3D Reconstruction/ Depth Sensing

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Outline

- Structure from Motion
  - Use slides from SFMedu
  - http://3dvision.princeton.edu/courses/SFMedu/
- Large Scale Reconstruction
- Depth Sensing

Large Scale Reconstruction

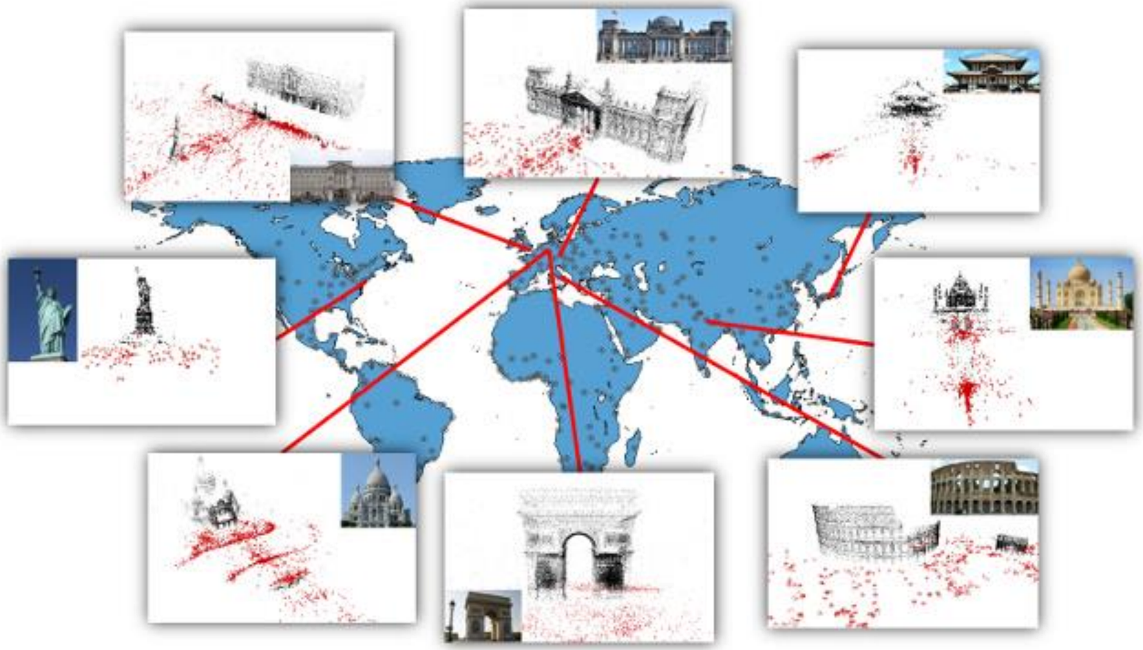
- Building Rome in a Day [ICCV 2009]
  - https://grail.cs.washington.edu/rome/

Large Scale Reconstruction

- Building Rome on a Cloudless Day [ECCV 2010]
  - https://www.youtube.com/watch?v=4cEQZreQ2zQ

Large Scale Reconstruction

- Reconstructing the World* in Six Days [CVPR 2015]
  - As captured by the Yahoo 100 million image dataset
  - http://www.cs.unc.edu/~jheinly/reconstructing_the_world.html
  - https://youtu.be/bRYqyoqUJuM



