Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Distributed Systems Group | Institute for Pervasive Computing

Projection-Based Augmented Reality

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The Bigger Picture

Overall topic: “Interaction in Intelligent Environments“.

- “[…] information and communication technology (ICT) disappears as it becomes embedded into physical objects and the spaces in which we live and work.”

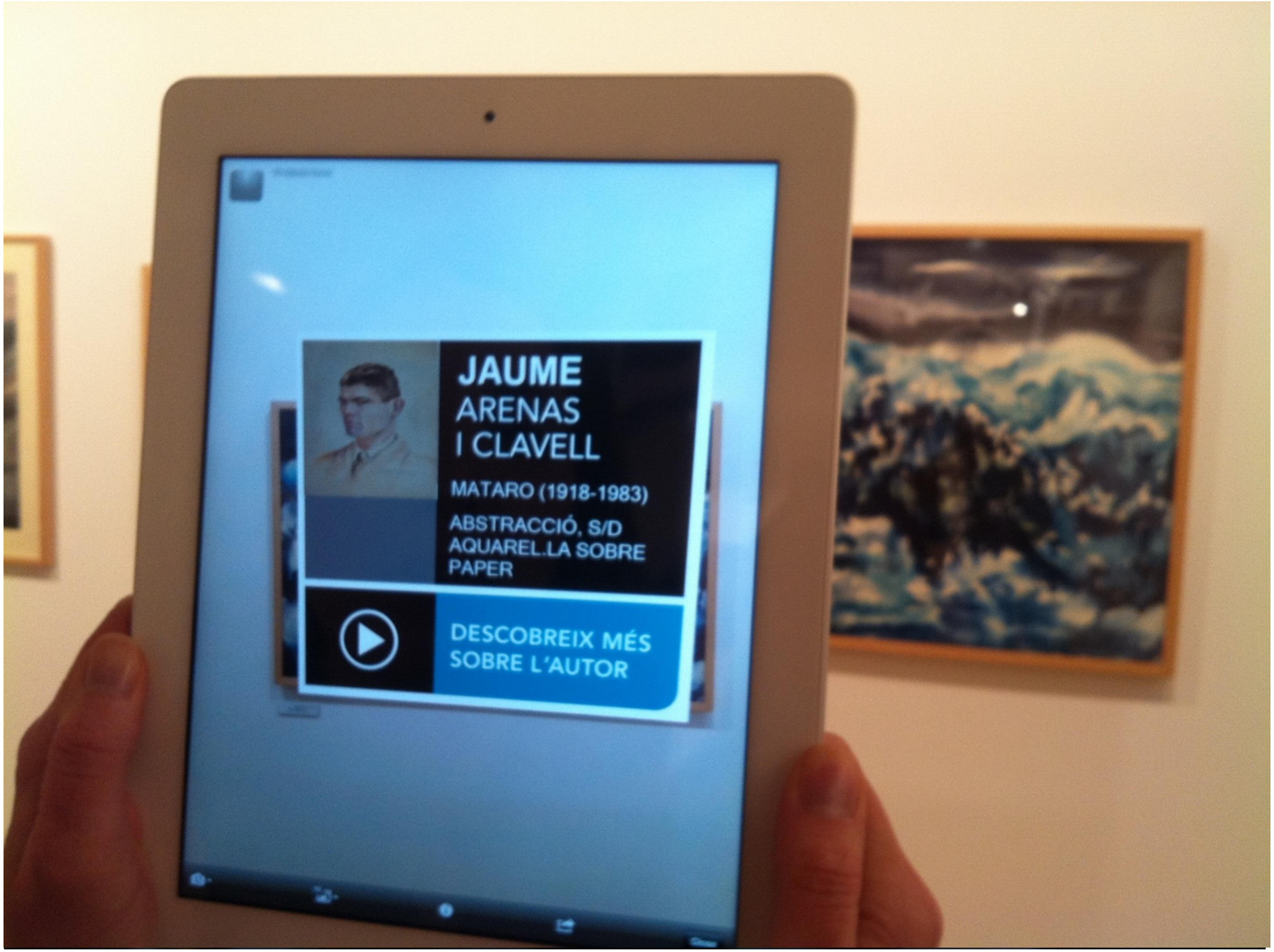
  (*Intelligent Spaces: The Application of Pervasive ICT (2006))*

http://web.media.mit.edu/~raskar/UNC/Office/sketch.gif

What is Augmented Reality?

- Augmentation of reality with virtual information
- Information is context-dependent

