Occupancy and Activity Estimation using Reflected Encoded Illumination

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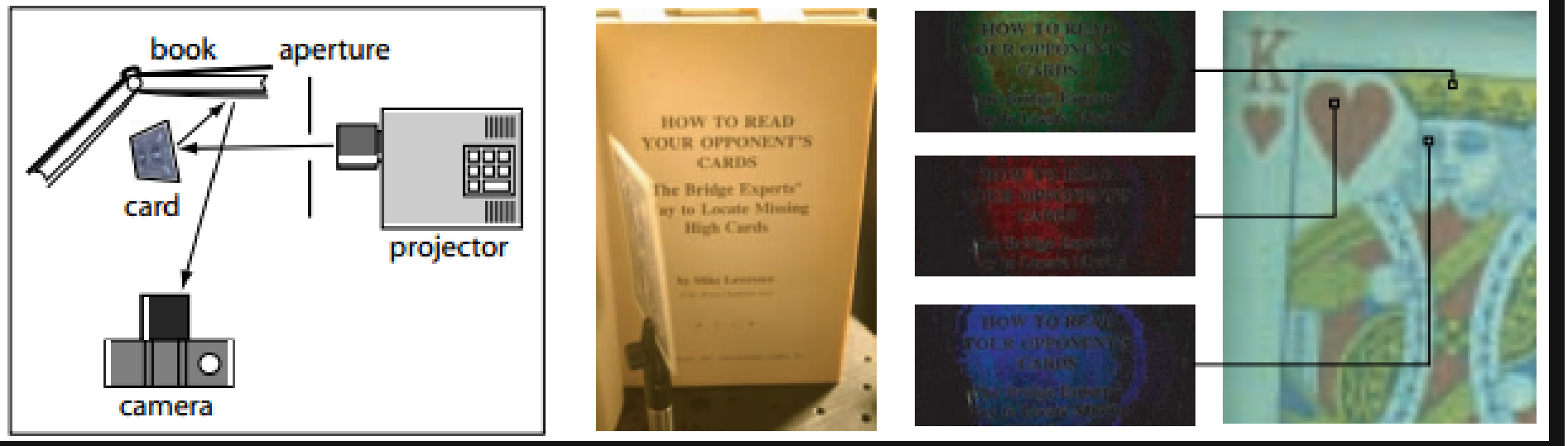
+
22 Industrial Members

OUTLINE

- Information in Reflected Light
- Modes of Harvesting Reflected Light Information
- Localization and Activity Estimation
- Comparison to other non-Light methods
- Summary

Information in Reflected Light

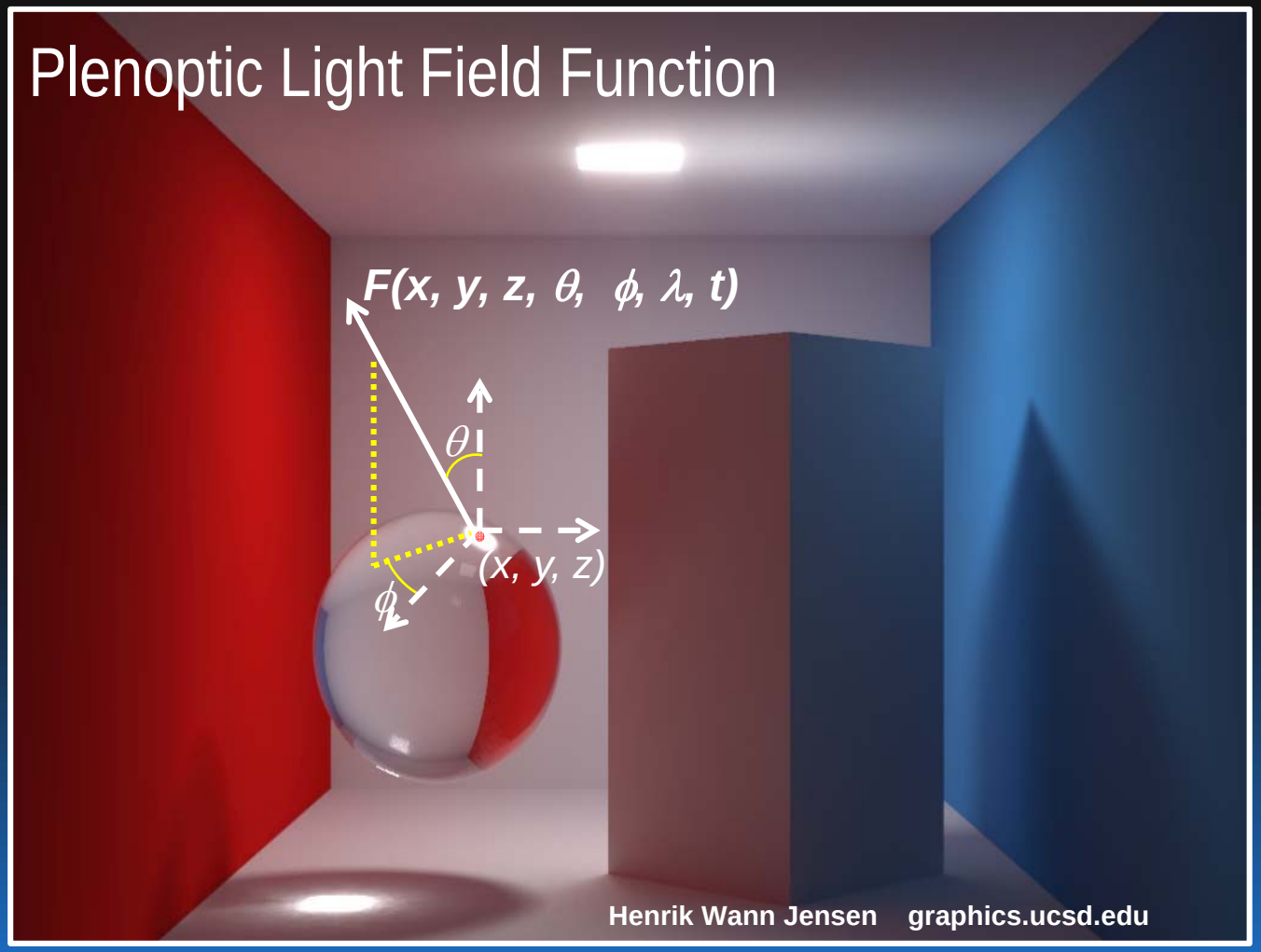


P. Sen et. al., ACM Transactions on Graphics 24 (3), 2005, 745-744

- Capture successive images of the scene under different lighting conditions
- Mathematically “swap” position of the light and the camera
- View “hidden” information

Structured light (spatially varying intensity, color) can be used to reconstruct a scene from any direction

Can Light Transport Concepts be used for 3D Mapping?



Modulated LED lighting (color and intensity)

