Touch Sensing Technologies

a tutorial at ITS 2010 by

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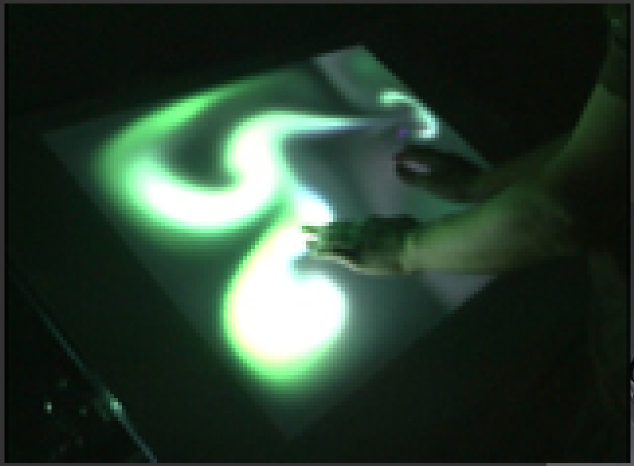
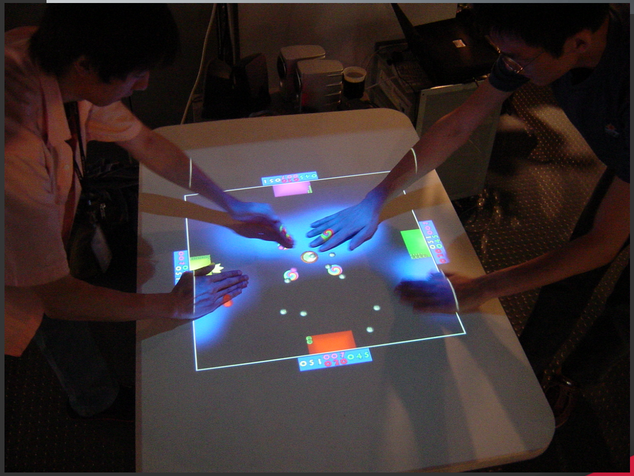
Touch Sensing Technologies

Part 1: *Technology Overview*

Technology Overview





Technology Overview

Touch Sensors

- acoustic
  - Surface Acoustic Wave (SAW)
  - acoustic pulse recognition
- electronic
  - resistive sensors
  - capacitive sensors
  - capacitive coupling
- optic
  - occlusion sensing
  - FTIR
  - „backscatter“ detection
  - free-air & assisted hand tracking

Acoustic Sensors
Surface Acoustic Wave (SAW)

- ultrasonic surface waves are injected into a glass pane
- transmitters and receivers on opposing sides
- touching finger partially absorbs wave energy

- used by some commercial touchscreens, e.g. SecureTouch by EloTouch
- vandalism-proof when using hardened glass
- mostly used in public settings

- only single-touch
- no object detection possible

Acoustic Sensors

Acoustic Pulse Recognition

- also used by some EloTouch products
- but mainly research projects
- usually requires pen or fingernail

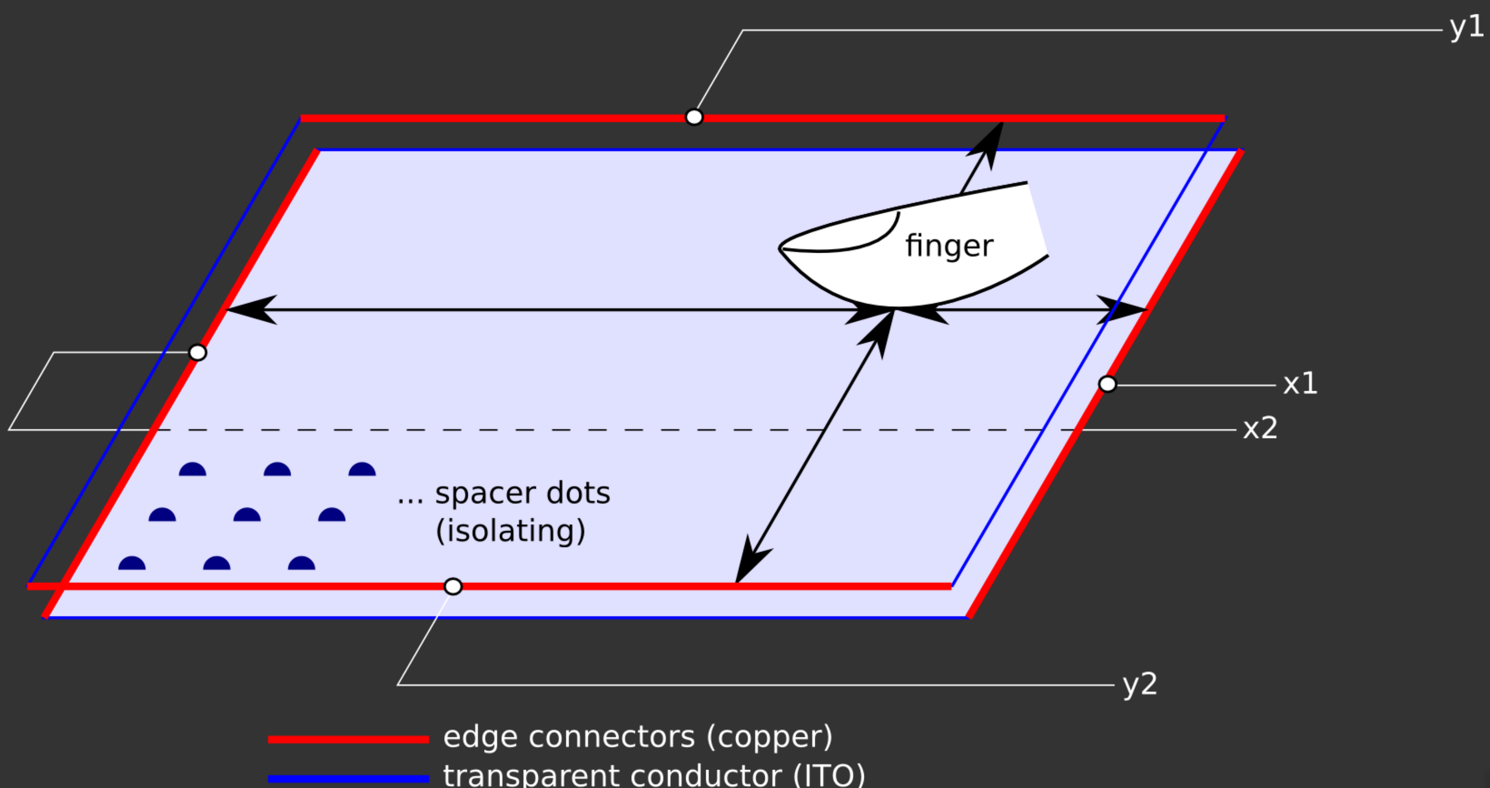
- Acoustic Template Matching: one microphone, compare with samples pre-recorded on a grid
- Time Difference of Arrival: several microphones, calculate wavefront peak at each one -> triangulation

- rather imprecise, depending on material (echoes & multi-path propagation)
- susceptible to environment noise
- does not support dragging, only tapping

Electronic Sensors

Resistive Touchscreens

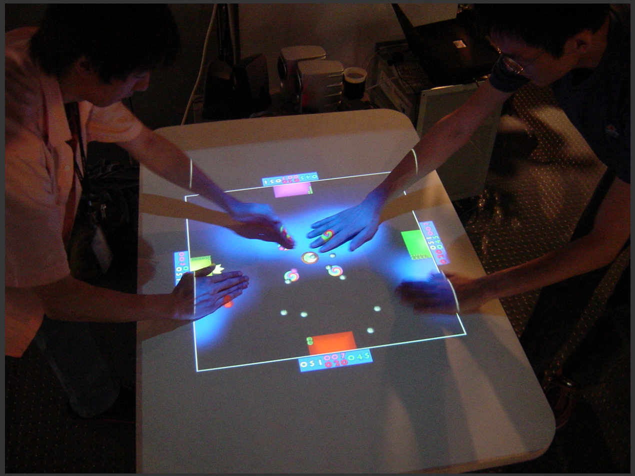
- cheap, „every-day“ touchscreens
- used in low-end mobile phones, PDAs etc.
- two transparent, conductive layers, separated by tiny spacers
- pressure creates contact -> measure resistance in both directions
- easy to damage, not really multi-touch capable (at best dual-touch)



