3. Render virtual content using camera's parameters
4. Compose results
5. Repeat 30 times per second

Marker-based tracking



(a) Template Marker (b) Bar-code Marker (c) Circular Marker

Simple and robust method

Lightweight to compute

Markers can encode data, e.g. IDs

Multiple targets / expanded tracking area

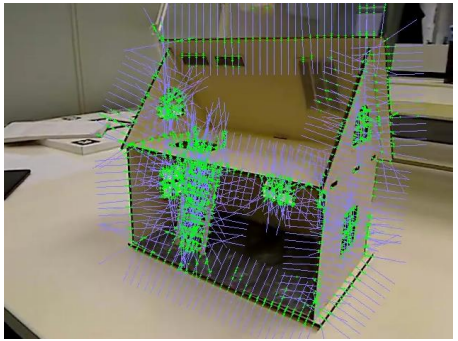
For small volume applications

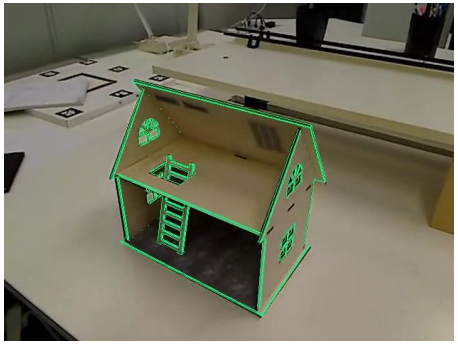
Sensitive to occlusions and lighting variations

Basic principle

1. Detect squares from the video
2. Using the square corner points, rectify the content
3. Analyse the pattern or image to determine the marker id
4. Use the corners to compute the camera pose

Model-based tracking (RGB)





CAD model of the target is used for tracking

Suitable for video see-trough approach

Accurate alignment

From small to large objects

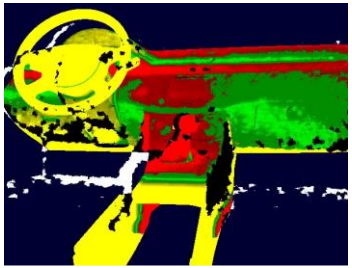
Basic principle

1. Render the visible edges using last known pose
2. Find strong edges from the image
3. Find transformation that aligns the edges best
4. Update CAD model's pose accordingly

Wuest, H. et al. *Adaptive line tracking with multiple hypotheses for augmented reality* Fourth IEEE and ACM International Symposium on Mixed and Augmented Reality, 2005

VTT's implementation https://www.youtube.com/watch?v=gF8Xa8i04R4

Model-based tracking (depth)



CAD model of the target used for tracking

3D camera as tracking device

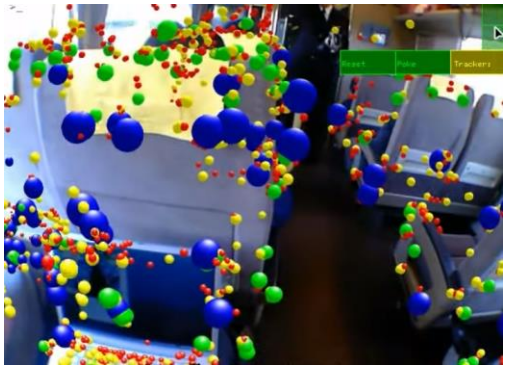
Robust for differences between the model and the real world

Basic principle

1. Render depth map from the CAD model using last known pose
2. Capture depth map of the target with depth sensing device
3. Convert the depth maps into 3D pointclouds
4. Find the transformation that aligns the pointclouds best

Otto Korkalo and Svenja Kahn *Real-time depth camera tracking with CAD models and ICP*
Journal of Virtual Reality and Broadcasting, 13(2016), no. 1.