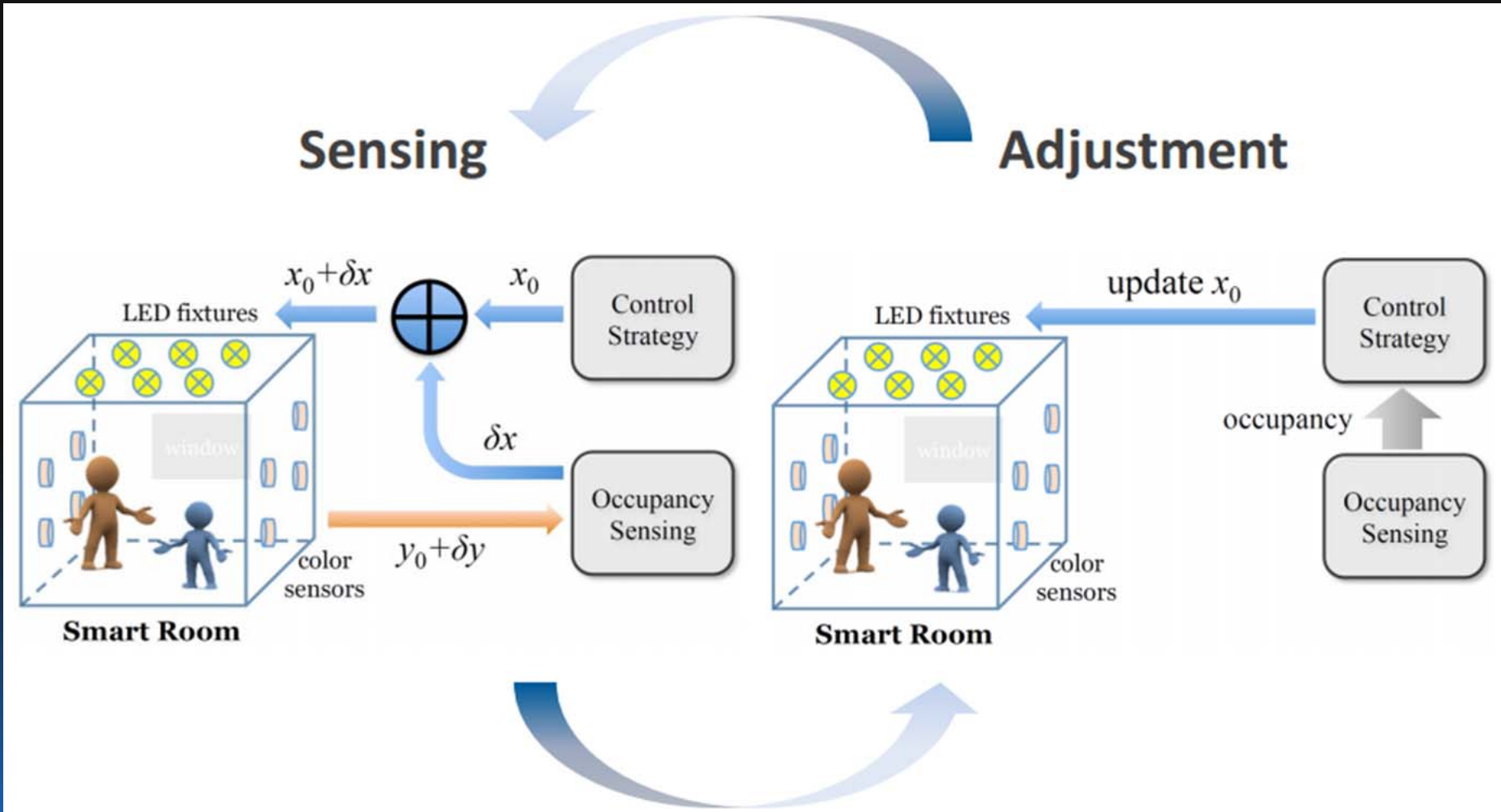
PLUS

a sparse, low cost sensor network in the ceiling

USED FOR

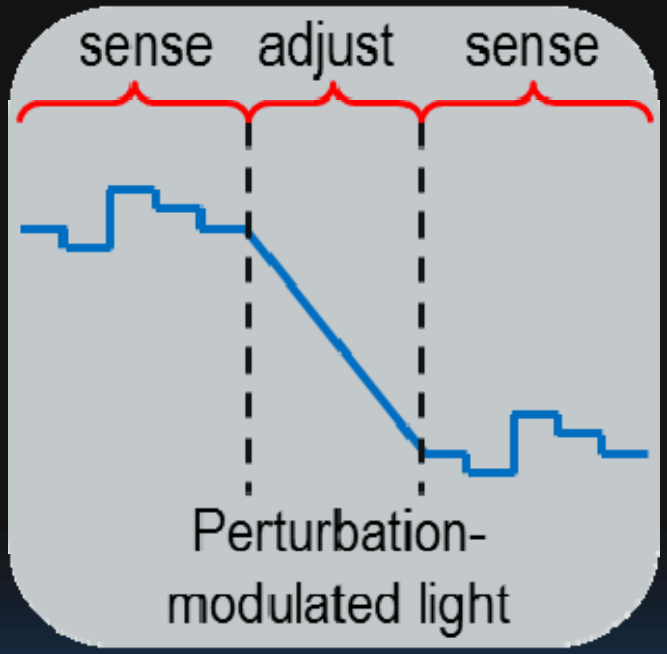
Privacy Preserving Occupancy and Activity Estimation

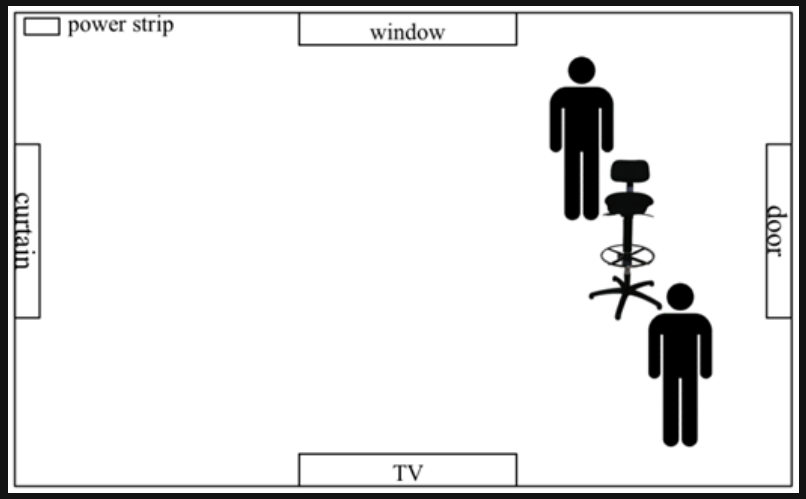
First – Light Transport in Light Blocking Model