Depth Sensing with 3D Cameras

Range Acquisition Taxonomy -- Optical Methods

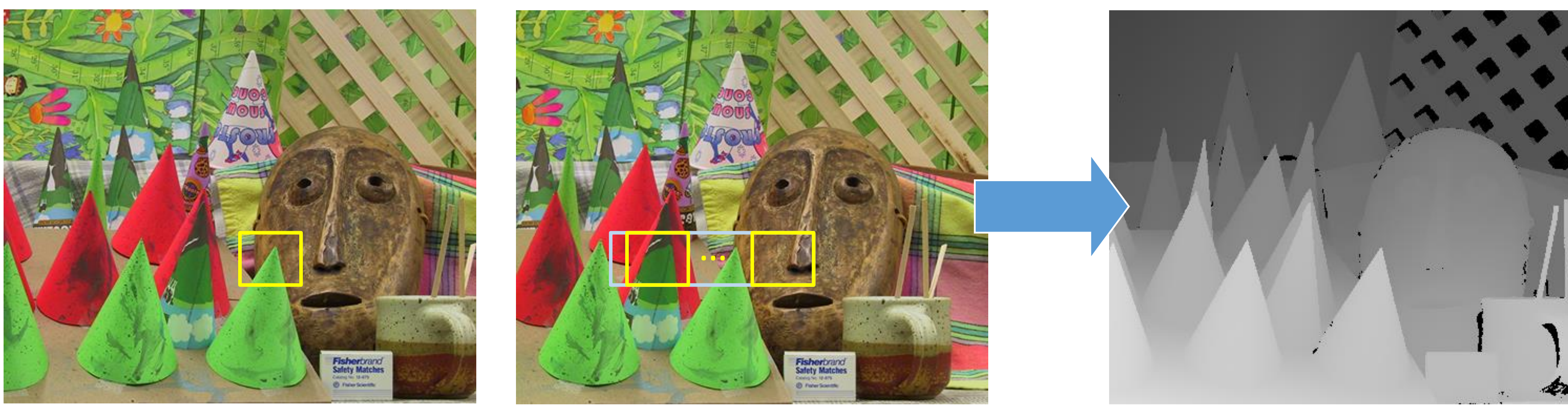
- optical methods
  - 2D-to-3D Conversion
    - depth from X:
      - focus
      - motion
      - color/texture/shading
      - geometry
    - Structure from motion
    - Depth Fusion
  - Active sensor
    - time of flight – Sharp Infra-red sensor
  - Passive sensor
    - Stereo/Multi-view triangulation
    - Light Field Cameras
    - Active+Passive Fusion

Acquisition (Off-the-shelf Products)

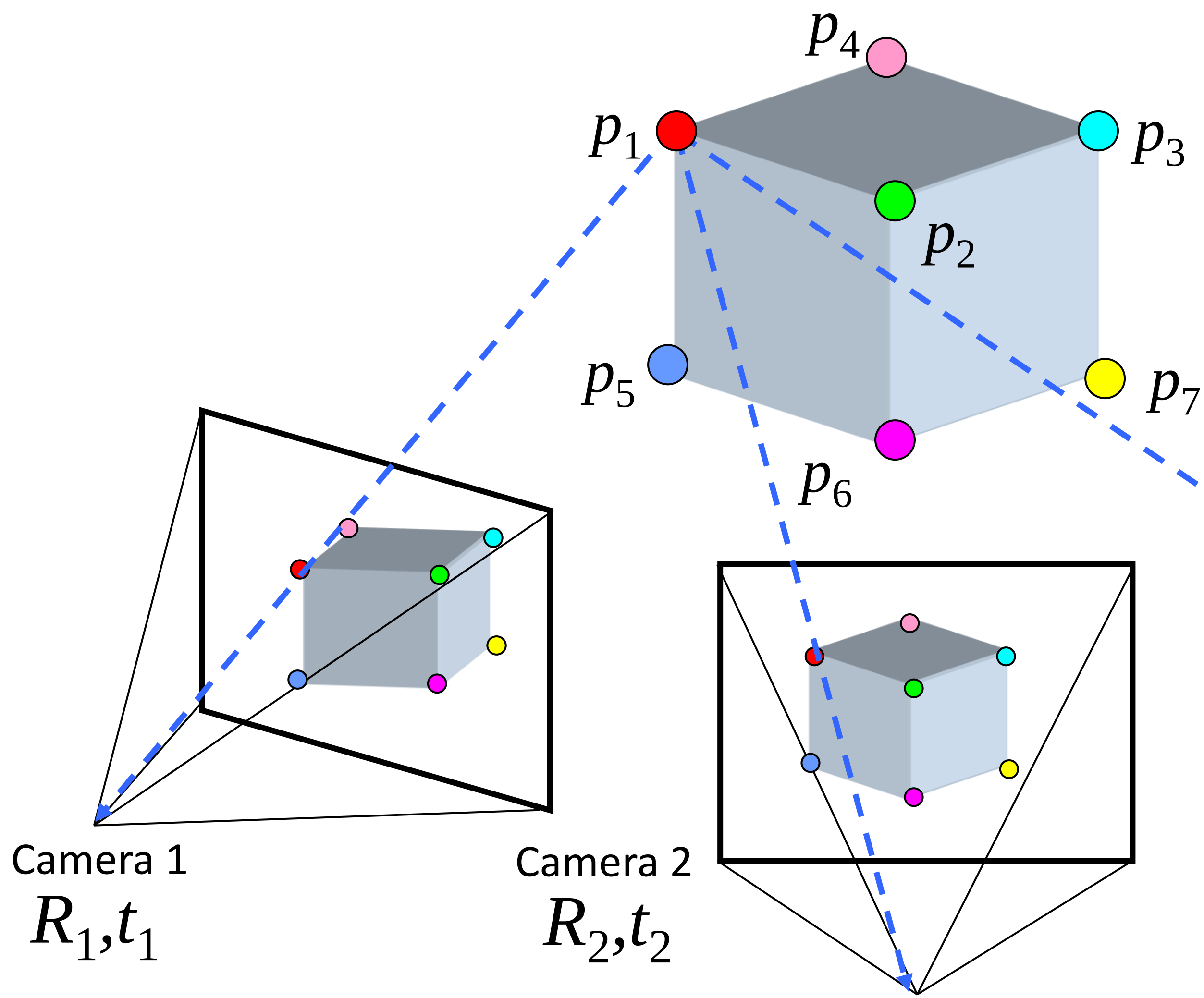
- Shape from stereo (Stereo Vision)
  - Leap Motion
- Structured light (Light coding)
  - Kinect
  - PrimeSense CARMINE 1.08 / 1.09 and Capri 1.25
  - Occipital Structure Sensor
  - Google Project Tango
  - Intel RealSense
  - Apple FaceID
- Time of flight
  - Kinect 2
  - SoftKinetic (acquired by Sony)