Pointcloud-based tracking / SLAM



3D map of points is used for navigation

Suitable for small and wide area tracking

Sensitive to changes in illumination

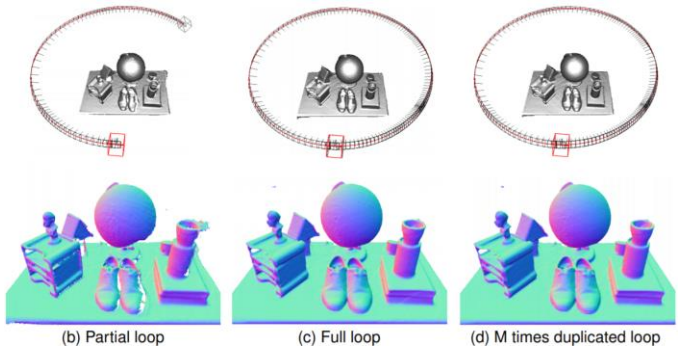
Basic principle

1. Given a map of 3D points, project them to image using latest camera pose
2. Detect corresponding map points from camera images
3. Find the updated camera pose that aligns the point matches best
4. In SLAM, the map is simultaneously updated and expanded

https://www.youtube.com/watch?v=Y9HMn6bd-v8

Klein, Georg & Murray, David *Parallel Tracking and Mapping for Small AR Workspaces* (over 11k citations)
6th IEEE and ACM International Symposium on Mixed and Augmented Reality, 2007

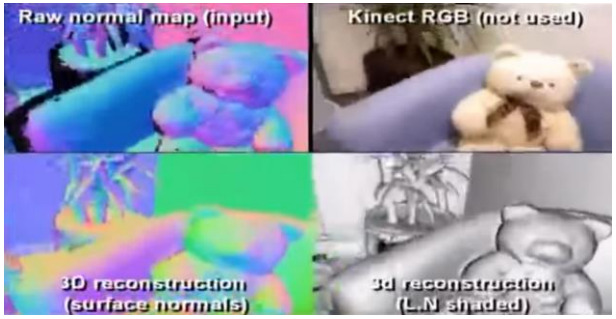
Dense Model Generation and Tracking



Depth camera is used to generate dense 3D model while simultaneously tracking the device (SLAM)

Enables interaction in unmodeled environment

Occlusion aware AR



https://www.youtube.com/watch?v=quGhaggn3cQ

R. A. Newcombe et al. *KinectFusion: Real-time dense surface mapping and tracking*
2011 10th IEEE International Symposium on Mixed and Augmented Reality, 2011