Wang *et. al. Journal of Solid State Lighting* 2014, 1:17

Early Light Blocking Model Results



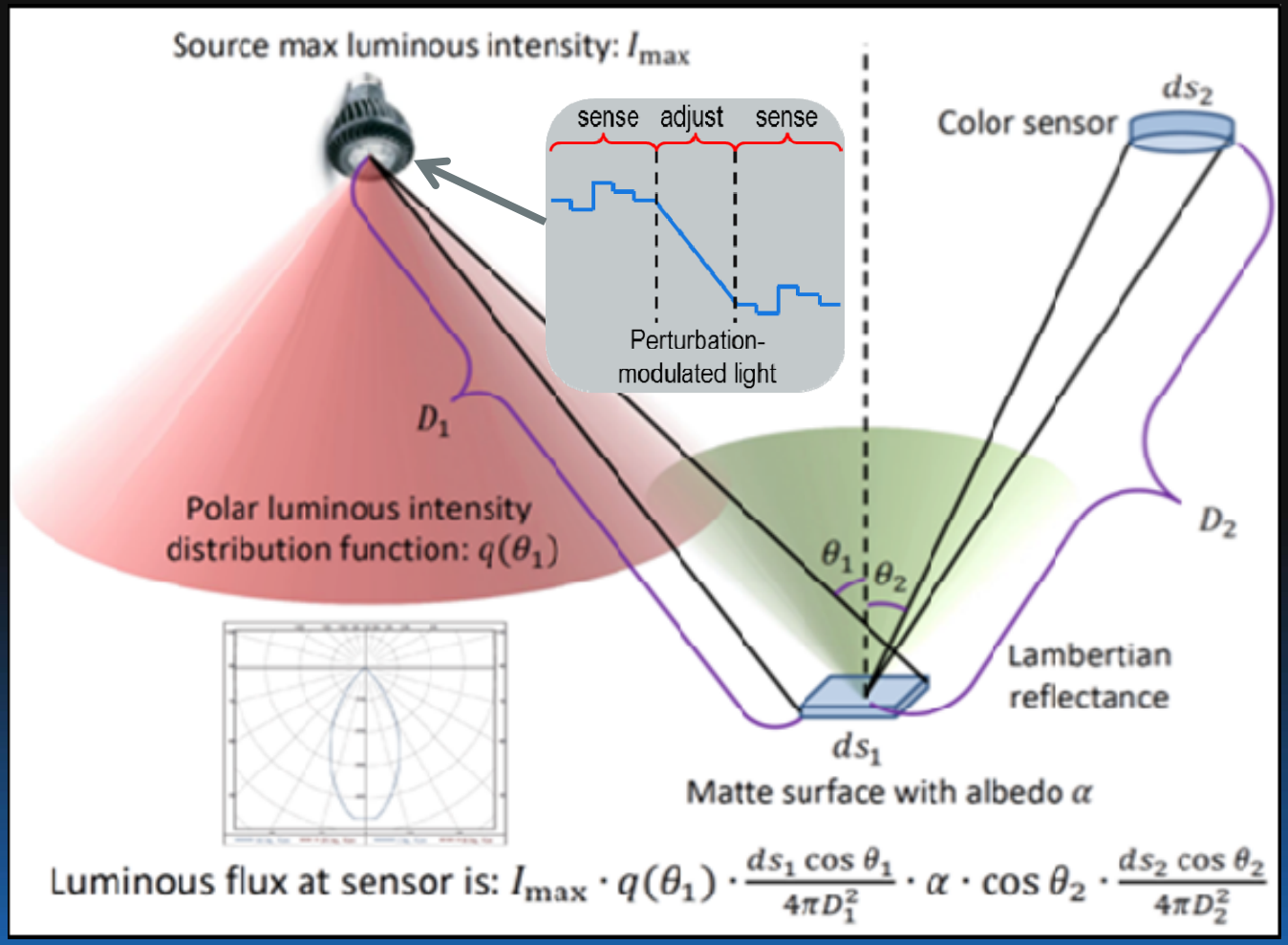


Can the same be done with reflected light using sensors in the ceiling?

Occupancy estimation with Sensors in Ceiling

Fixtures and Sensors in Ceiling

Simplified Deployment Use reflected VLC data?



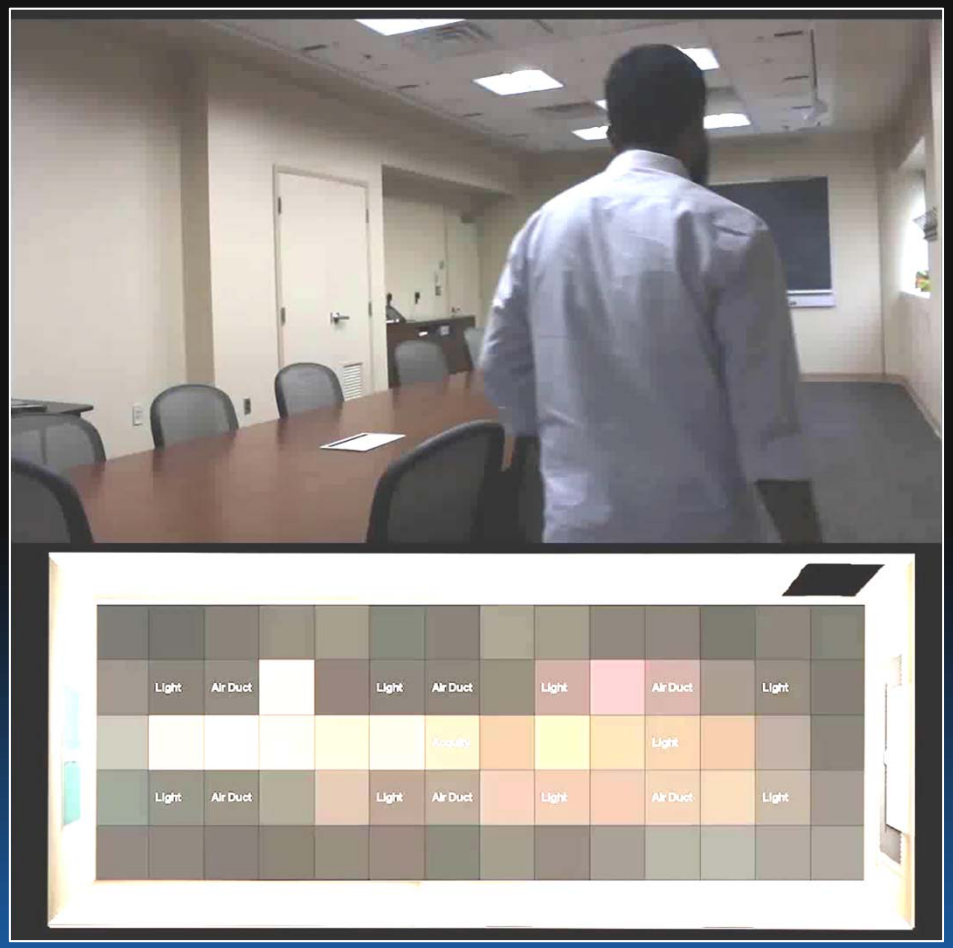
Can we used reflected VLC information for sensing?

Conference Room Testbed Facility

- Color Tunable Lighting
- ToF cameras
- Ceiling mounted Color Sensors

Tunable spectral power density in lighting improves sensing performance

Reflected Light Field Tracking

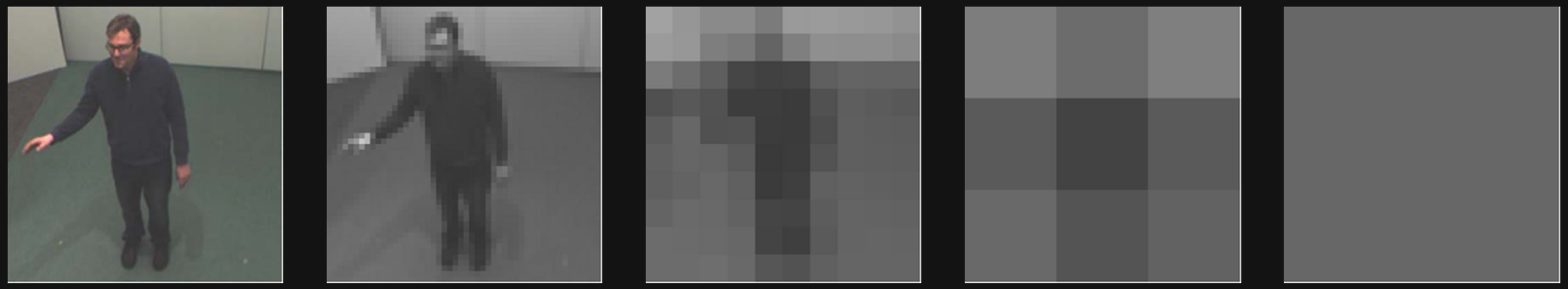


Use Simple RGBW Color Sensor Network
(no modulation)

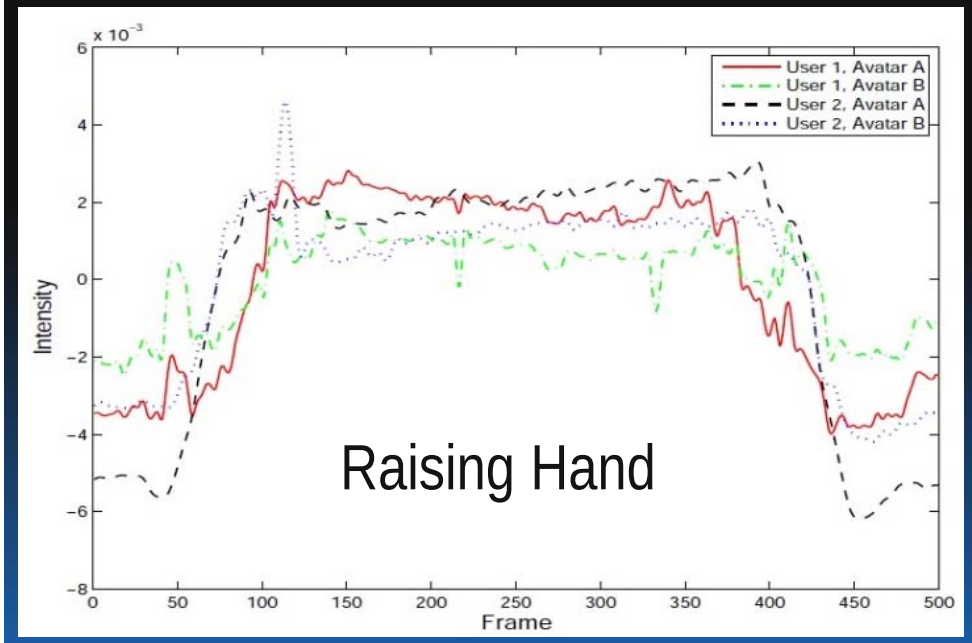
Detect Changes in Time Dependent Reflectivity
(all color channels)