Optical vs. Video See-Through Displays



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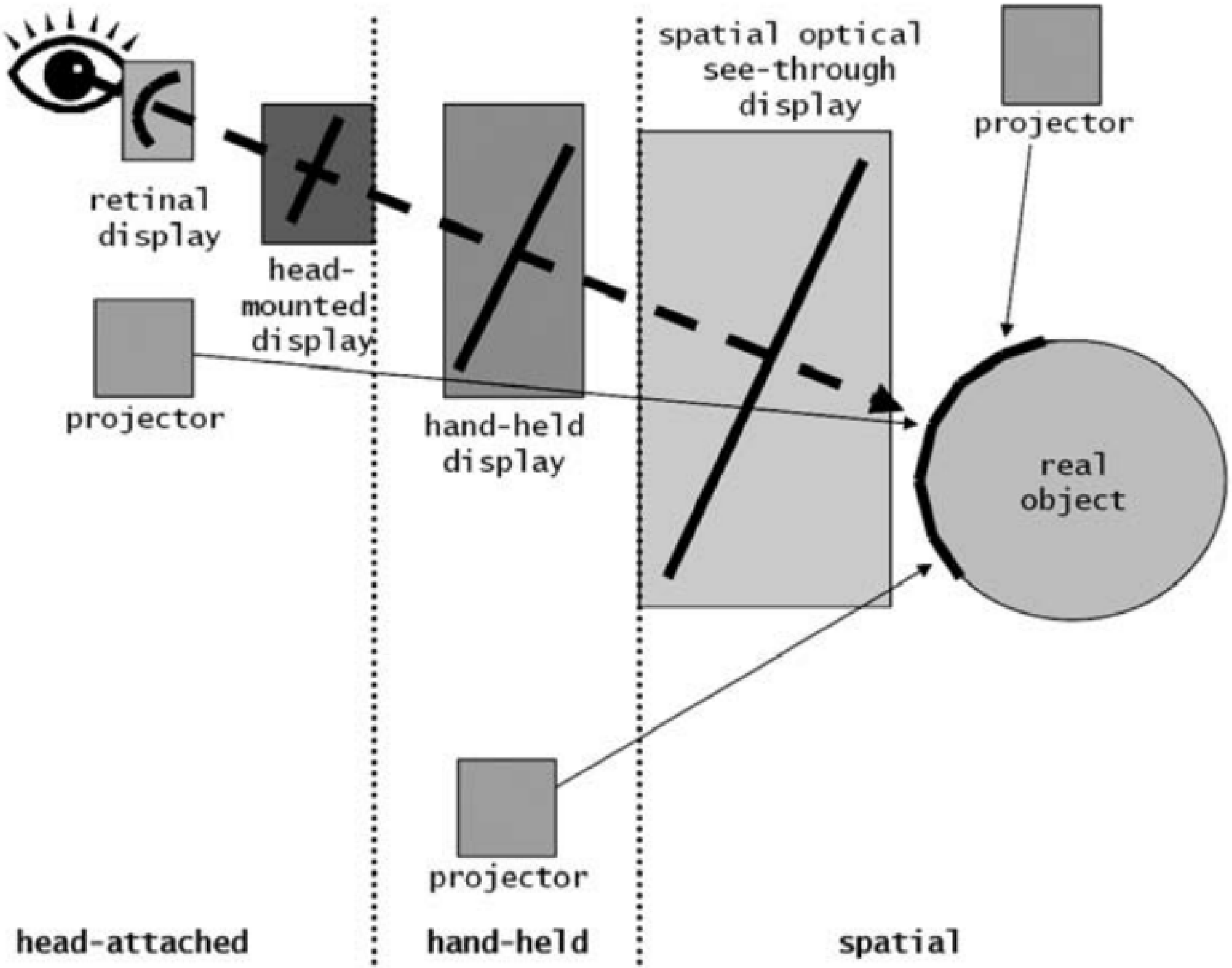
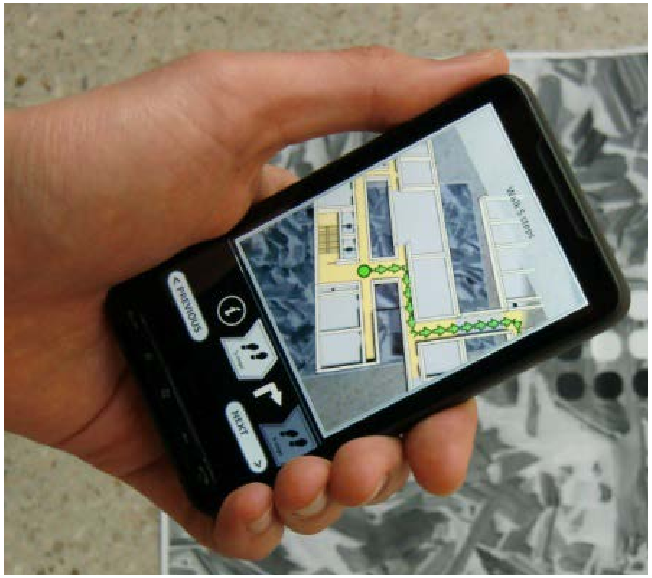
Overview



(Spatial Augmented Reality Merging Real and Virtual Worlds
Oliver Bimber, Ramesh Raskar)

Earlier Talk: “Handheld Augmented Reality”



- Indoor Navigation
- Touch-free interface
- Visualization

Why Smart Phones?

- Hand-held video see-through displays

Advantages of smart phones:

- Relatively cheap
- Common and available
- Has a range of sensors already built in: GPS, accelerometer, …
- Unlimited field of view through moving the smart phone around

Why Smart Phones are not Enough?

However:

- Small display:
  - Limited field of view, if one does not want to move the phone all the time
- User might need to hold / move the device over an extended period of time
- Limited resolution:
  - With video mixing reality has the resolution of the camera.

One solution:

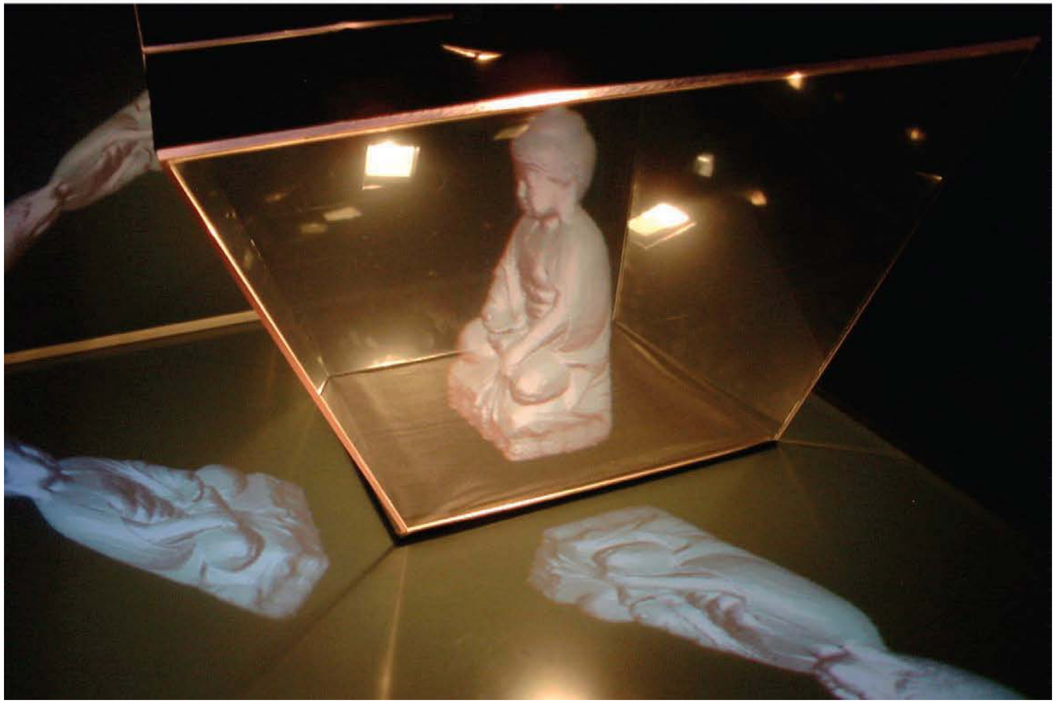
- Spatial optical see-through display

Spatial Optical See-Through Display

One possible build:

- Combining a beam splitter with a projector or monitor.

Standard example: Virtual Showcase

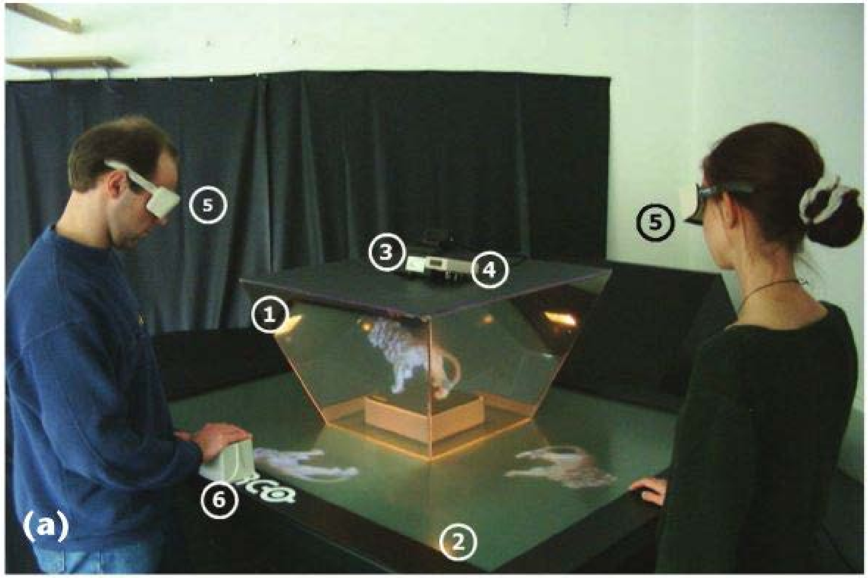


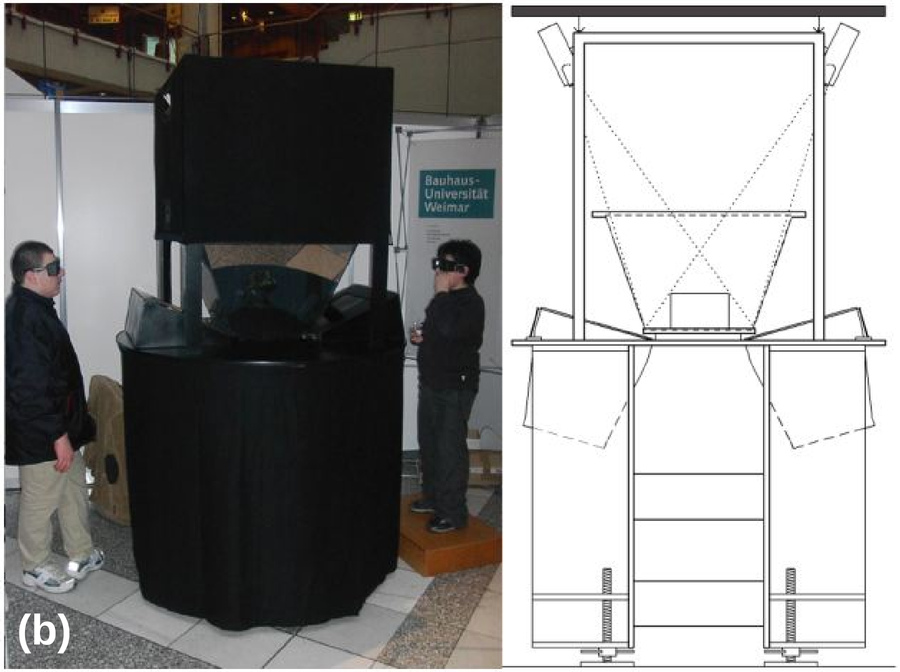
Discussed in:
The Virtual Showcase as a new Platform for Augmented Reality Digital Storytelling [Bimber2003]

How is One Build?

It is a spatial optical see-through display.