Shape from Stereo

- Two (or more) cameras concurrently capture the same scene
  - Find correspondence between stereo images



Shape from Stereo



minimize

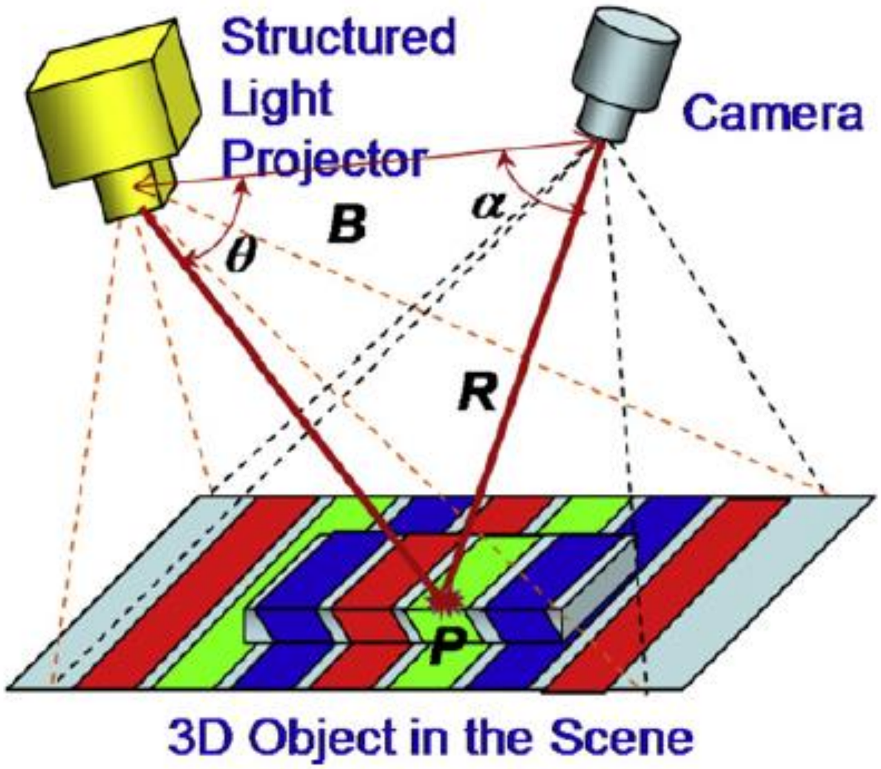
$$f\,(\mathbf{R}, \mathbf{T}, \mathbf{P})$$