VIEWING

Mobiles and tablets

Display

Processor

Camera

IMU

Input

Communications

Example APIs for mobile development

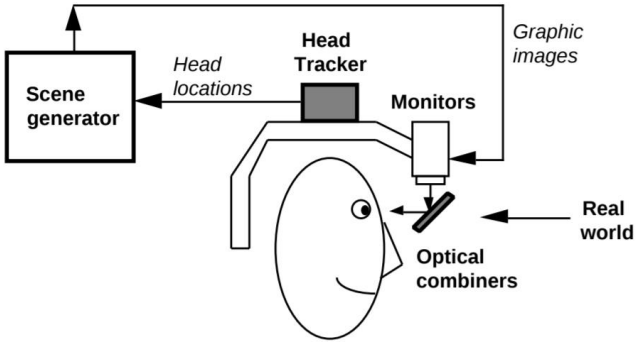
VTT's ALVAR library

ARCore (Google) image feature + IMU based SLAM

ARKit4 (Apple) utilizes IPadPro's sensors including LiDAR

https://www.viewar.com/blog/apples-ipad-pro-with-lidar-sensor/

Optical See-Trough HMD

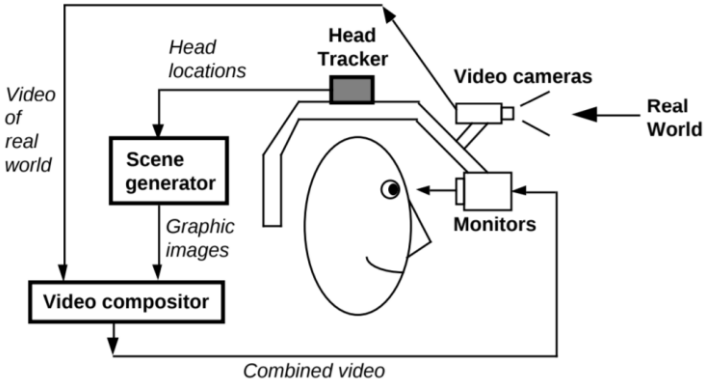


MS Hololens 2

Multi-sensor SLAM for tracking

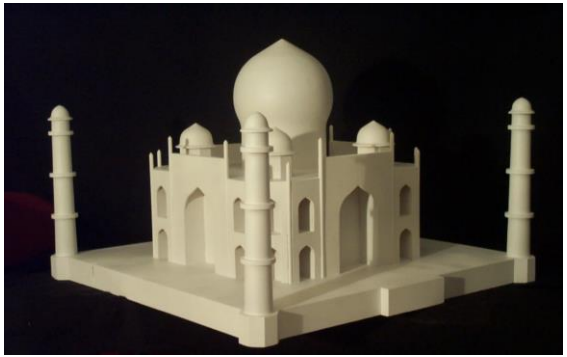
Stereo rendering, waveguide technology

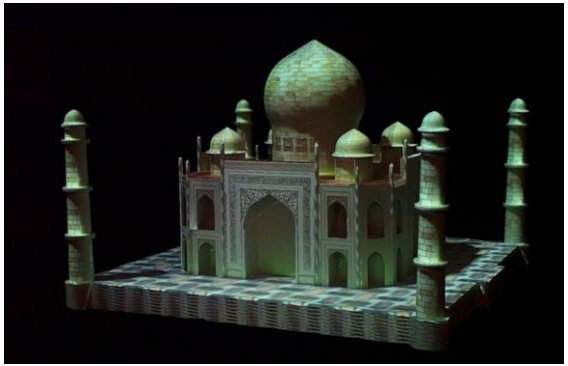
Video See-Trough HMD



Varjo XR-1

Spatial AR





Projector-based rendering

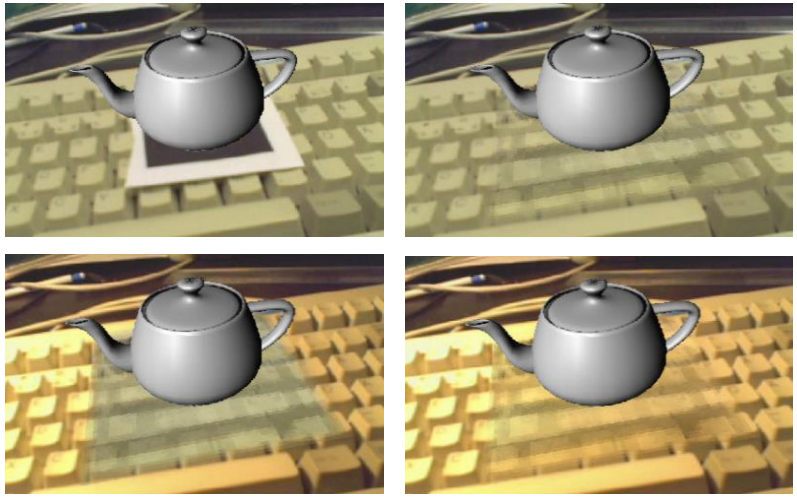
No tracking, model registration beforehand

Careful fusion of colors, texture, intensity

How about moving projectors?