- Two designs were discussed





(1) Convex assembly of four half-silvered mirror beam splitters

(2) Projection screen

a) Single CRT projector

b) Four CRT monitors

(3) Controllable light projector

(4) Infrared emitters

(5) Shutter glasses

(6) Electromagnetic tracking device

http://www.youtube.com/watch?v=qgN8T-iVRL8

Advantages and Problems

Advantages:

- Provides a high resolution
  - Even higher with the monitor-based approach.
- Increased control over environmental factors (lighting, sound, …) inside and outside the Virtual Showcase.
  - Example: Creation of realistic occlusion effects through pixel-wise illumination of physical content.
- Easier eye accommodation (usually a problem with optical see-through displays, which are distant from the augmented object)
- Furthermore: Larger screen size

"Retina" displays + HD camera

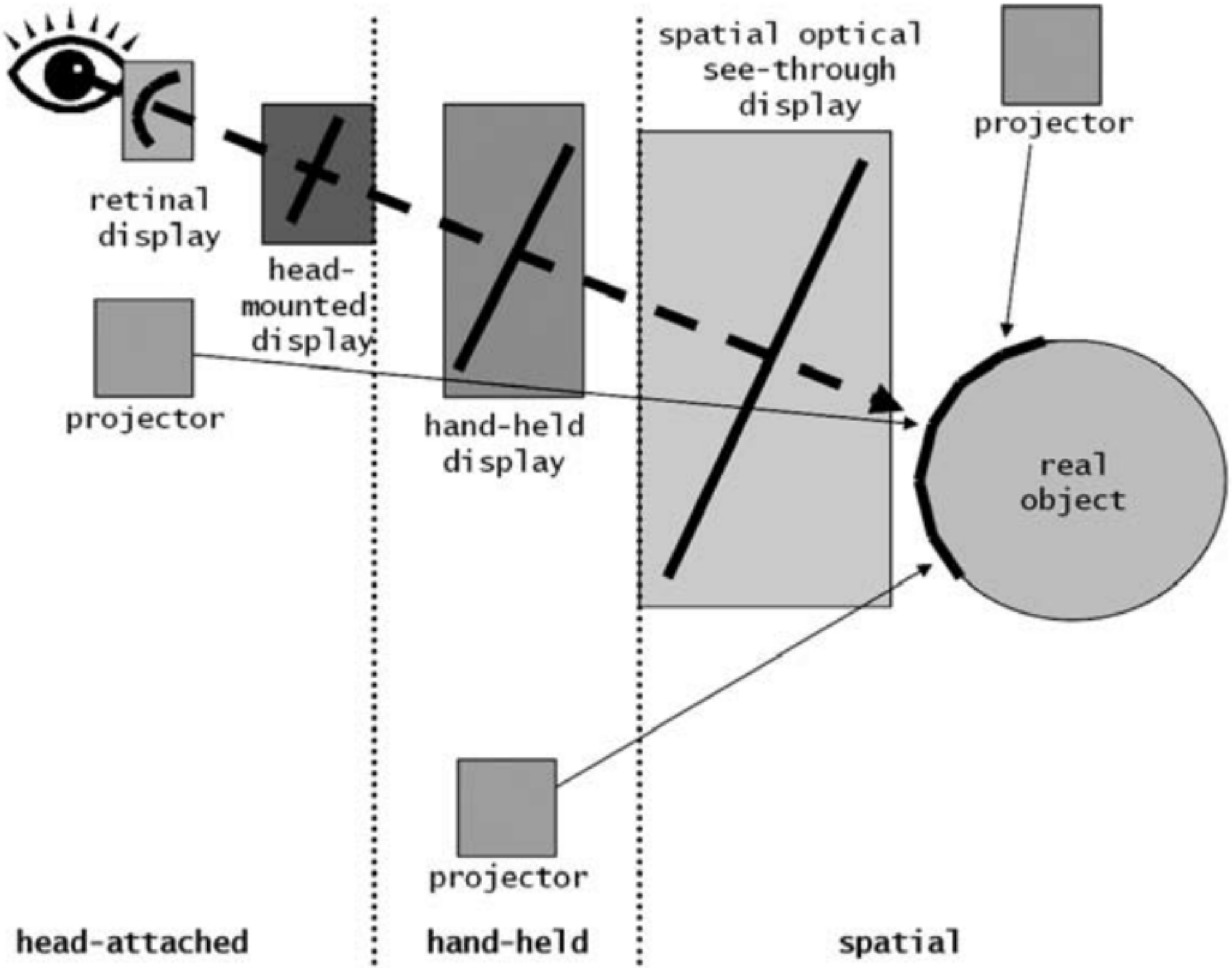
Video mixing

Problems:

- Limitations in multi-user support
  - currently only four users can be supported simultaneously

Price: Useless for mobile applications

Overview



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What are the Main Advantages of Projected AR?

A projector

- allows planar displays of various shapes.
- allows non-planar, curved displays.
  - Can directly project onto physical objects
- overcomes the restriction that display size dictates device size.
  - Unlimited field of view
  - Can be transported easily compared to large screens.

How to Make Use of These Advantages?

- Can be transported easily compared to large screens.
- Can directly project onto physical objects

Possible solution: iLamps

Identified problems:

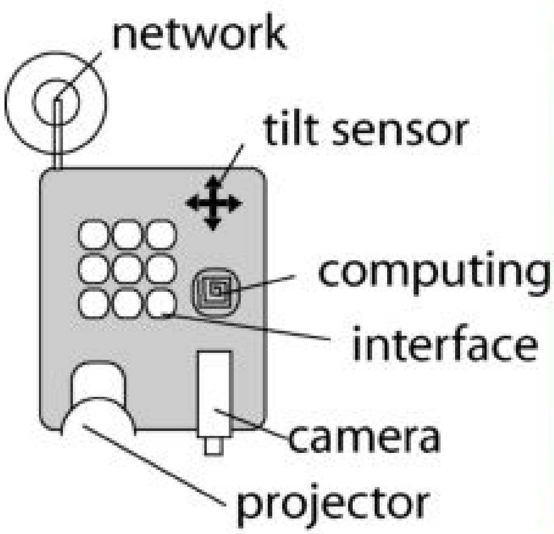
- Self-contained:
  - Little to no dependence on infrastructure.
- Geometric-aware:
  - Understanding of the geometry of display surface.
  - Orientation of projector
- Self-configuring:
  - Ad-hoc integration into a cluster of projectors.