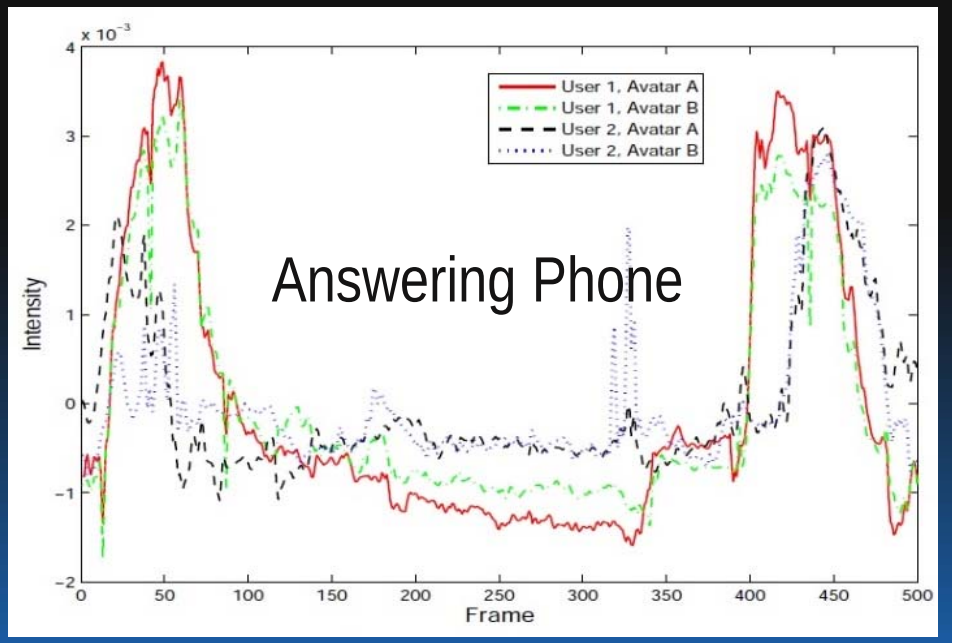
Simple Tracking

Gesture Recognition from networked color sensors

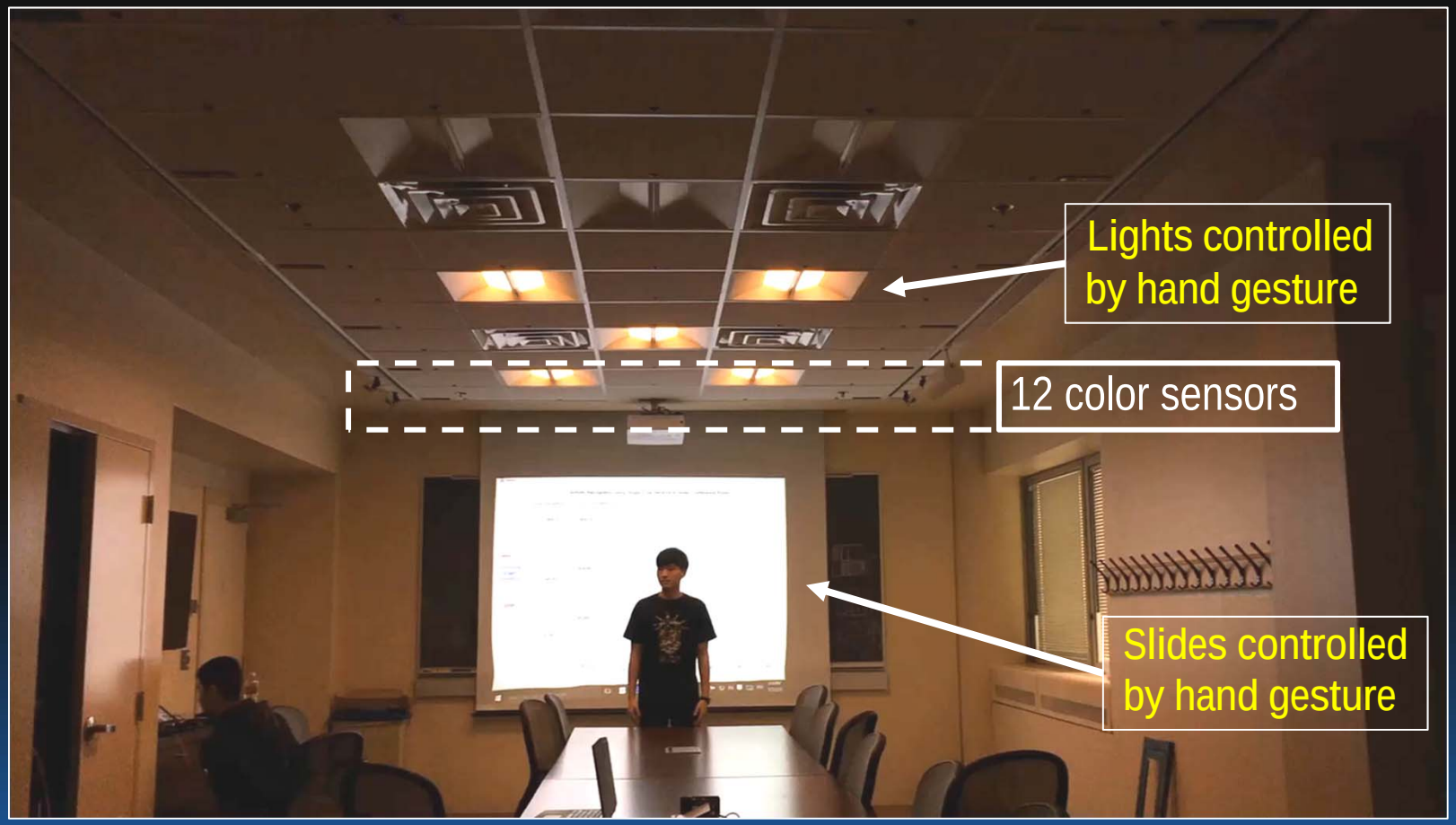


Dai, Saghafi, Wu, Konrad, Ishwar, *IEEE Int'l. Conf. on Image Processing,* 2015





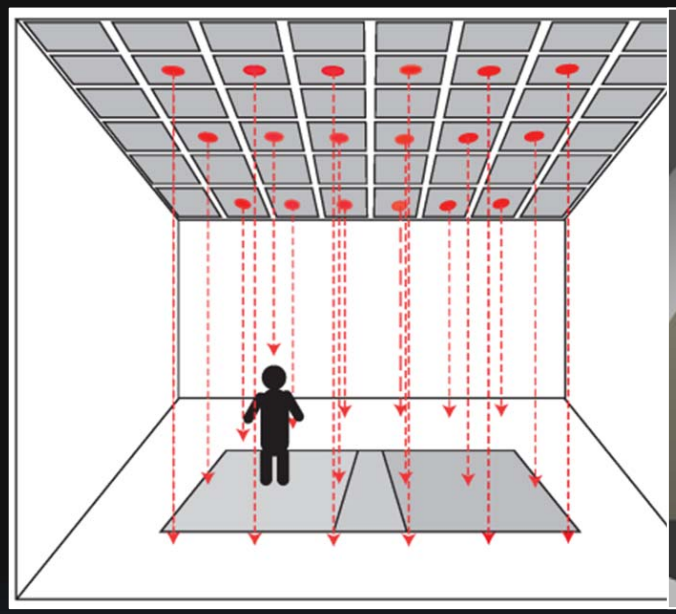
Activity Controlled System using Color Sensors