Electronic Sensors

Capacitive Sensing

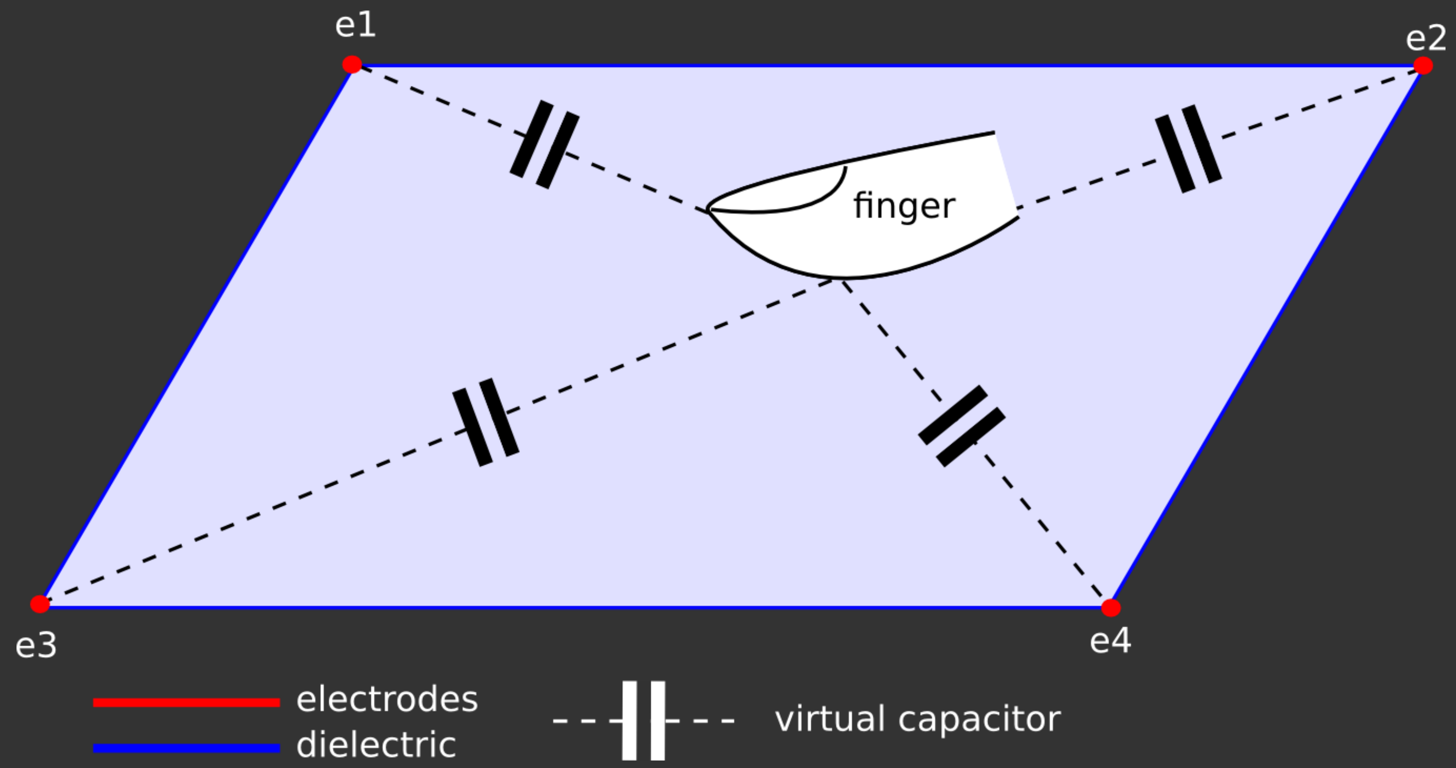
Popular examples: iPhone, DiamondTouch (Mitsubishi), SmartSkin (Sony)



Electronic Sensors

Capacitive Sensing

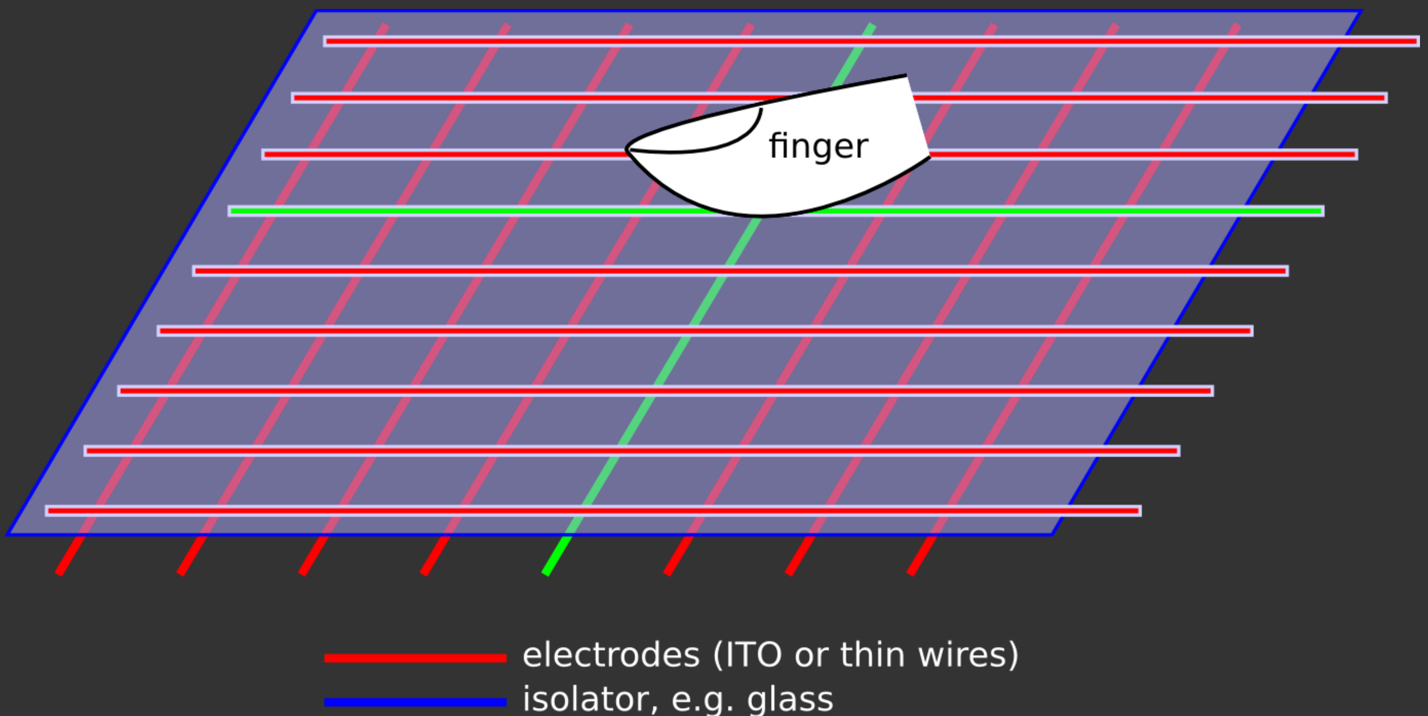
- reliable & thin
- transparent dielectric necessary
- presence of conductor (human skin) changes capacitance
- can at best sense conductive objects



Electronic Sensors

Projected Capacitive Sensing

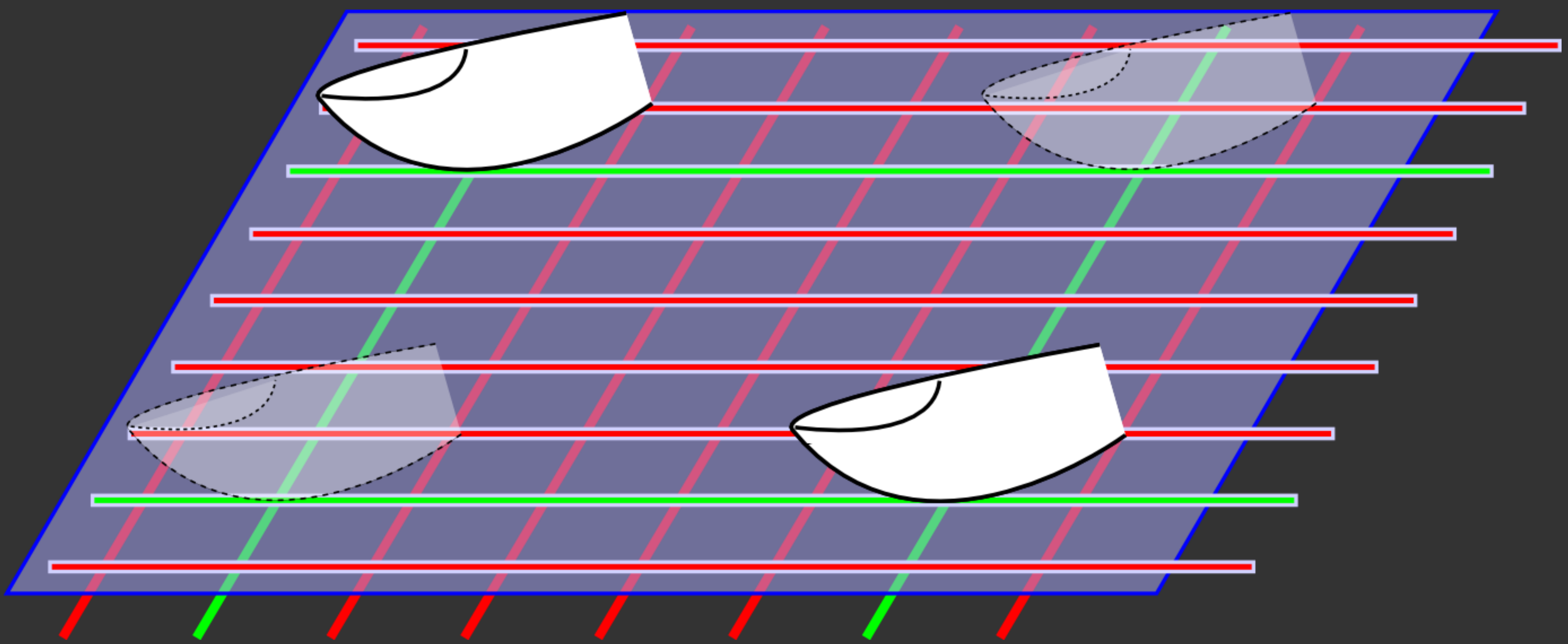
- most current commercial products based on this technology
- expensive to manufacture, usually made of ITO (indium tin oxide)
- each conductor resp. each crossing forms a capacitor
- two sub-categories:
  - self capacitance: each row/column measured independently
  - mutual capacitance: each crossing measured independently