Discussed in:
iLamps: Geometrically Aware and Self-Configuring Projectors

Creation of an Self-Contained Projector

Add:

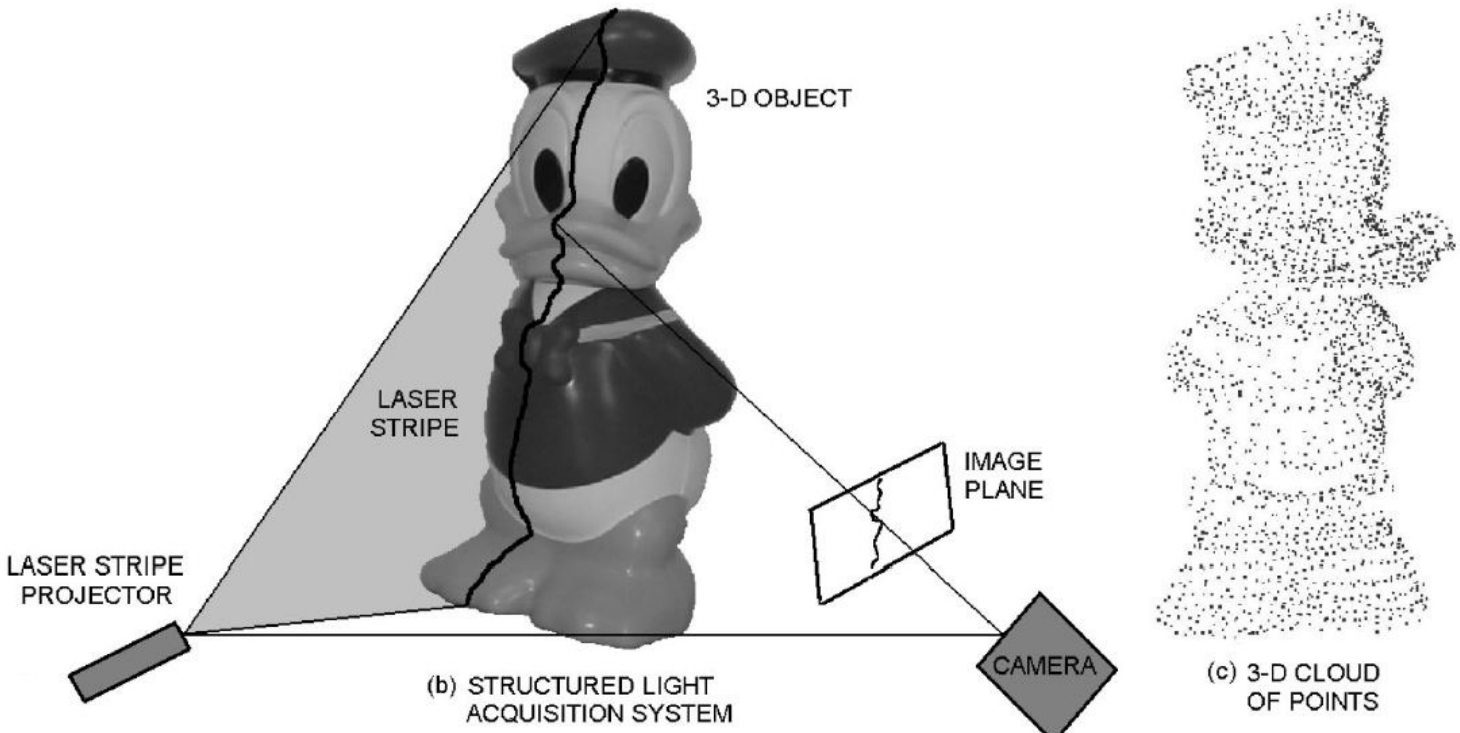
- Sensors
- Ability to communicate with objects and other devices
- Computing and an interface



Geometric Awareness Through Structured Light

Method:

1. A known light pattern (e.g. parallel stripes, random dots) is projected onto the scene.
2. From the deformation of the pattern, depth and surface information can be computed.



Ajmal Saeed Mian, Mohammed Bennamoun and Robyn Owens: 3D model-based free-form object recognition – a review

How to Adapt to Unideal Display Shapes?

Problem:

- Use of surfaces like room corners or columns.
- Regardless of the viewpoint, the distortion of the projected image should be minimized.

A possible solution:

- Measure distortion with conformality (angle preserving)
  1. Use the camera to capture images of projected structured light.
  2. Generate 3D mesh.
  3. Compute a conformal map, which is used as texture map.

How to Adapt to Unideal Display Shapes?

http://www.youtube.com/watch?v=7IdHTt6pCjY

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Problems

- Field of view is still limited
- Low light intensity

Possible Solution:

- So far: Only one projector

Cluster of projectors (iLamps)

Cluster of Projectors

Does the new projector belong to group?

- 'Ready to join' msg. + light pattern
  - If seen by any other camera, then quick calibration step.

Quick calibration

- Sequentially: Projection of structured pattern (checkerboard)
- By each unit (i.e. in parallel):
  - Computation of the largest inscribed rectangle.
  - Checking how own projection fits into this rectangle.
  - Projection of corresponding image part.

Cluster of Projectors

http://www.youtube.com/watch?v=NfB5qwD9z9s

Problems

- Field of view is still limited
- Low light intensity

Possible Solutions:

- So far: Only one projector

1. Cluster of projectors (iLamps)

- Remember: Hand-held displays can be moved around …

2. Steerable displays (Beamatron)

Steerable Displays

The Beamatron:

Problems:

- Geometric-aware:
  - Project images ‘correctly’ on arbitrary surfaces
  - Stabilize projected graphics during movement.
- Track the user position

Discussed in:
Steerable augmented reality with the beamatron

Stabilize Projected Graphics During Movement

Problem:

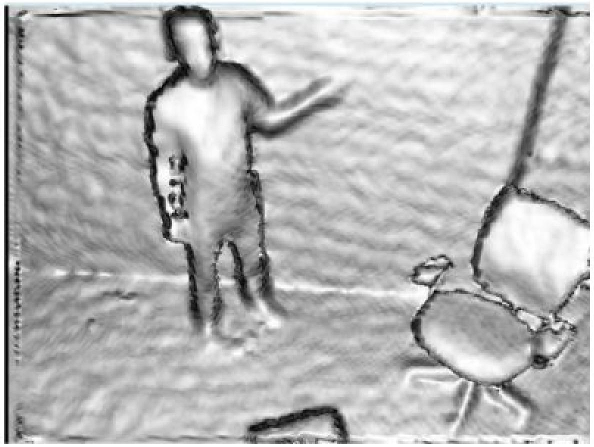
- The light platform does not provide any feedback on the pan and tilt configuration.
- Real-time knowledge of the platform pose is critical for projecting stabilized graphics.