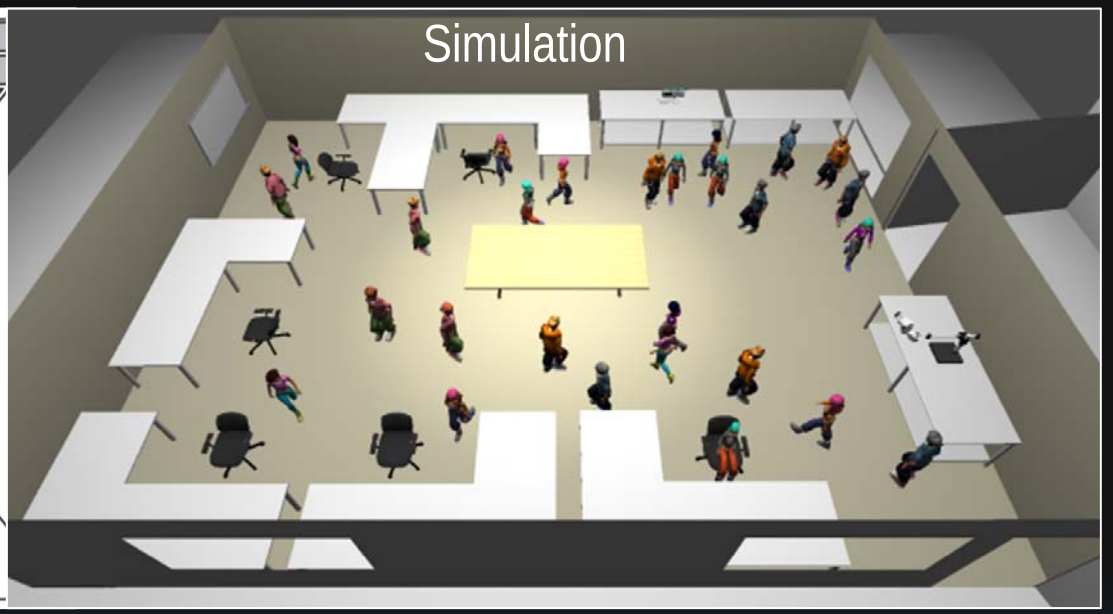


Dai, Saghafi, Wu, Konrad, Ishwar, *IEEE Int'l. Conf. on Image Processing,* 2015

Basis for human – system control interface?

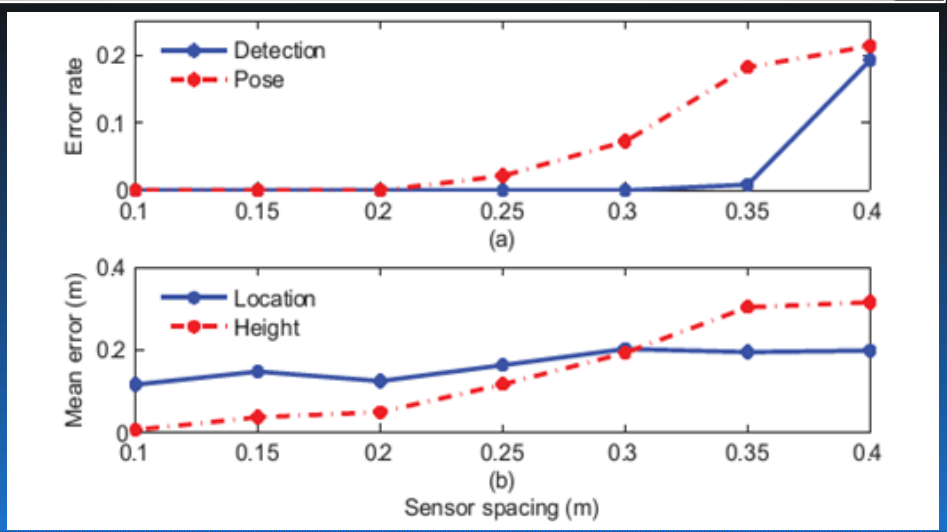
Time of Flight Sensing: Another Approach



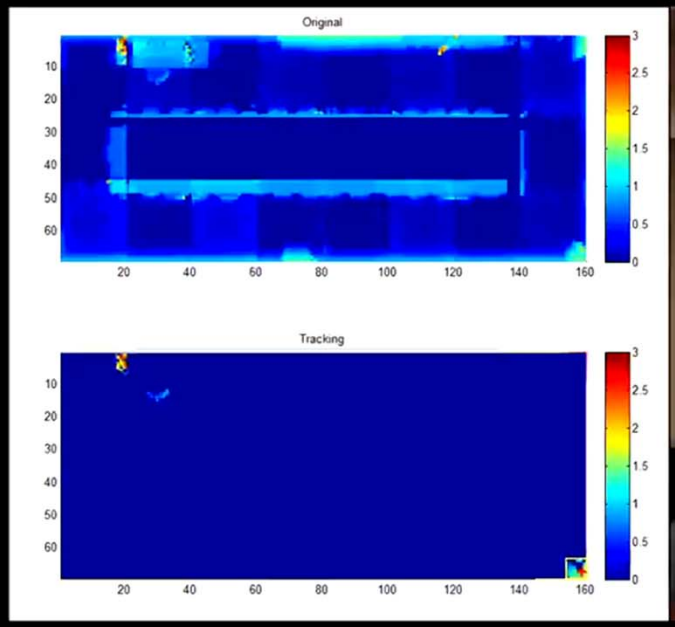


Li and Radke, IEEE Transactions on Industrial Informatics,**10** (1), 2014, 689-696

Can ToF sensors be applied to privacy preserving activity estimation?



Time of Flight 3D Mapping/Tracking



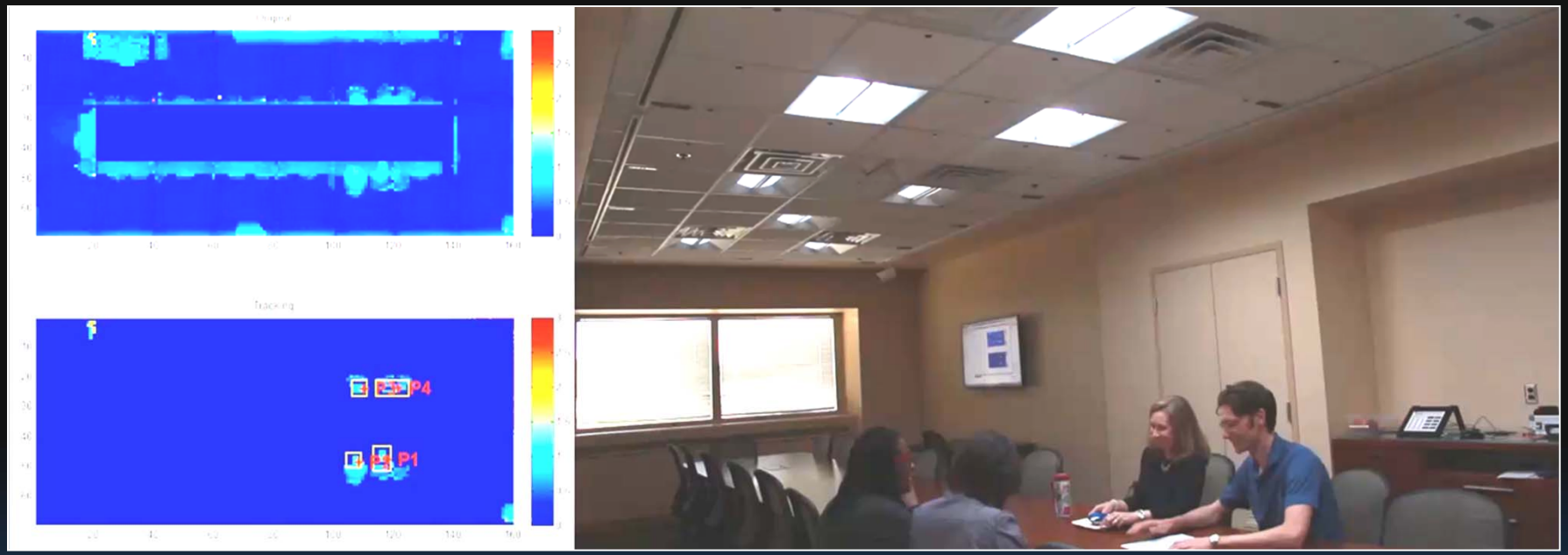
Number of people: 1

	ID	Position	Height
1	1	[158, 67]	1.52

Collaborators:
Richard Radke
Art Sanderson
TKae Woodstock
Indrani Bhattacharya

Distance measurement, not heat maps (accurate to +/- 5 cm)