Electronic Sensors

Projected Capacitive Sensing

- self capacitance: at most dual-touch possible
- reason: ambiguity for more than 1 touch point
- can be improved with clever tracking



Electronic Sensors
Capacitive Coupling

- DiamondTouch/SmartSkin do not directly measure capacitance
- instead: capacitive coupling

- DiamondTouch by MERL:
  - signal transmitted *through* the user
  - uses, e.g., special seat cushion or foot mat
  - -> identification possible

- SmartSkin by Sony:
  - signal transmitted through rows, received through columns
  - user acts as ground, drains signal

- no complete image can be formed, just row/column intensities
- similar to self capacitance setup

Optical Sensors
Occlusion Sensing

- also commercially successful
- examples: SmartBoard, Citron DreamTouch, low-end dual-touch monitors

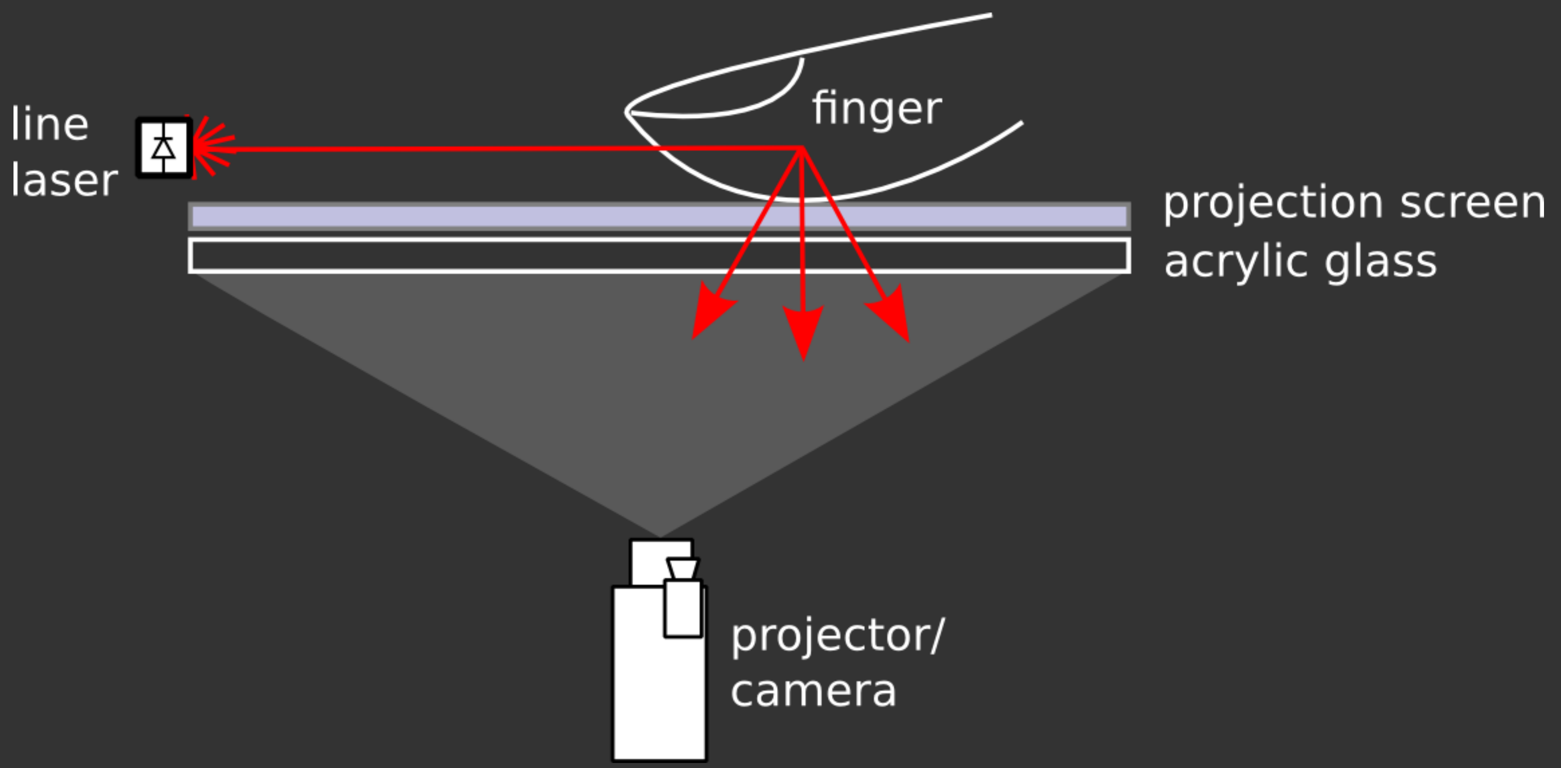
- SmartBoard
  - two or more cameras looking over the surface from the corners
  - infrared light strips are occluded -> calculate touch points

- Citron DreamTouch
  - similar approach with distributed photosensors
  - entire rim consists of LEDs and sensors
  - enable single LED, check all sensors

- dual-touch monitors
  - regular grid of light barriers
  - similar issues as with self-capacitance

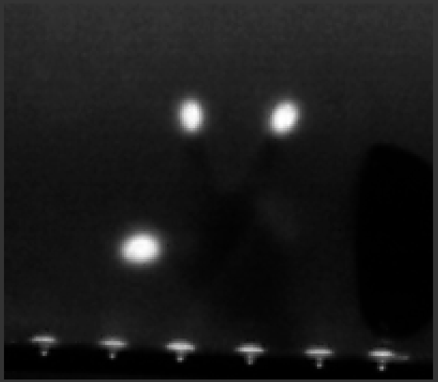
Optical Sensors
Occlusion Sensing

- low-cost variant with line lasers & cameras
- „light plane“, e.g. LaserTouch by Andrew Wilson

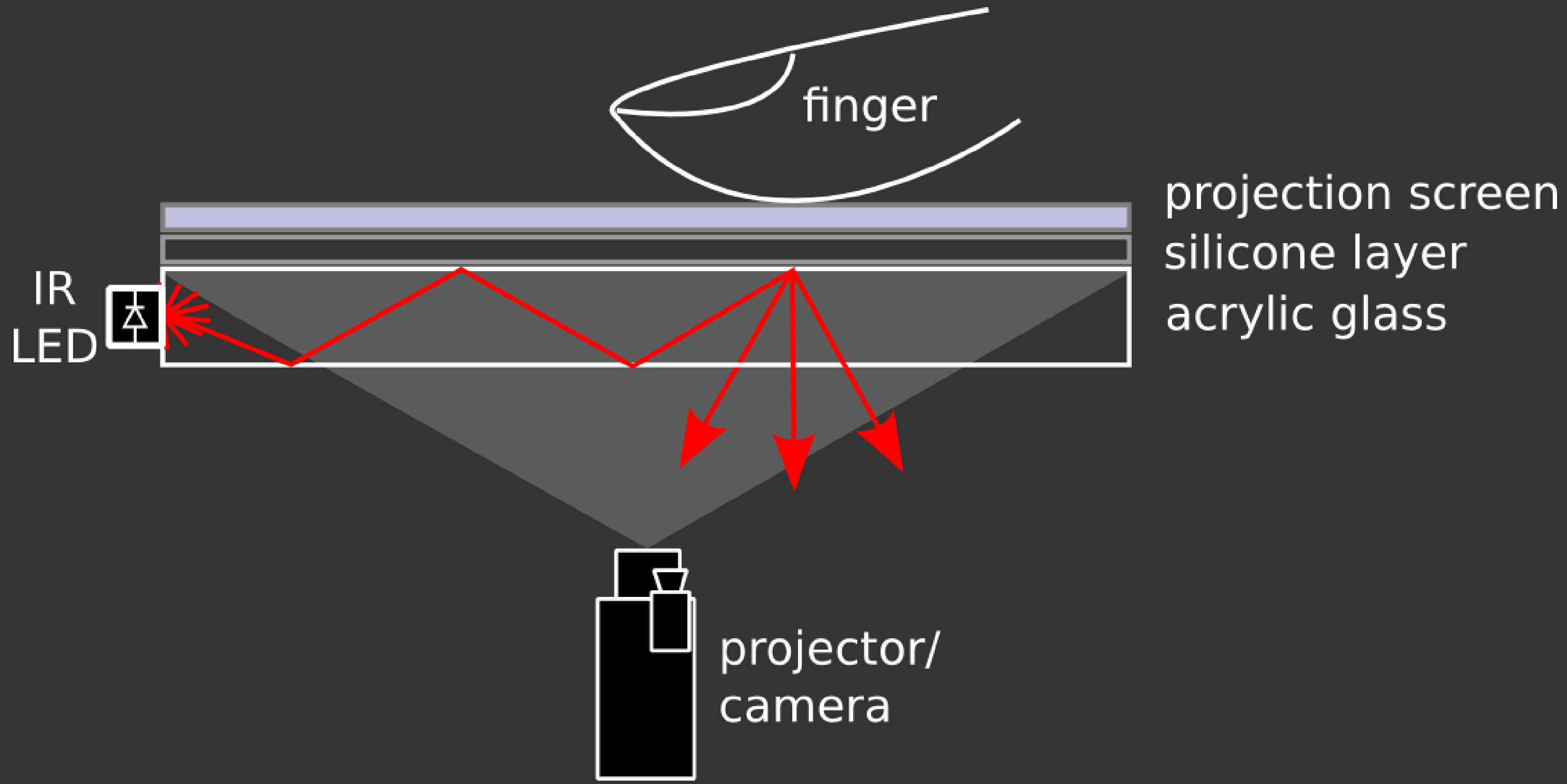


Optical Sensors

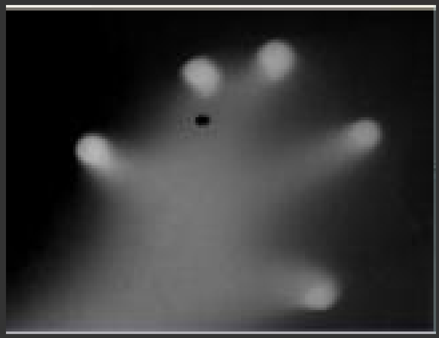
FTIR – Frustrated Total Internal Reflection