Solution:

- Build a circuit board which directly connects to the built-in pan and tilt sensors of the platform.

Understanding the Geometry of the Display Surface

- Use the mounted Kinect sensor with Kinect Fusion to obtain smoothed depth images:



Project images ‘correctly’ on arbitrary surfaces

Already have seen
- ‘Wall-paper’ an image onto a real object.

Now:
- Create the illusion of a real 3D Object.

Requires two rendering passes:

1) Render the real objects along with virtual objects from the point of view of the user.
2) Use the result as texture map for the rendering of the real geometry.

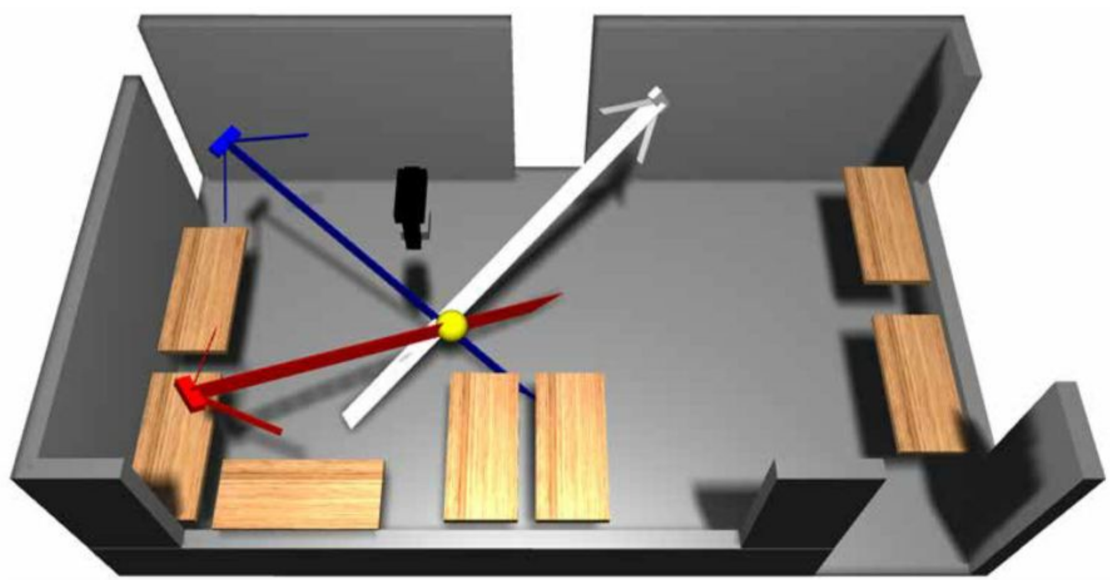
Track the User Position

Problem:

- Hard to monitor events outside of the field of view of the Kinect sensor.

Solution:

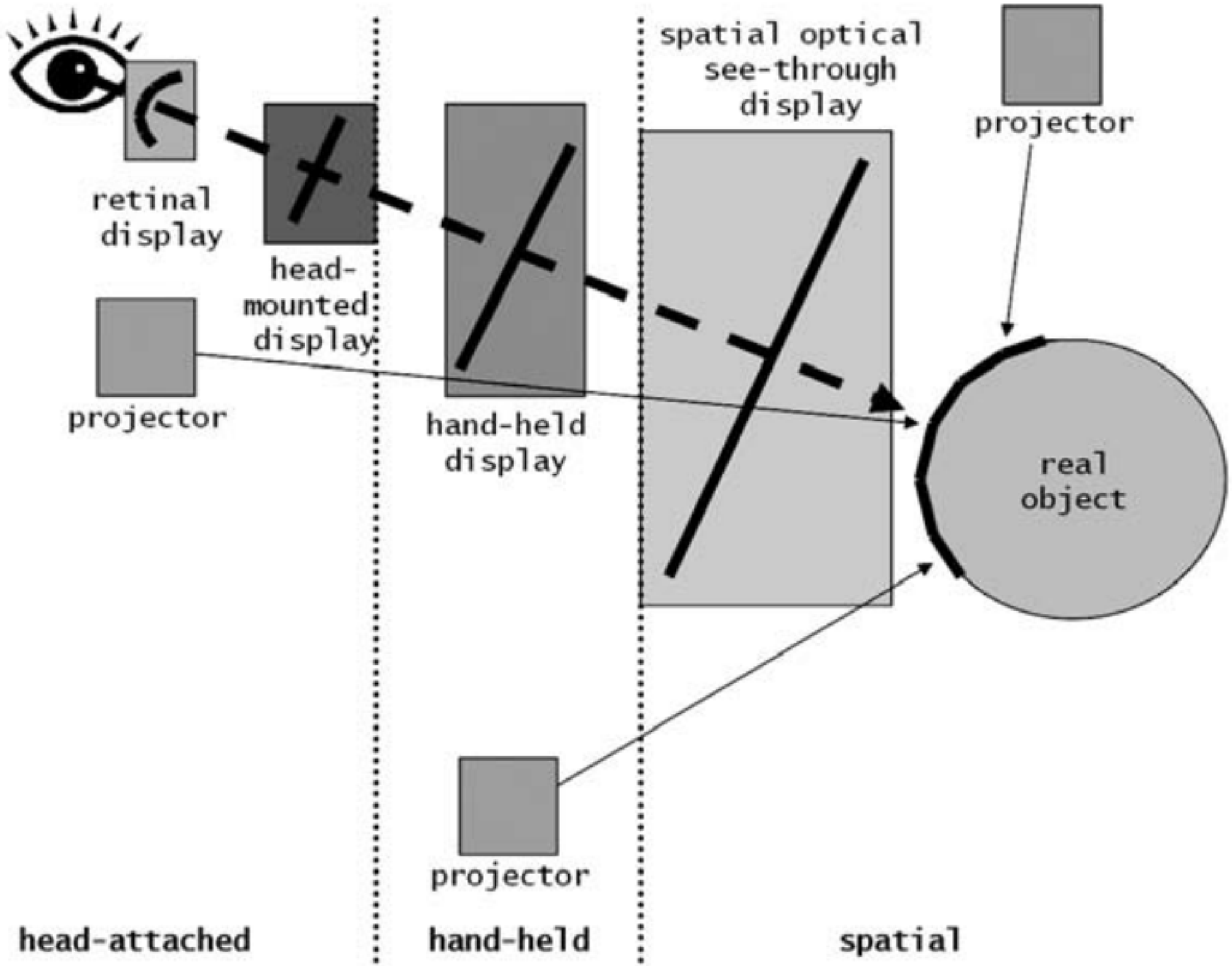
- Use the array microphone of the Kinect sensor to localize the user as they speak.
  - Also useful for recognizing commands.
- Three Kinect sensors are mounted in the corners of the room. Two horizontally and one vertical.
- One sensor covers a range of around 100°