R. Raskar, G. Welch, K. L. Low, and D. Bandyopadhyay
Shader Lamps: Animating Real Objects with Image-Based Illumination
In Proceedings of Eurographics Rendering Workshop, Springer-Verlag, 2001

Diminished Reality

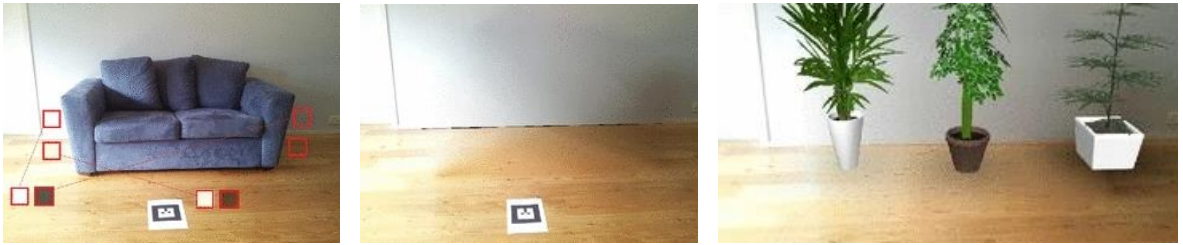


In contrast to adding virtual content to the view, remove content from the view

Combines real time 3D tracking, object detection and inpainting

Steve Mann

Korkalo, O., Aittala, M., & Siltanen, S. *Light-weight marker hiding for augmented reality* In Proceedings of the 9th IEEE International Symposium on Mixed and Augmented Reality, 2010



Siltanen, Sanni *Diminished reality for augmented reality interior design* The Visual Computer, 2015

Photorealistic Rendering

Aittala, Miika, 2010
https://www.youtube.com/watch?v=fhFzStkoE50

Realistic shadows

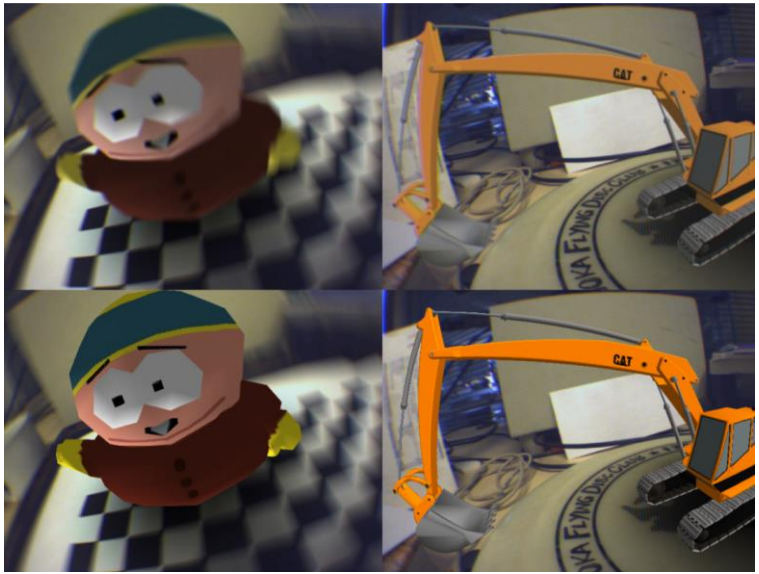
Different materials

Automatic capture of illumination

Motion blur

Camera lens distortions

Camera imaging process



Georg Klein and David Murray *Compositing for small cameras* In Proceedings of the 7th IEEE/ACM International Symposium on Mixed and Augmented Reality, 2008

EXAMPLE APPLICATIONS

Spatial Visualization of Historical Photos (VTT)