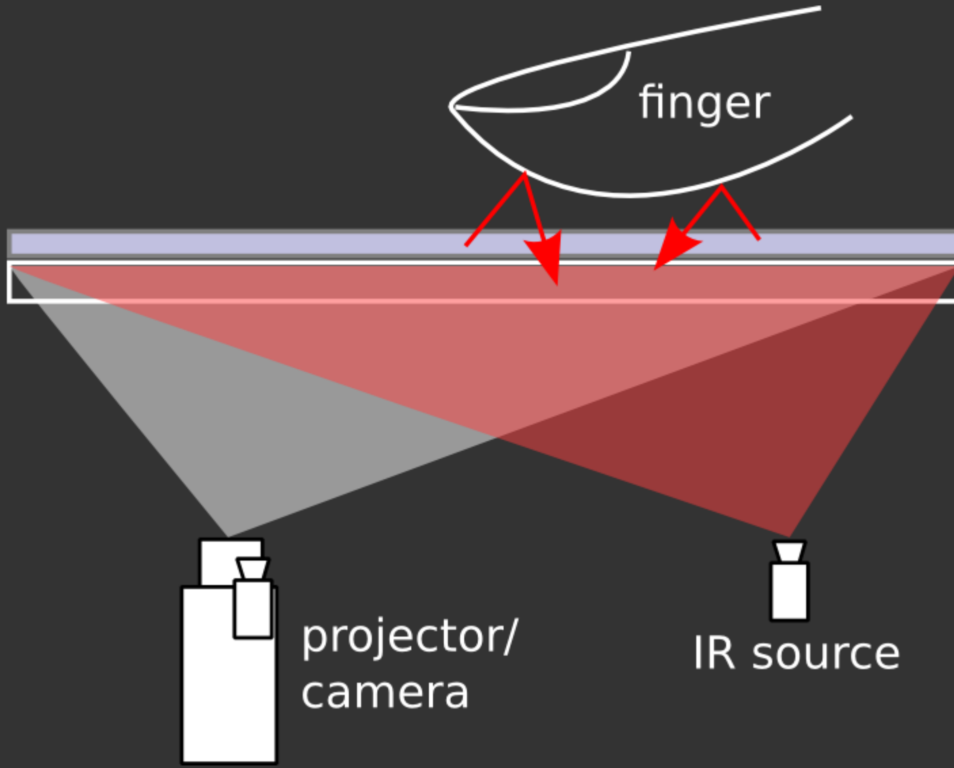
- patented in 1965 for fingerprint scanning
- adapted for touch sensing in 2006 by Jeff Han
- very easy to build - popular method for DIY setups
- touch on acrylic uncomfortable -> add „compliant“ overlay



Optical Sensors
„Backscatter“ Detection

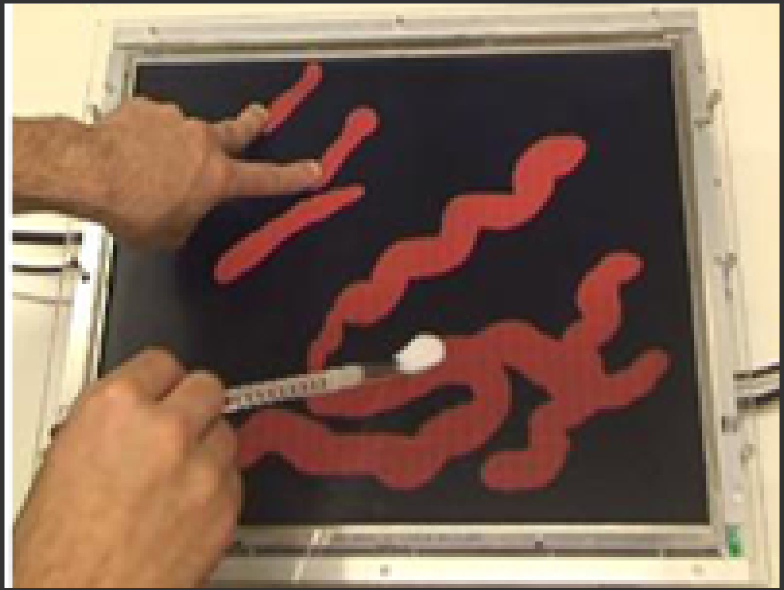


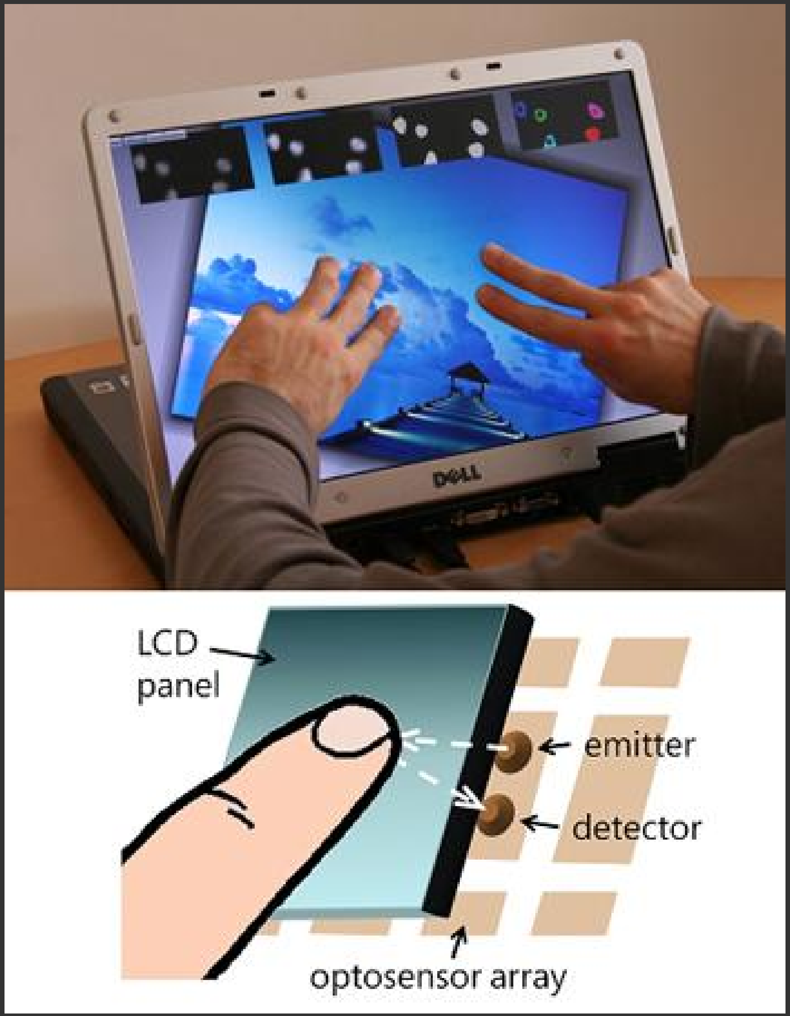
- „DI“/„DSI“: IR source below projection surface
- well-known examples:
- Microsoft Surface, Reactable
- advantage: easier to build than FTIR
- drawback: image processing slightly more involved



Optical Sensors
„Backscatter“ Detection

- „ThinSight“ by Steve Hodges et al.
- IR distance sensors behind LCD panel
- can sense touches as well as objects
- expensive & complex, but one of the most promising solutions