Application: Beamabuggy

http://www.youtube.com/watch?v=Z4bdrG8S1FM

Overview



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Raskar)

Going Mobile

Until now:

- Orientation of the projector
- Shape of the real-object
- Cluster: Position relative to other projectors

➢ Geometric-awareness

Now:

- Position of the projector relative to the scene

Going Mobile

Idea:

- Spatial awareness: System infers location and orientation of the device in 3D space.
- Geometry awareness: System constructs the 3D structure of the world (User, Furniture, Walls, …) around it.

Two approaches:

1) Infrastructure-based: Uses sensors positioned in the environment.
2) Infrastructure-less: All sensors are attached to the projector.

Discussed in:
Interactive Environment-Aware Handheld Projectors for Pervasive Computing Spaces

Going Mobile

Use of markers allows:

- computation of camera and hence projector pose relative to the markers.
- identifying individual objects.

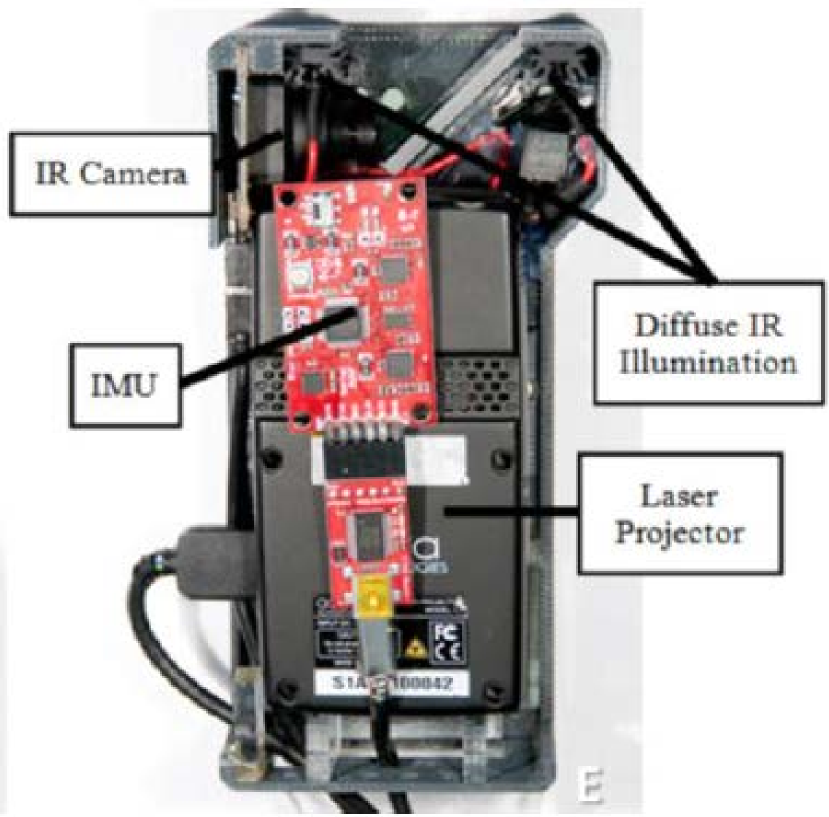
Going Mobile

http://www.youtube.com/watch?v=yJZLIHBr1G0

Infrastructure-Based: RoomProjector

The Projector:

- Inertial Measurement Unit (IMU)
  - Orientation of the device
- IR Camera



In the room:

- Four Kinect cameras mounted at the ceiling at the mid-point of each wall.