Adaptive, responsive systems

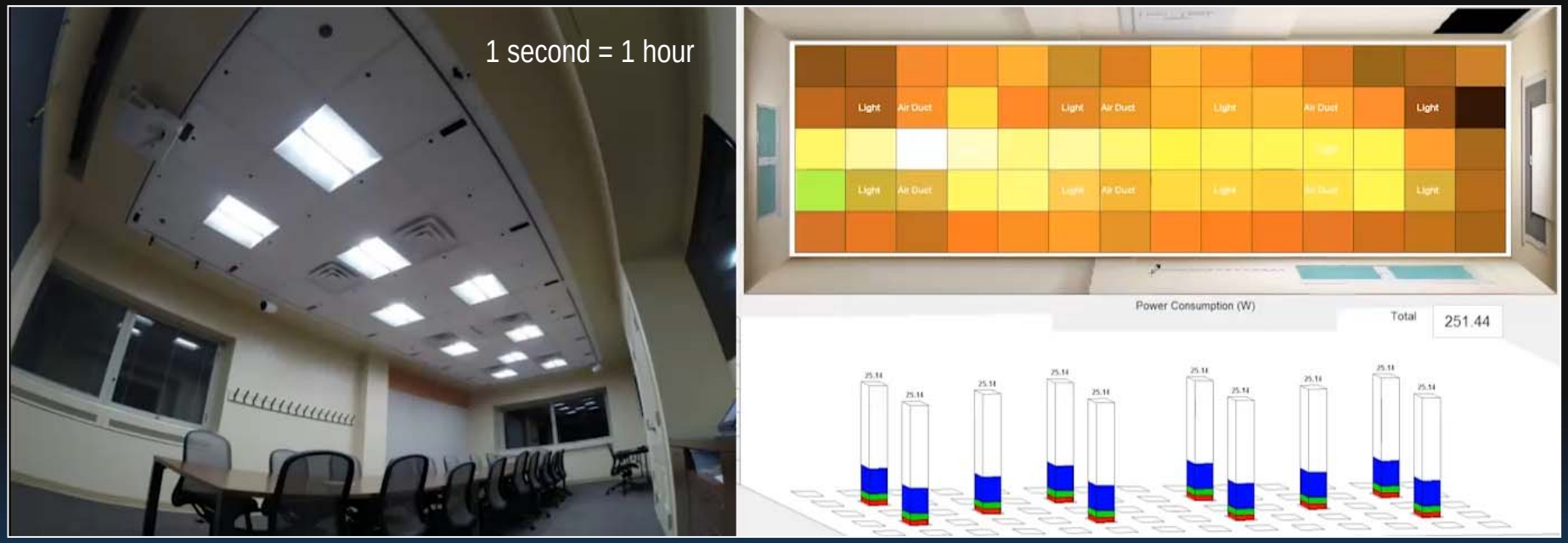


Woodstock, Radke, Sanderson, *FUSION 2016*

- Lighting control
- HVAC
- Other building services (cleaning, security, resource allocation

Applications in Energy Efficient Building Management

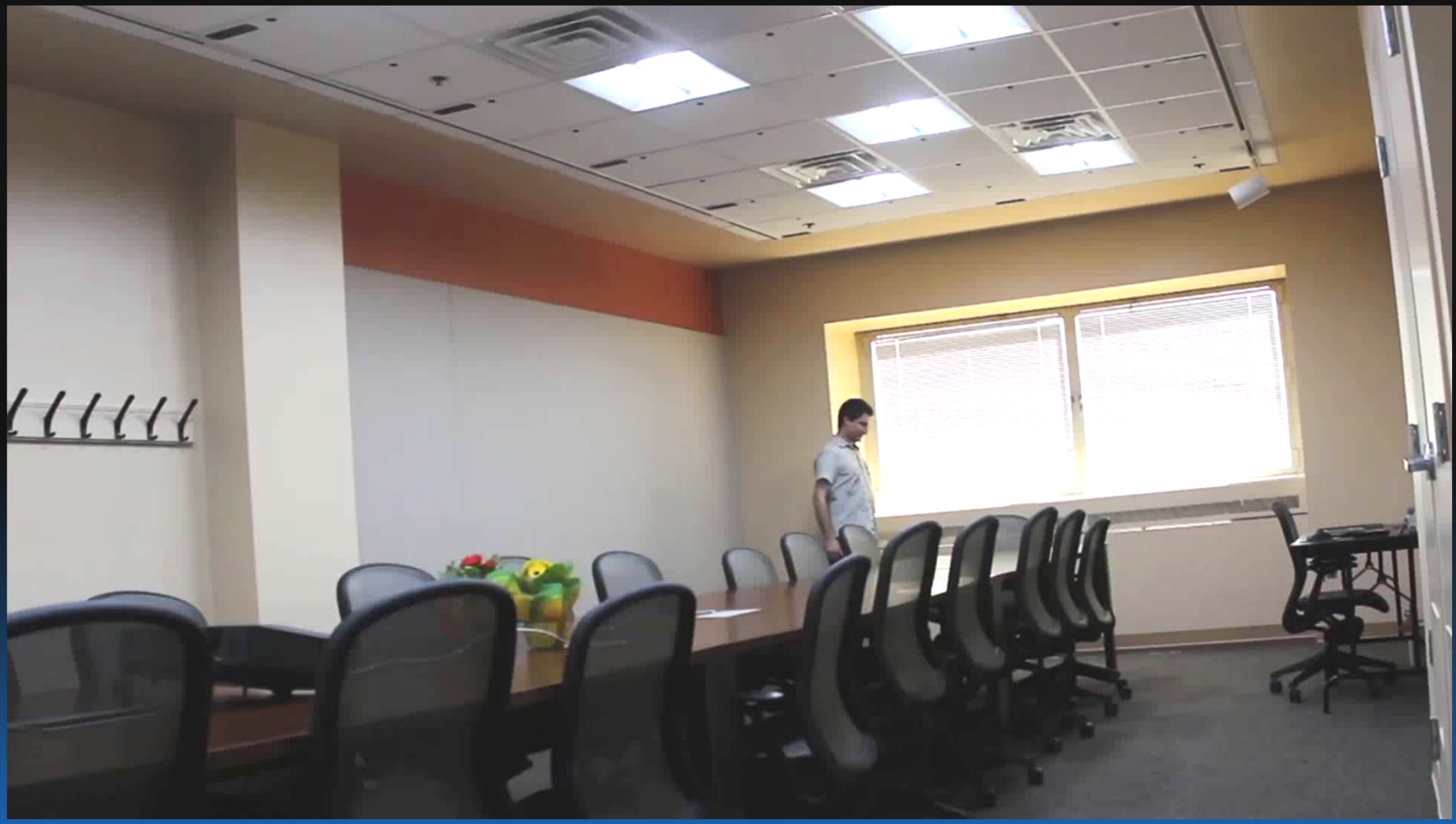
Adaptive Lighting Control



- Dynamic brightness and spectral control
- Impact on worker productivity, learning, circadian management