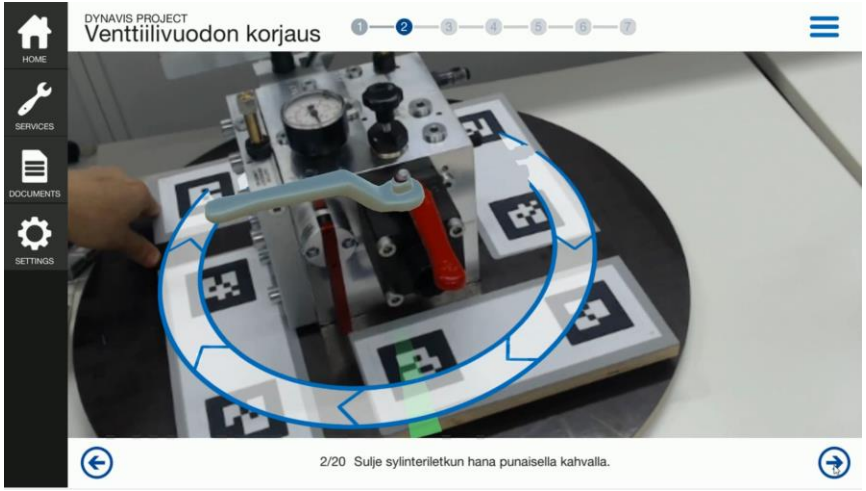
Custom-made pointcloud-based registration and tracking on mobile phones

Reconstruction from several images using photogrammetry

Photo billboards aligned beforehand using custom application

https://www.youtube.com/watch?v=5ZLNjnnXinA

AR Workflow (VTT)



https://www.youtube.com/watch?v=rgkdK9_WmyI

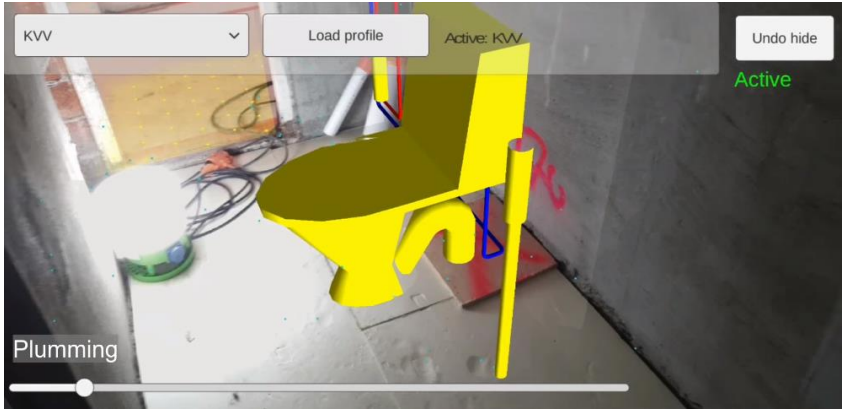
System to create and visualize maintenance tasks in AR

Marker-based tracking

Combines multiple UI components and widgets for visualization

Unity-based content creation tool

AR Visualization of Work Task Information (VTT)



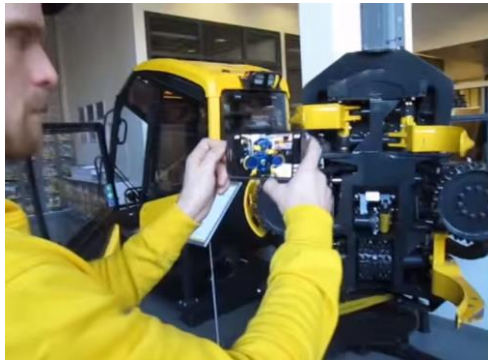
https://www.youtube.com/watch?v=rcGQzuUwSA4

System to create and visualize maintenance tasks with AR

Marker-based initialization for tracking, SLAM for free movement (ARCore)

3D models, 2D blueprints

Remote Maintenance Assistance (VTT)



- **Collaborative tool that combines VR and AR**
- **Remote operator annotates instructions to the machine with VR**
- **Maintenance guy sees the instructions spatially aligned with AR**
- **Multiple simultaneous clients**
- **Pointcloud-based tracking in client**

https://www.youtube.com/watch?v=_vnqNrK1jLg

Climball (Valo Motion)

Example of Spatial AR

Outside-in player tracking with depth cameras

Real-time motion analysis & interaction

https://www.youtube.com/watch?v=rjWcE25s7kQ

Thank you!

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