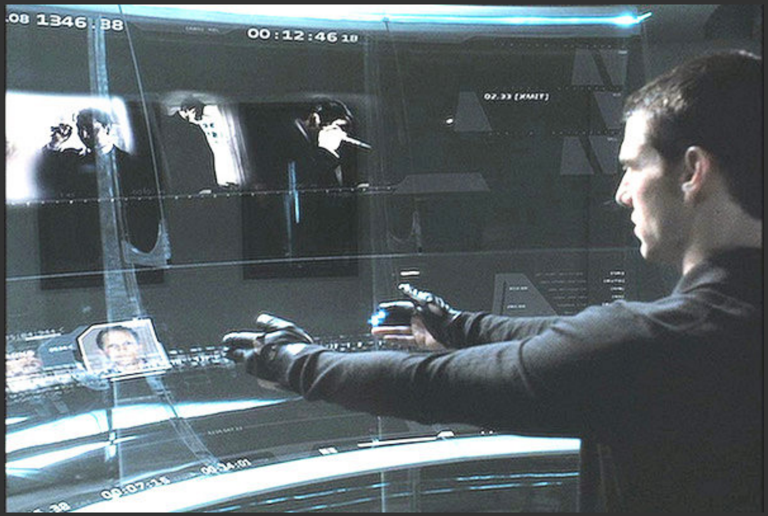


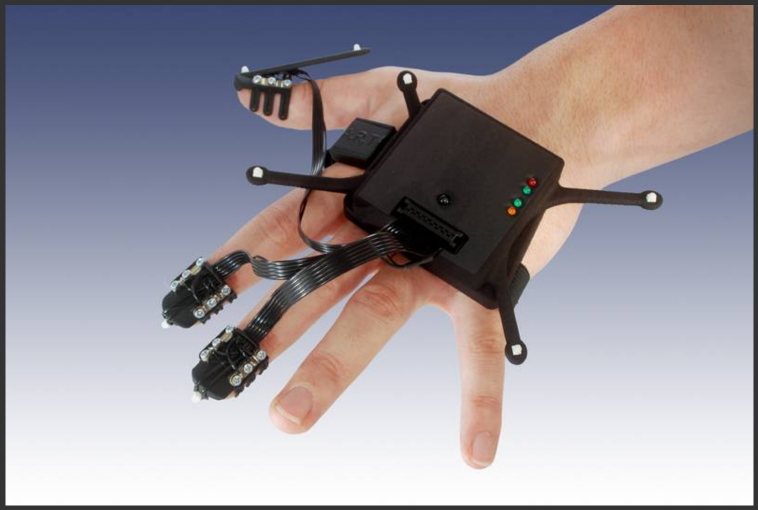
Optical Sensors
Assisted Hand Tracking

- Wiimote contains high-performance IR camera
- can track up to 4 points
- add IR light source & gloves with reflective markers
- really fast & cheap „multitouch“ sensor
- Based on work by Johnny Lee,
- enhancements by Luc Vlaming et al.

Optical Sensors
Assisted Hand Tracking

- „Minority Report"-Style
- ART Handtrack: active-IR gloves
- dedicated tracking cameras above screen
- tracks fingertips in 3D, hand in 6D (position + orientation)
- can be used for touch sensing, but provides much more data
- drawbacks: large cameras, expensive





Optical Sensors
Free-Air Hand Tracking

- „TouchLight“ by Andrew Wilson et al.
- requires holographic screen
- projection & sensing simultaneously

- „SecondLight“ by Sharam Izadi et al.
- „privacy glass“ screen
- switchable between transparent & opaque

- „PlayAnywhere“ by Andrew Wilson et al.
- illuminate plane with IR light
- sense touch by analyzing shape of shadow
- round shadow -> distant from plane
- pointed shadow -> close to plane

Summary

Touch Sensing Technologies

Technology	Multi-User	Multi-Touch	Direct	Hover	Object Detection	Fiducial Markers
Acoustic (SAW)	-	-	+	-	-	-
Acoustic (Pulse)	-	~	+	-	~	-
resistive	-	~	+	-	~	-
capacitive	-	-	+	-	~	-
projected cap. (self)	-	~	+	-	~	-
ProCap (mutual)	-	+	+	-	~	-
Cap. Coupling	+	~	+	-	~	-
occlusion	-	+	+	~	-	-
FTIR	-	+	+	-	-	-
backscatter (DI,...)	-	+	~	+	+	+
Hand tracking (assisted)	+	+	~	+	~	~
Hand tracking (free-air)	-	+	~	+	~	~

Outlook

What's next?

- display manufacturers: moving towards „in-cell“ sensors
- instead of RGB subpixels: RGB + sensor
- can capture touch, fiducials, even text documents
- prototypes available by, e.g., Sharp
- current problem: still too slow for interactive usage

- capacitive touch: may suffer from indium shortage
- prediction: in 5 – 10 years, mainly in-cell sensors
- camera-based sensors remain for niche applications

Touch Sensing Technologies

Part 2: *Advanced DIY Sensing Techniques*

Advanced DIY Sensing

Optical DIY Touch Sensors

- Using LEDs as Sensors
  - Theory of operation
  - Implementation
- Improving FTIR & DI with pulsed light
  - Common Issues
  - Pulsed Light
  - Implementation

Using LEDs as Sensors

Theory of Operation

- light detection using LEDs pioneered by Forrest Mims ~1975
- adapted for touch sensing by Scott Hudson et al.

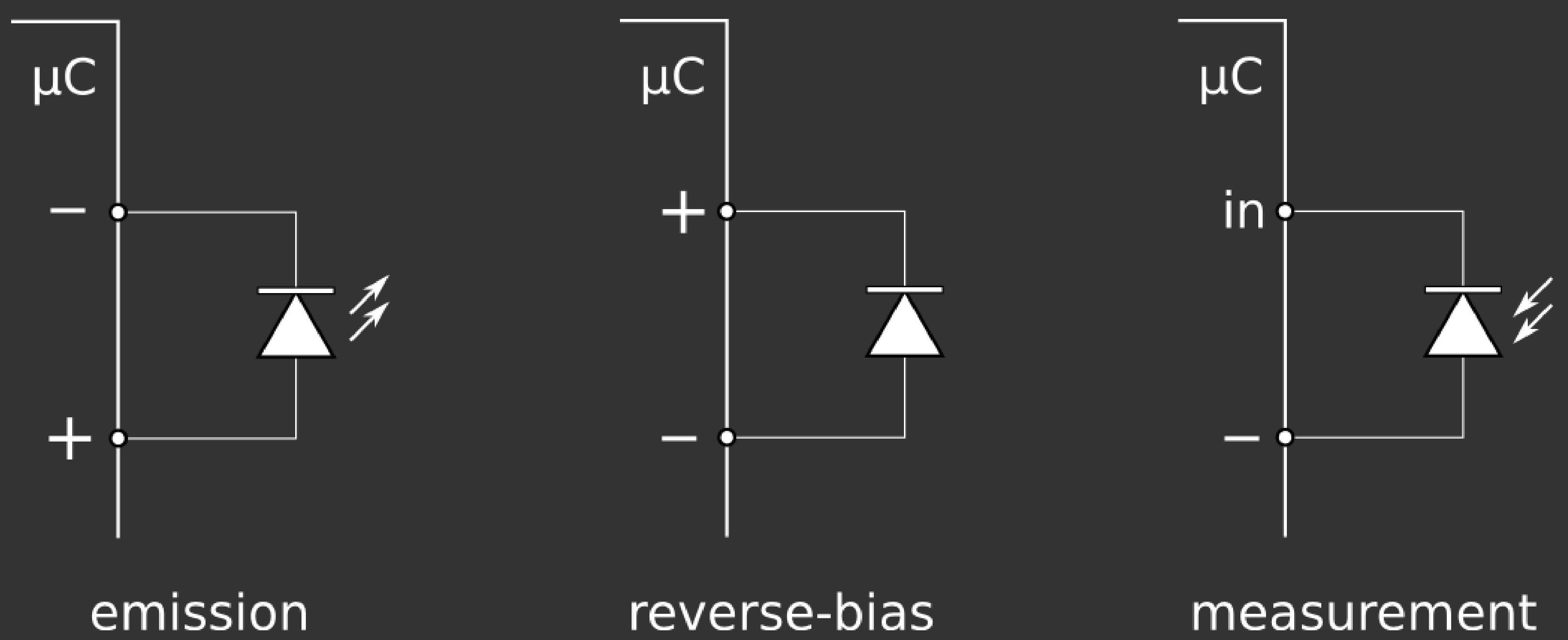
- why bother?
- LEDs are cheap and small, can be put in a lot of places
- e.g. behind LCD screens (compare ThinSight)

- every LED is also a (really bad) photodiode
- incoming light generates a (very small) photocurrent

Using LEDs as Sensors

Implementation: quick-and-dirty

- connect both LED terminals to microcontroller I/O pins
- enables 3 different modes of operation:
  - emitting (normal operation)
  - reverse-bias (charge)
  - sensing (discharge)



Using LEDs as Sensors

Implementation: quick-and-dirty

- assuming an LED matrix:
- use some LEDs as emitters
- use neighboring LEDs as sensors