Applications in autonomous lighting control

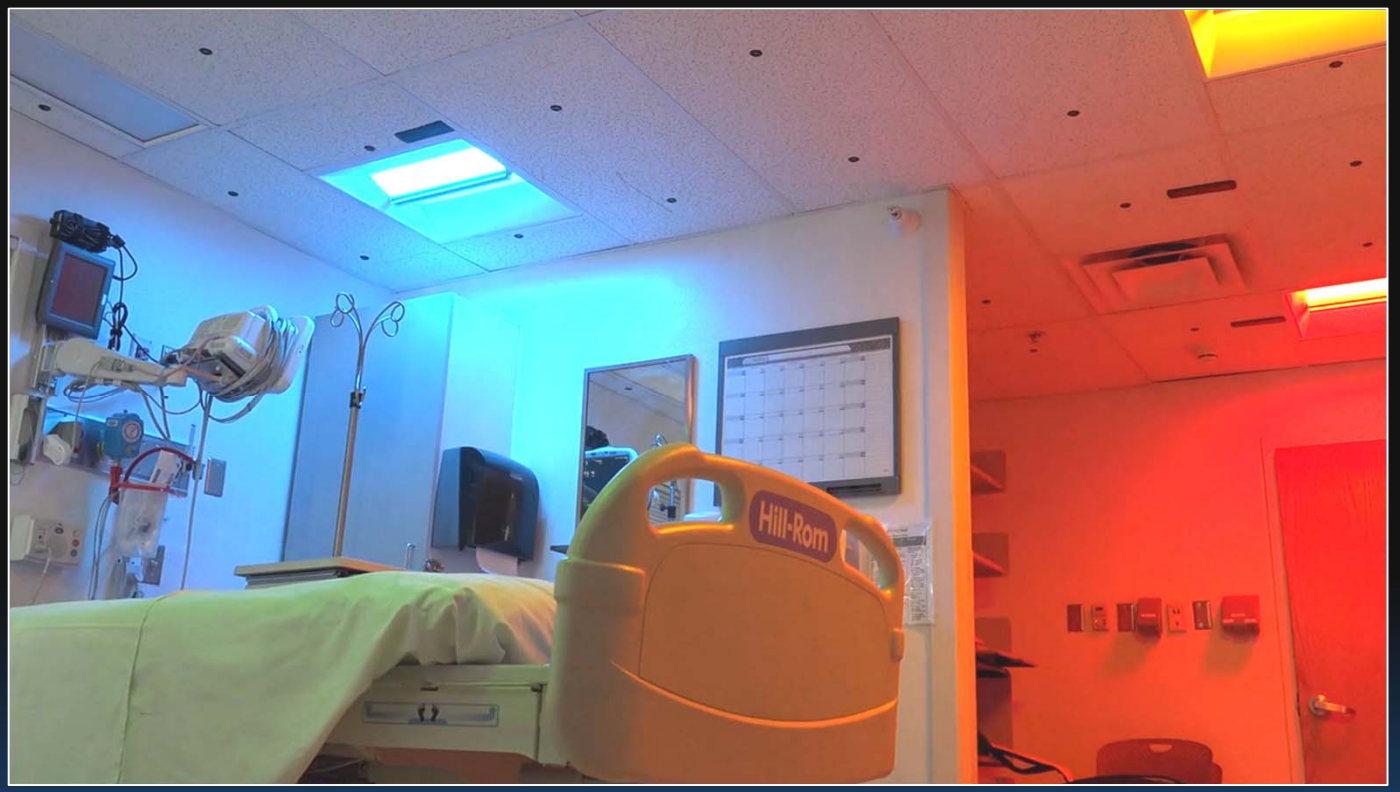
Activity Logging, Safety, Security



Applications in Healthcare and Eldercare

Rich Radke. Art Sanderson and Students

System Replicated @ University of New Mexico



Meeko Oishi, Lee Brown and Students

- Same Lighting and sensor network as at Rensselaer
- System just installed in early 2016
- Adaptive Lighting and room actigraphy

Hospital Room Testbed

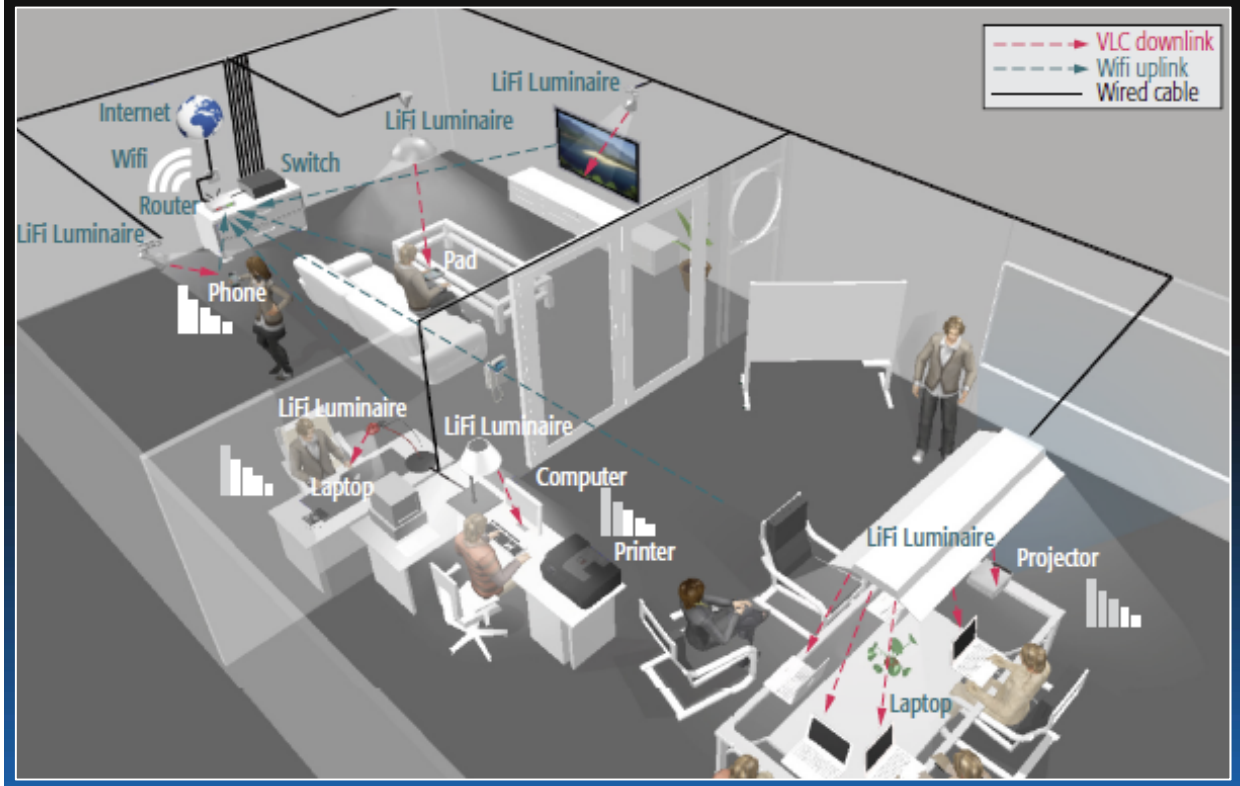
Dual Use – VLC plus Illumination

Long range goal – reflected VLC signal sensing!

VLC: Communication AND Sensing

VLC Receivers in Devices: Visible Light Communications

*Modulated lighting for **both** light sensing **and** communications*



Receivers in Ceiling:

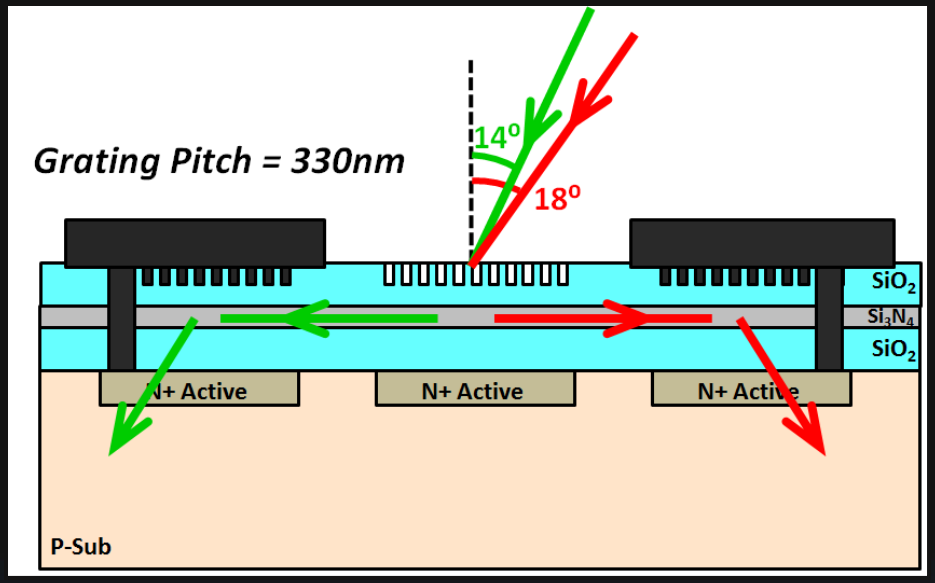
- 3D spatial maps
- Track location, motion
- Estimate activity
- Preserve Privacy