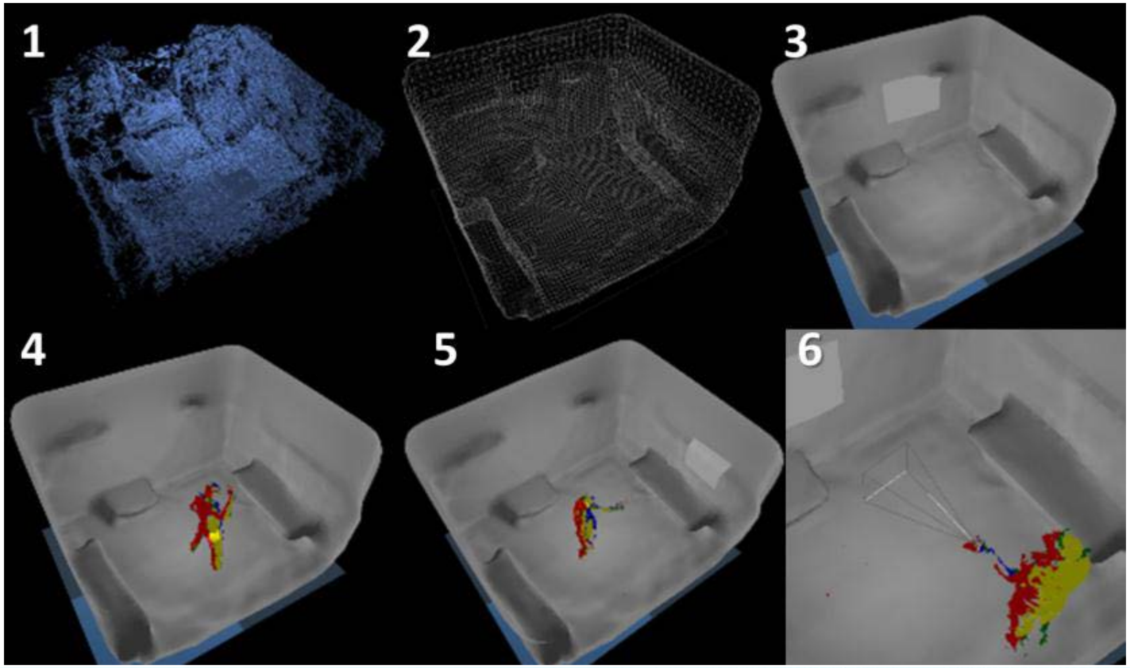
Discussed in:
Interactive Environment-Aware Handheld Projectors for Pervasive Computing Spaces

Register the Environment

When the room is empty:

- For each Kinect sensor the average of a number of depth map samples is computed.
- From these averages a single fused point cloud is generated.
- The point cloud is used to produce a background mesh.

➢ This mesh is used for background subtraction.



Track the Projector Position

Absolute position in the room:

- Cover the projector with retro-reflective tape:
  - Light pattern from the Kinect will be reflected and appears much brighter in the 2D Kinect IR image.
- The position of the projector can then be triangulated.

Orientation of the projector:

- Provided by the Inertial Measurement Unit

Project Images ‘Correctly’ on Arbitrary Surfaces

Mesh of the room + Absolute position in the room + Orientation

- Automatic correction of projected content.

Furthermore:

- Flashlight-like metaphor: Can associate 2D image with any surface and use the projector to “reveal” it.

Interaction

- Use of a hot (IR) mirror: IR camera and projector are coaxial.
- Can segment hand of user.

http://www.youtube.com/watch?v=frGEzlrhve0

- Interactions happen in the coordinate space of the camera.

Interaction

Combine data from IR camera and Kinect sensors:

http://www.youtube.com/watch?v=frGEzlrhve0

Interaction: Objects in Mid-Air

- Virtual image projected onto the surface
- How to render virtual objects, which are in mid-air?
  - Project shadows
  - Use a mobile plane as viewport into the virtual world

Interaction: Objects in Mid-Air

http://www.youtube.com/watch?v=frGEzIrhve0

Advantages and Problems

Advantages:

- Small sensing window of the projector is overcome.

Problem: Coarseness

- Only prominent objects can be recovered from the scene.
- Hybrid tracking of projector can be noisy and error prone:
  - camera occlusion
  - ferrous objects interfering with the IMU

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Infrastructure-Less: SLAMProjector

SLAM: Simultaneous Localization and Mapping

- Kinect sensor is directly mounted on the projector.


- KinectFusion uses its depth data to:
  - Building a reconstruction of the environment in real-time
  - ➢ Geometry awareness
  - Recover the pose of the projector
  - ➢ Spatial awareness

Interaction

- Interaction similar to those of the RoomProjector are possible.
- Furthermore, can move Kinect to object of interest:
  - Higher resolution:
    - Possible to interact with less prominent objects
    - ➢ Can segment and copy them
  - No camera occlusion.

Interaction

http://www.youtube.com/watch?v=frGEzIrhve0

Advantages and Problems

Advantages:

- High 3D sensing fidelity
- Independent from infrastructure

Problem:

- Shadow interaction: User occludes a large part of the Kinect depth image. Can degrade the tracking quality of the projector.
- Location is tracked from the built model, accumulated errors can lead to drift.

Summary

Spatial optical see-through display:

- Virtual Showcase

Main advantages:

- Can directly project onto physical objects of various shapes
- Overcomes the restriction that display size dictates device size.
  - Unlimited field of view
  - Can be transported easily compared to large screens.

Summary

How to Make Use of These Advantages?

- iLamps:
  - Self-contained, Geometric-aware and Self-organizing
- Disadvantages:
  - Limited field of view
  - Light intensity

Solutions:

- Cluster of projectors
- Steerable displays
  - Beamatron

Summary

Going mobile:

- Geometry AND spatial aware
- Infrastructure-based:
  - iLamp: Markers
    - Only discrete number of surfaces
  - RoomProjector: 4 Kinect sensors
    - Advantage: Extended sensing
    - Disadvantage: Coarse
- Infrastructure-less:
  - SLAMProjector: Kinect sensor mounted on projector
    - Advantage: High 3D sensing fidelity
    - Disadvantage: Drift of camera position

➢ Problem when displaying virtual objects in mid-air.

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Future

Combination of smart phones with projectors:

Future

Augmenting a complete room:

http://www.youtube.com/watch?v=N_cKsOe7hLI