Shape from Stereo

- Problems
  - The identification of common points within the image pairs, the solution of the well-known correspondence problem
  - The quality depends on the sharpness of the surface texture (affected by variation in surface reflectance)

Structured Light

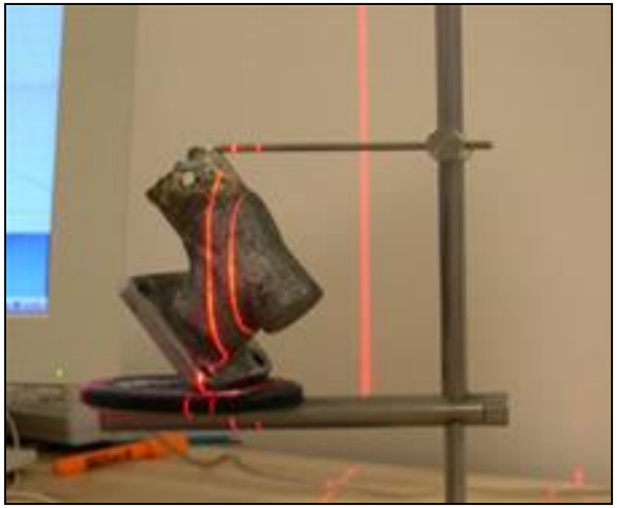
- Tri-angulation principle

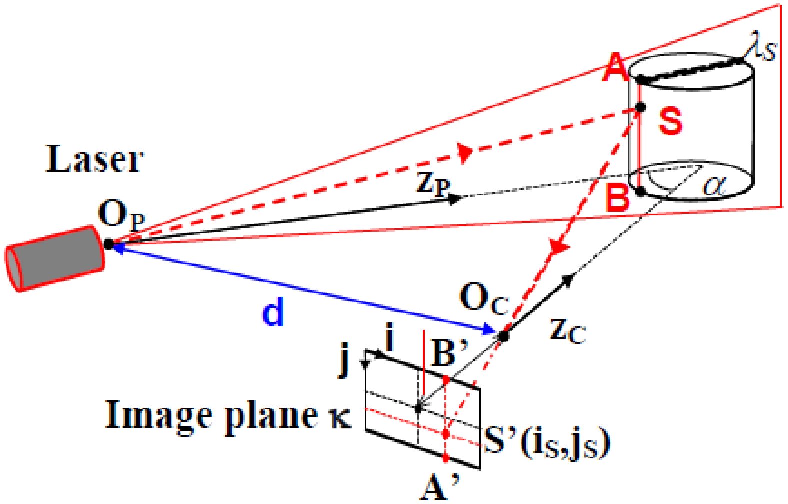


$$R = B\frac{\sin\theta}{\sin(\alpha+\theta)}$$

Structured Light

- Two types
  - Single-point triangulators
  - Laser stripes
- All based on the active triangulation principle





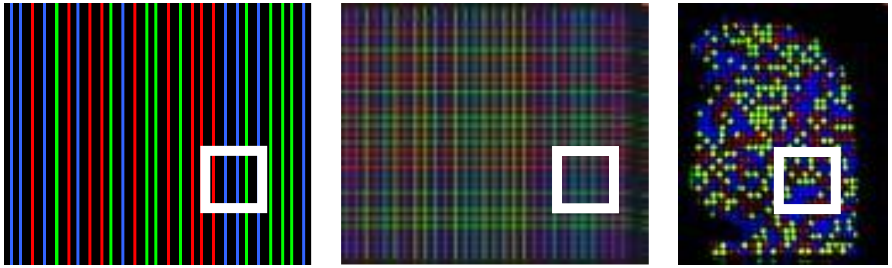
Structured Light

- Active triangulations
  - Active version of shape from stereo
- Project a spatially- and/or temporally-encoded image sequence using projector