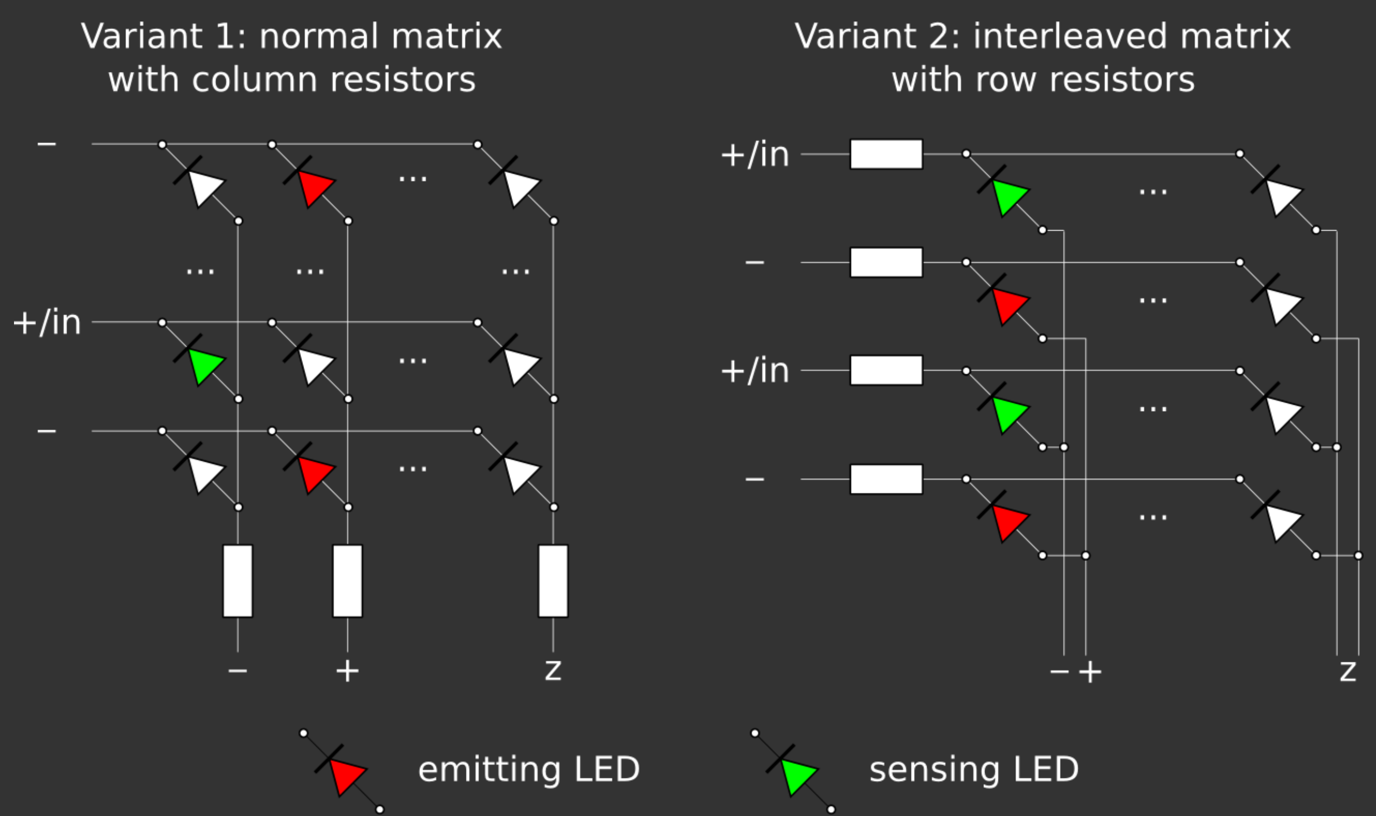
- Step 1: enable emitters
- Step 2: reverse-bias sensors
- Step 3: switch to measurement
- Step 4: measure delay until input reads as 0

- more reflected light -> faster decay of charge
- imprecise due to LED variations, external noise
- delay may be significant -> low update rate

Using LEDs as Sensors

Implementation: sophisticated

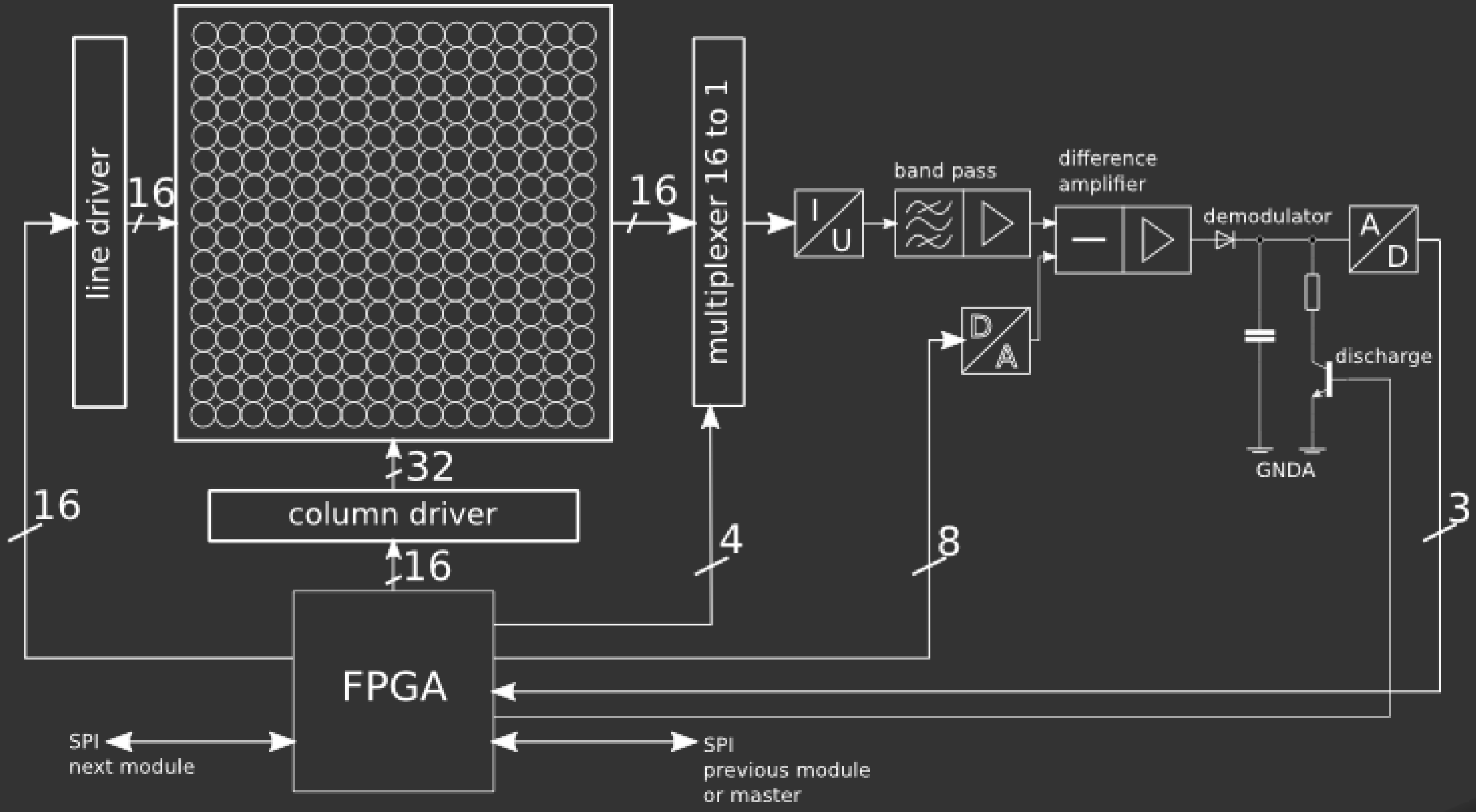
- basic concept by Thomas Pototschnig
- central difference: interleaved LED matrix
- avoids cross-talk between emitters & sensors
- drawback: no commercial matrices available



Using LEDs as Sensors

Implementation: sophisticated

- additional „tricks“:
  - modulate emitted light at 10 kHz, filter with band pass
  - use base intensity from LED as calibration, feed into difference amplifier