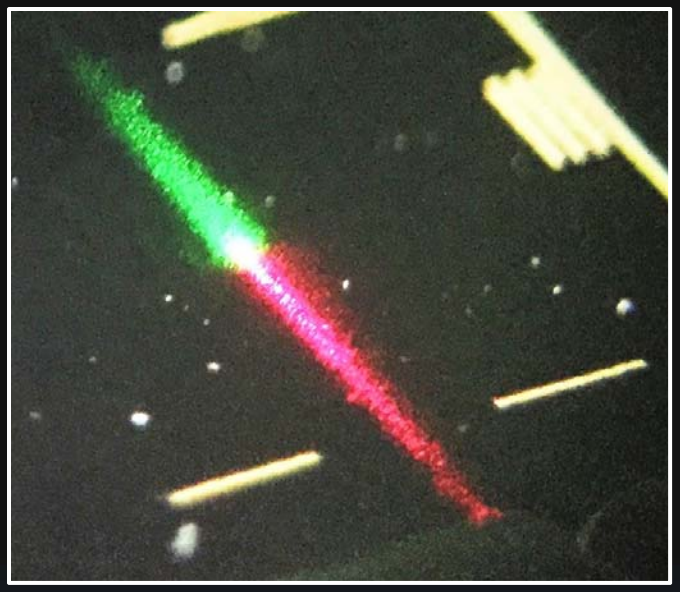
Comparison to other activity sensing methods

Existing Sensor Technology	Location Accuracy	Pose Estimation	Privacy Preserving	Localize Objects	Comments
PIR Motion Detectors	⊗	⊗	✓	⊗	False negatives and positives
IR Imaging Arrays	✓	⊗	✓	Limited	Not CMOS compatible, costly
Ultrasonic Sensing	⊗	⊗	✓	⊗	False positives
RF Tagging	Limited	⊗	⊗	If tagged	RFID tags needed, RF penetrates walls complicating location
RF Attenuation	Limited	⊗	✓	Limited	RF wall penetration issues complicates precision localization
Camera Systems	✓	✓	⊗	✓	Cannot be used everywhere due to privacy concerns
Plenoptic Sensing Technology	✓	✓	✓	✓	Precise Dynamic Localization of People and Things

Light Field Sensing: more powerful than other methods

New Kinds of Sensors are Needed





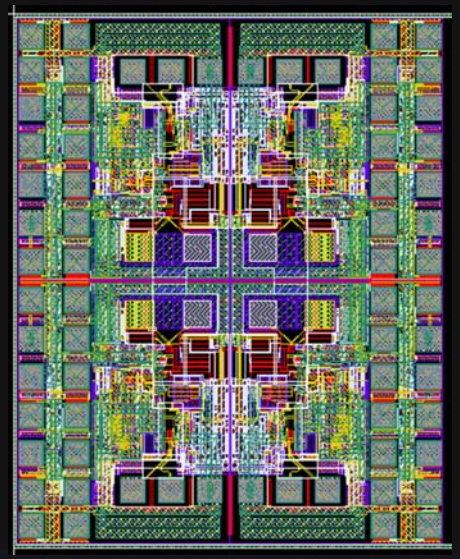
New plenoptic light field sensor (CMOS Compatible)

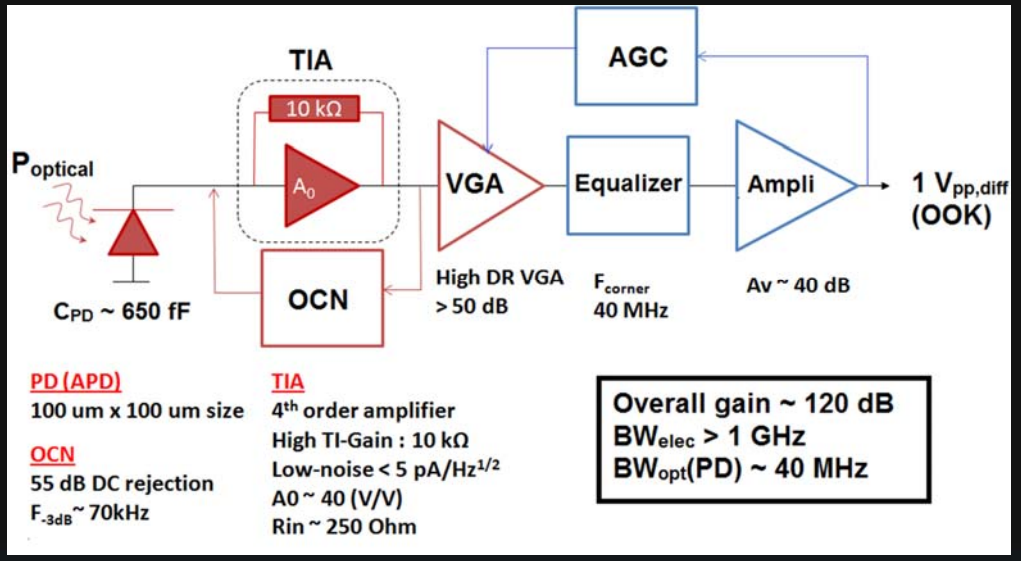
- Couples to integrated APD array
- Array readout deconvolves direction and wavelength
- Colors aligned to fixture color channels

APD array is also used for VLC receiver (w/o the grating)

Collaborators:
Steven Brueck
Payman Zarkesh-Ha
Mona Hella
Bassem Fahs
Mottaleb Hossain
Javed Ghasemi

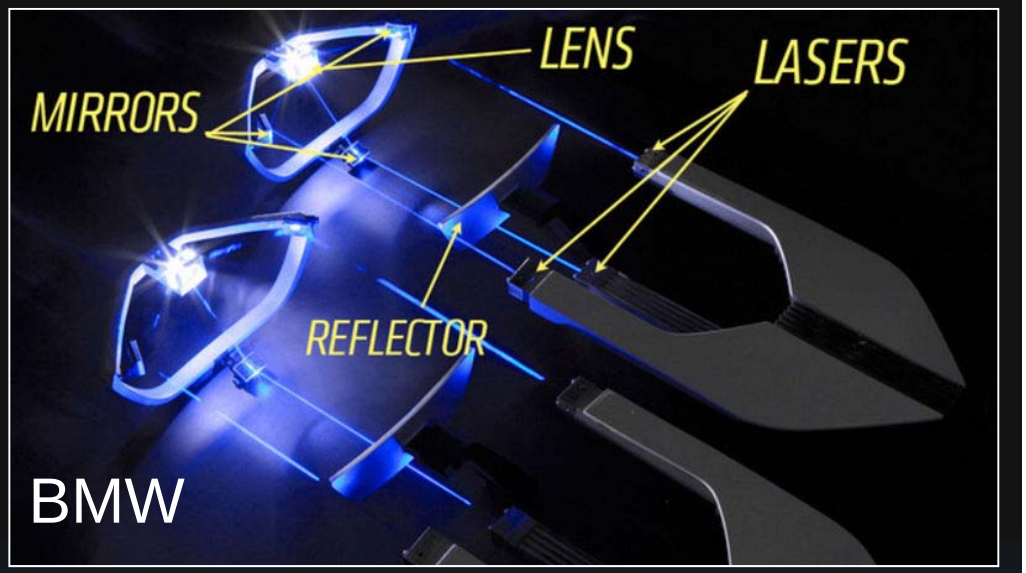
VLC Receiver R&D





- Advanced VLC Receiver Design (fabricated by ams)
- Novel APD and blue enhanced PD design (UNM)
- Capabilities for the basis for VLC, TOF (visible light) and Light Transport 3D spatial mapping
- Everything is CMOS compatible – therefore has low cost potential

Lasers for Lighting and Communications?



- Lasers & Superluminescent LEDs (SLDs) – droop free
- High bandwidth compared to LEDs
- Incorporation into lighting possible (but challenging)

Summary

- Light Transport Analysis useful for privacy preserving occupancy and activity estimation
- ToF Sensing can provide similar information with precise localization information
- Integration of VLC with illumination can provide both wireless communications and powerful occupancy/activity estimation data
- New sensor technologies will make reflected light field sensing a powerful new methodology for a wide range of adaptive systems

Acknowledgements

- LESA Faculty (and Students)
  - Richard Radke
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  - Steve Brueck (UNM)
  - Meeko Oishi (UNM)
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