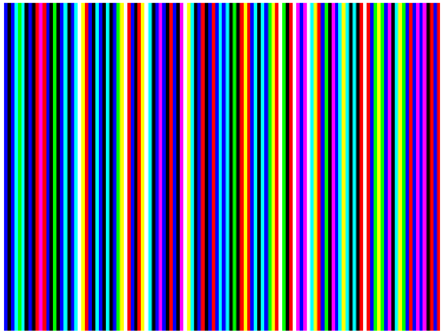
Douglas Lanman and Gabriel Taubin, "Build your own 3D scanner: Optical triangulation for beginners," Siggraph 2009 and Siggraph Asia 2009 courses. http://mesh.brown.edu/byo3d/index.html

Structured Light

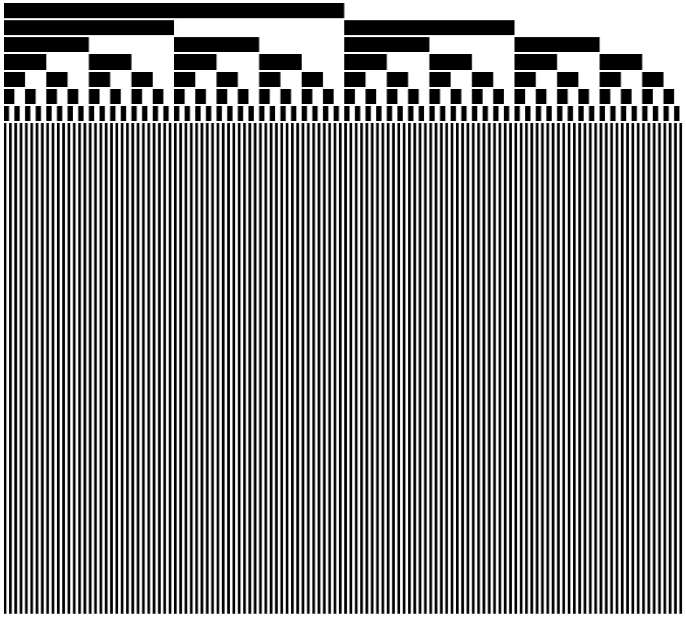
- Examples of projected patterns



Single-shot patterns (N-arrays, grids, random, etc.)