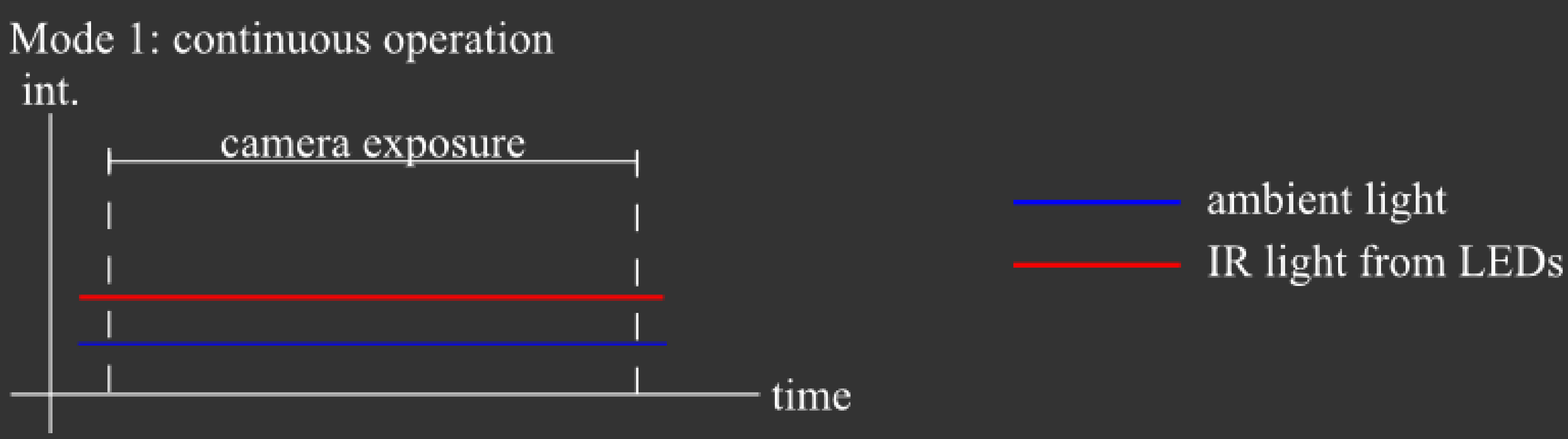
Using LEDs as Sensors

Implementation: sophisticated

Video

Pulsed Light
a.k.a. Synchronized Illumination

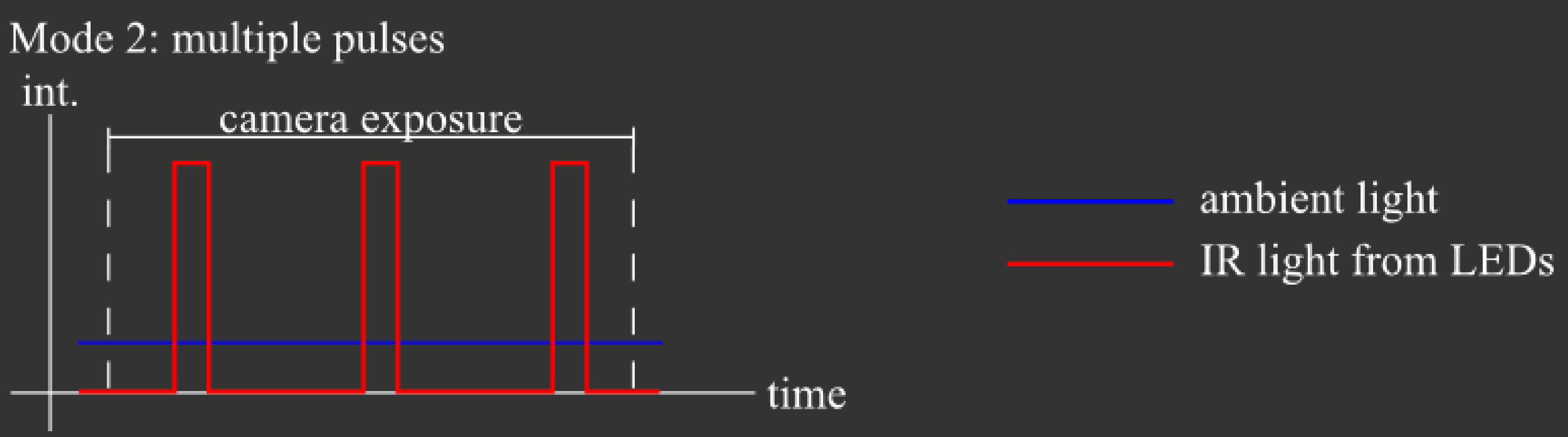
- problems common to many FTIR & DI setups:
  - susceptible to stray light
  - low sensibility to light touch (esp. FTIR)
  - generally: low signal-to-noise ratio
- => goal: increase SNR



Pulsed Light

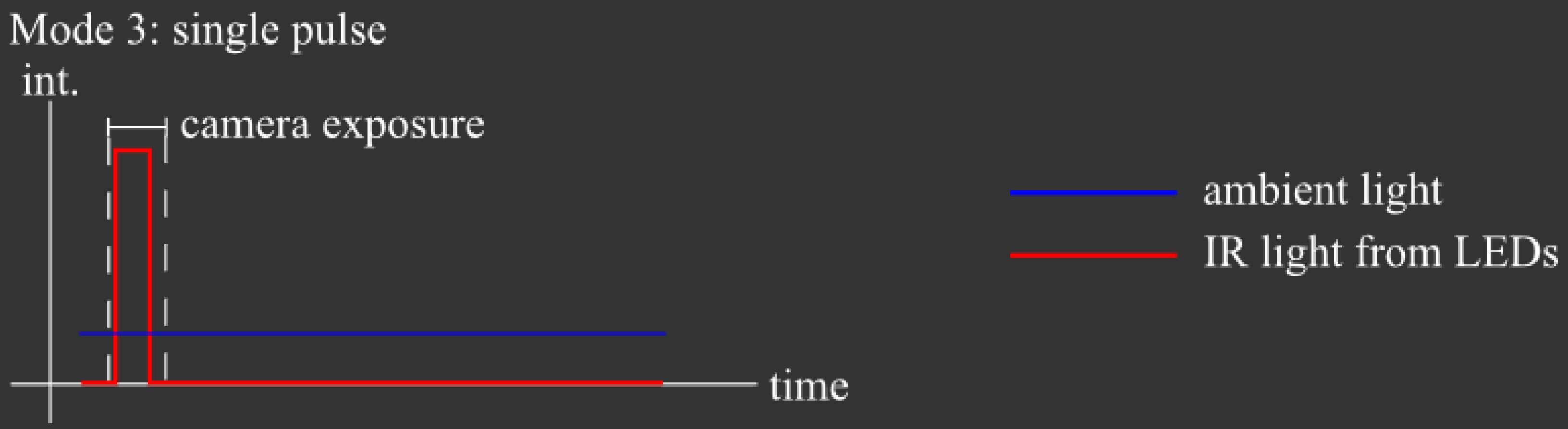
a.k.a. Synchronized Illumination

- LEDs can be *pulsed*
- rule of thumb: 10x current for 5% of time (depends on exact type of LED)
- problem: ambient light still active in cool-off period
- camera sensor integrates all light during exposure time
- -> no significant gains relative to continuous method



Pulsed Light
a.k.a. Synchronized Illumination

- Solution: reduce exposure time to single pulse
- LED is brighter by approx. one order of magnitude
- global brightness decreases due to shorter exposure
- but: vast increase in signal-to-noise ratio



Pulsed Light
Implementation

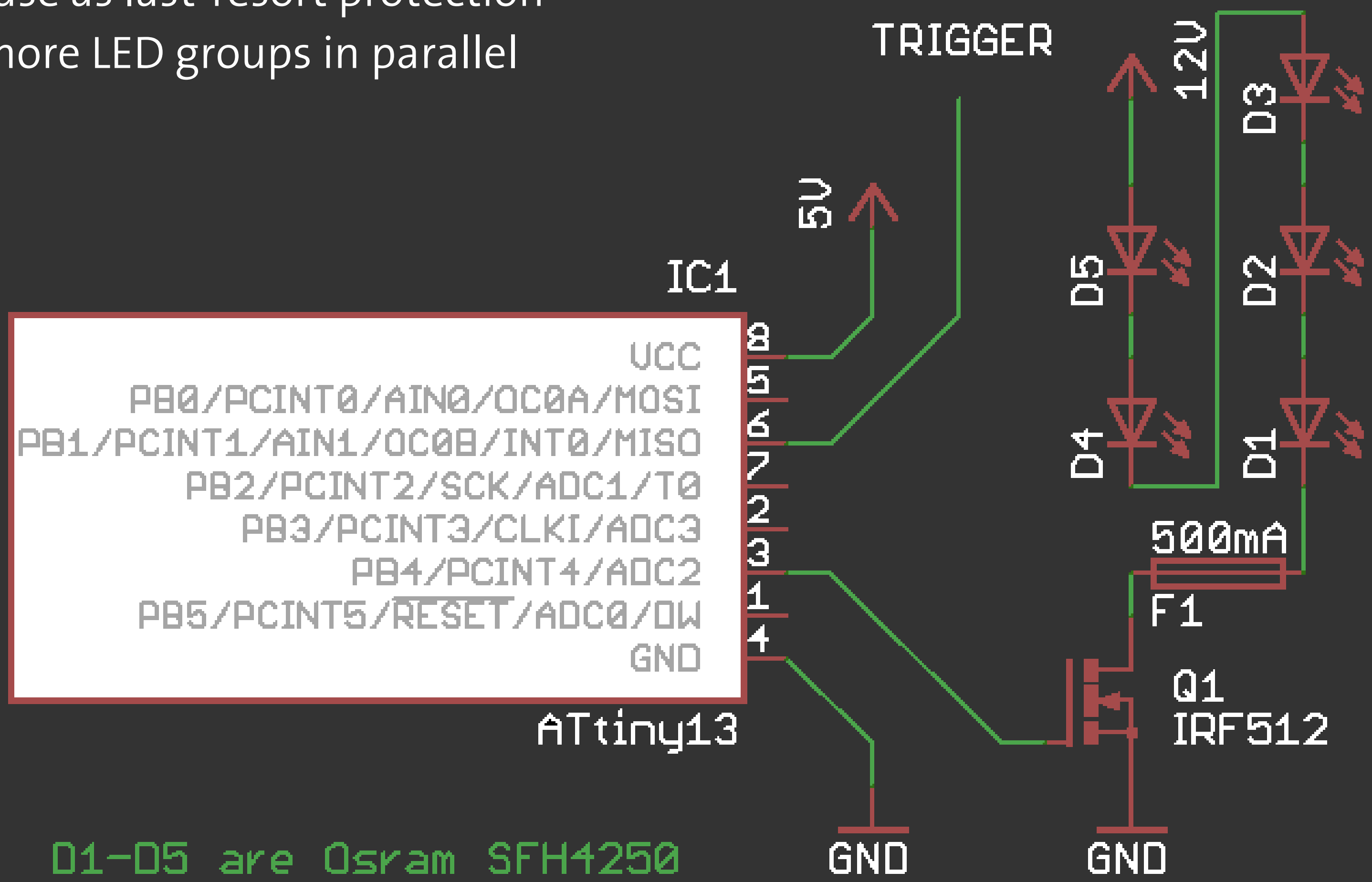
- required camera features:
  - fine-grained exposure control (< 500 µs)
  - trigger input or output
  - global shutter
- rules out cheap webcams
- example for suitable camera: Firefly MV (~300 $)

- also required: power switching circuit
- recommended safety features: microcontroller & polyfuse