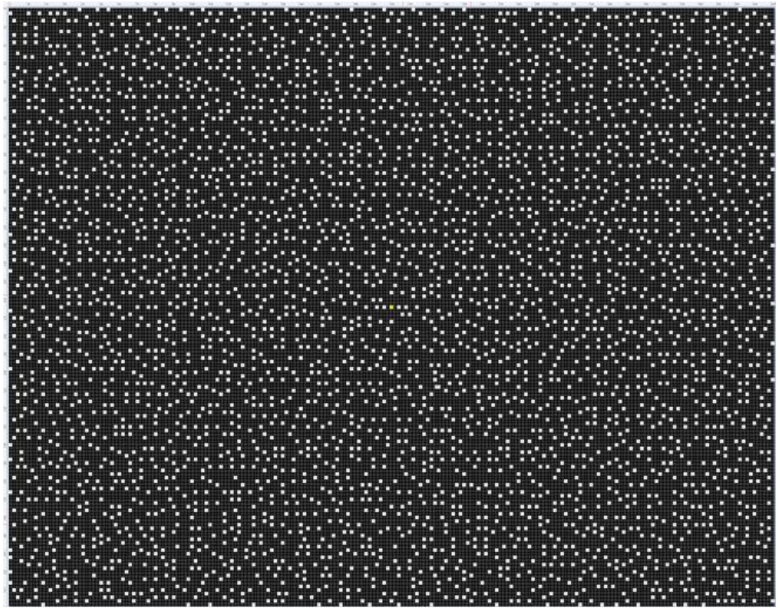
De Bruijn Sequence

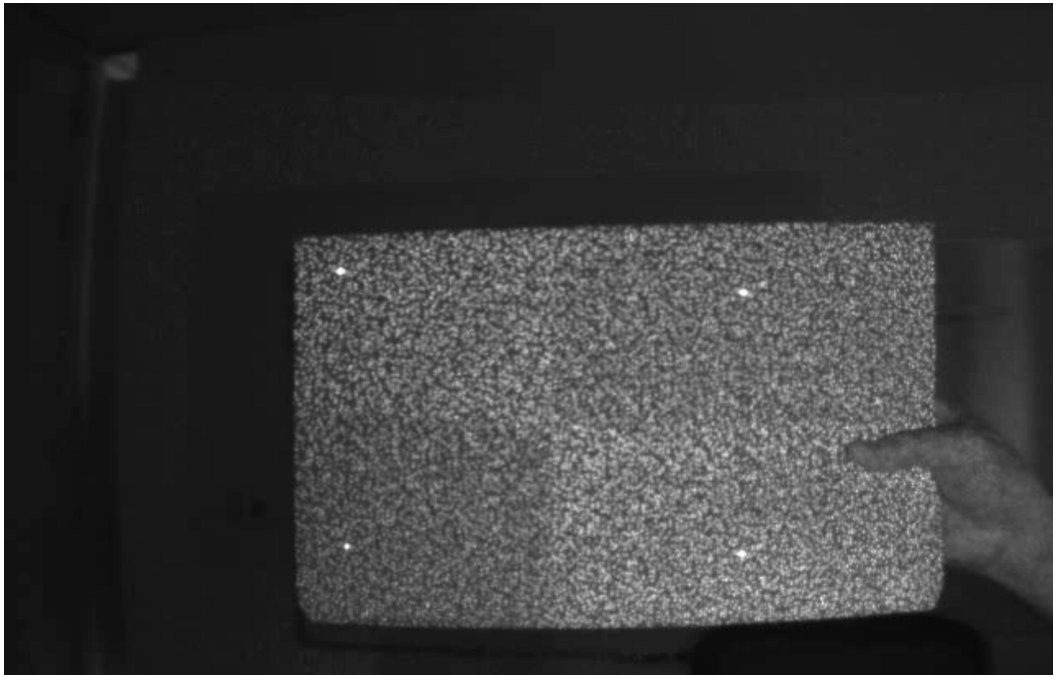


Binary Codes

Structured Light

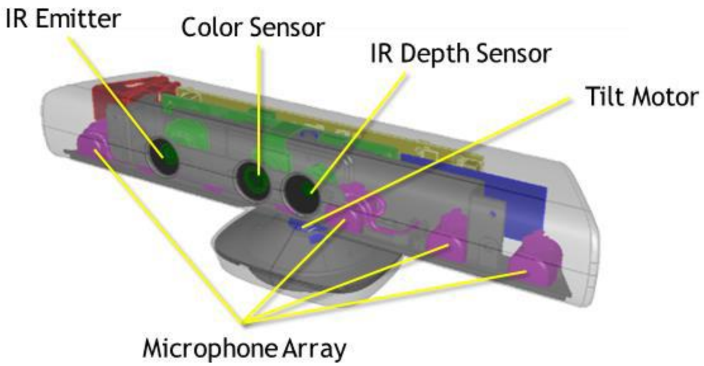
- Kinect projected pattern
  - https://www.youtube.com/watch?v=uq9SEJxZiUg