Pulsed Light

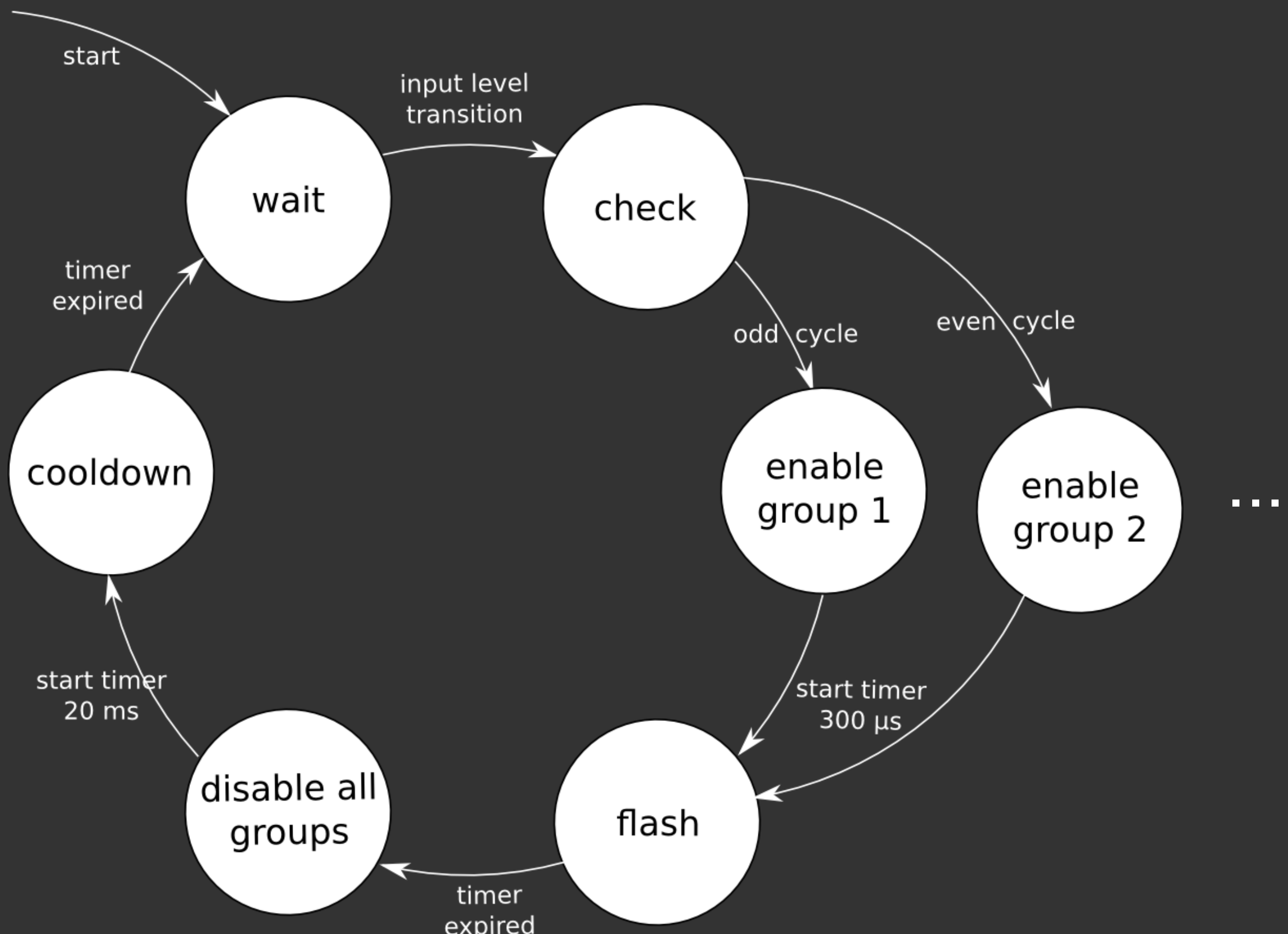
Implementation

- circuit example:
  - microcontroller to check timing
  - polyfuse as last-resort protection
  - add more LED groups in parallel



Pulsed Light
Implementation

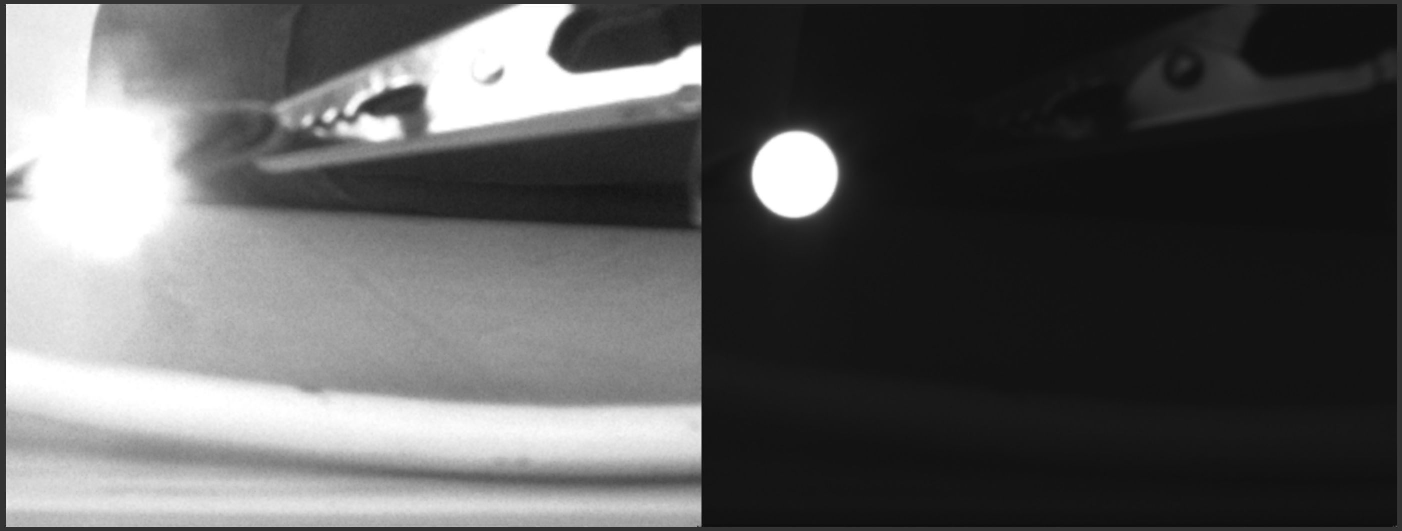
- microcontroller state machine
- enables more complex setups, e.g. multiple light sources



Pulsed Light
Results

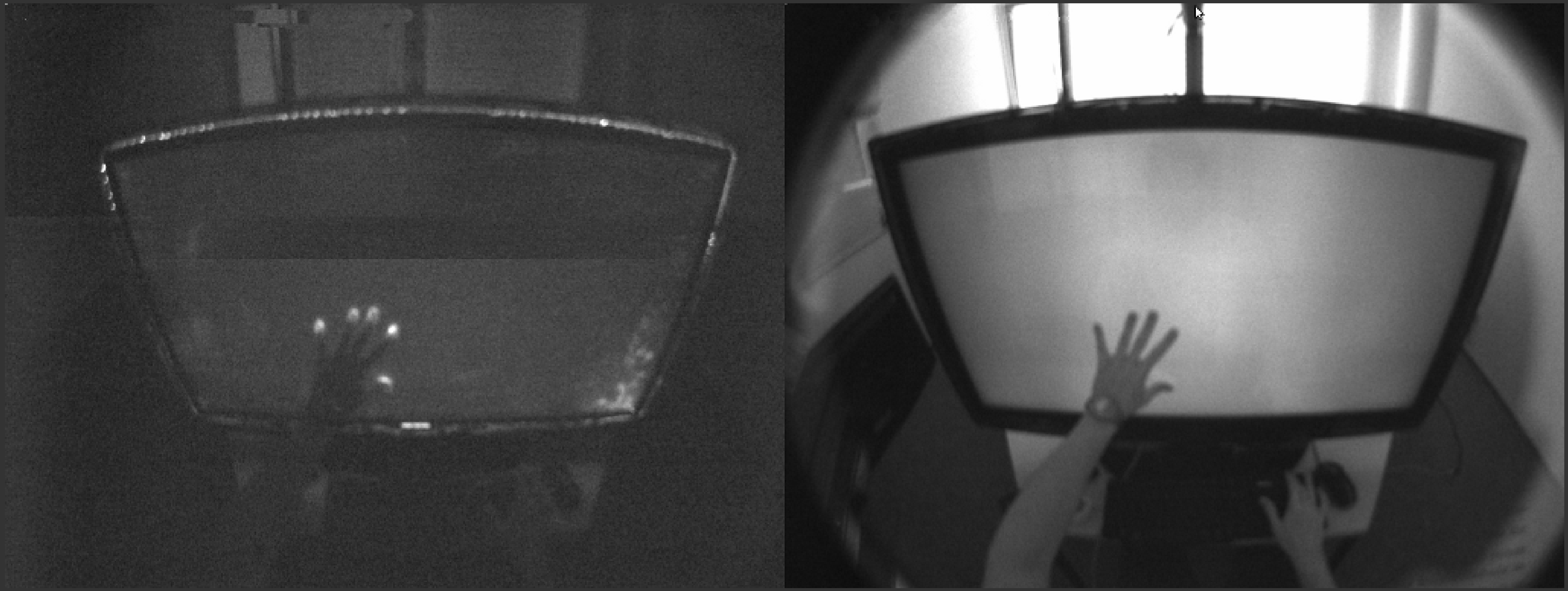
- single IR LED, viewed head-on – 8-bit grayscale image
- left image: mode 1 (constant light)
- right image: mode 3 (pulsed & synchronized)

- LED intensity: 255 in both images, background intensity:
  - left image: ~ 160
  - right image: ~ 20
- contrast increase by factor 8



Pulsed Light
Results

- real-world example:
- Inverted FTIR setup
- very low SNR
- still usable thanks to synchronized illumination



Thank you for your attention!

Questions & comments?