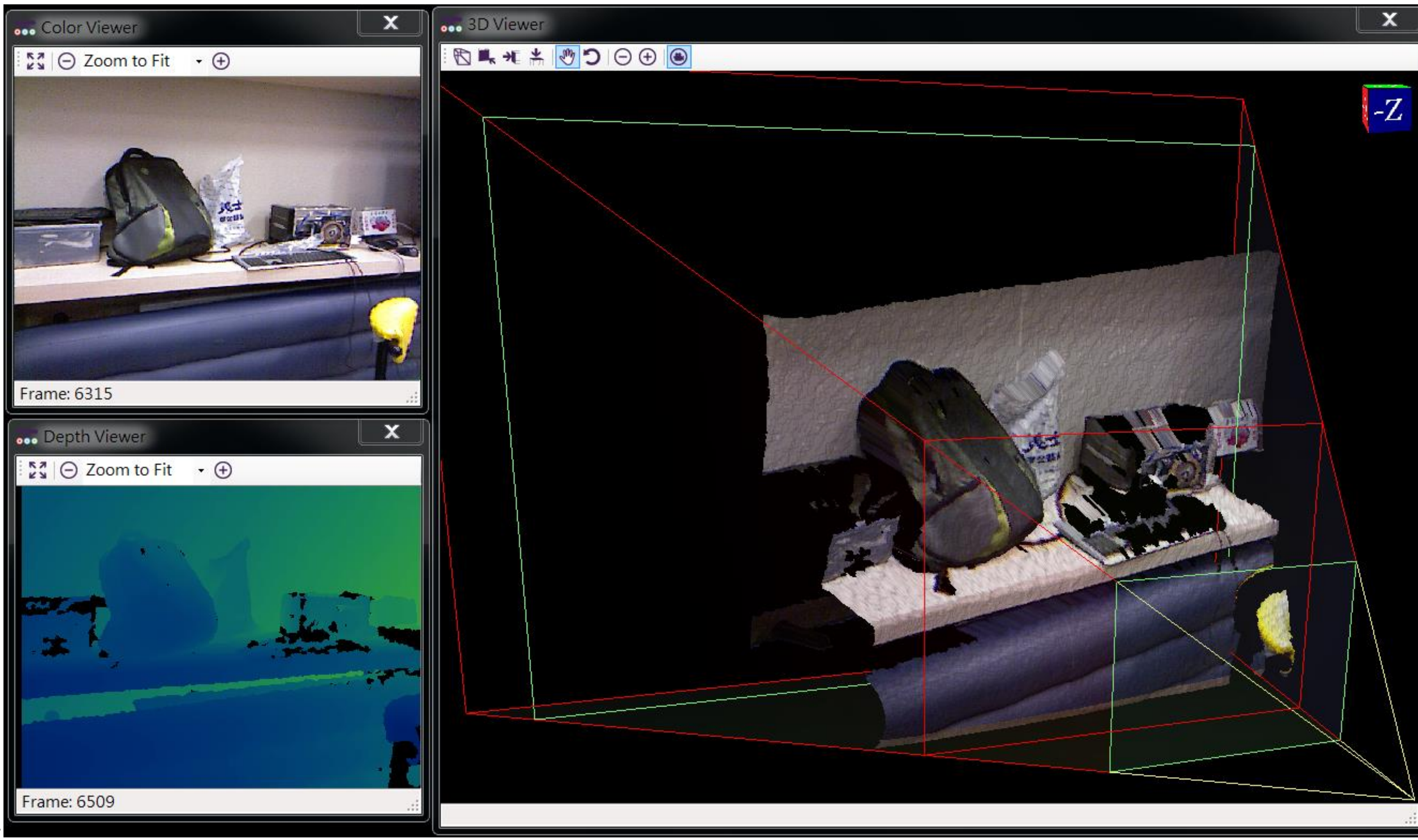
Kinect

- Distance: 0.8-4m
- Near mode: 0.4-3m (Kinect for Windows)
- FOV：57°H、43°V
- RGB: 1280x960@12FPS / 640x480@30FPS / 640x480@15FPS
- Depth: 640x480 / 320x240 / 80x60 (30FPS)



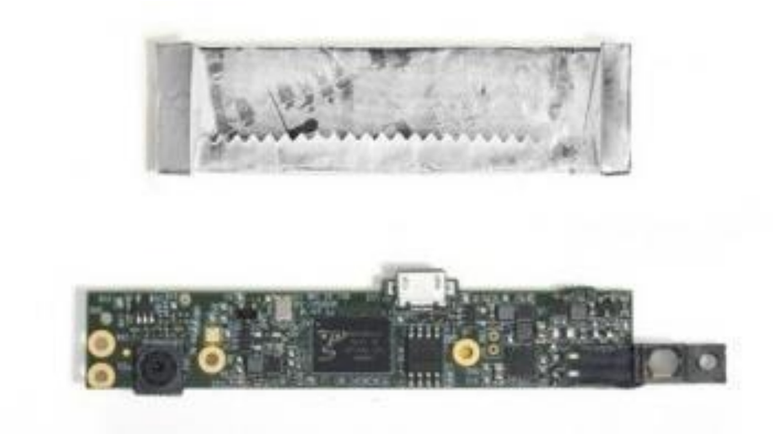
Kinect: RGB + Depth + Point Cloud

- Point cloud from Kinect



Primesense Capri 1.25

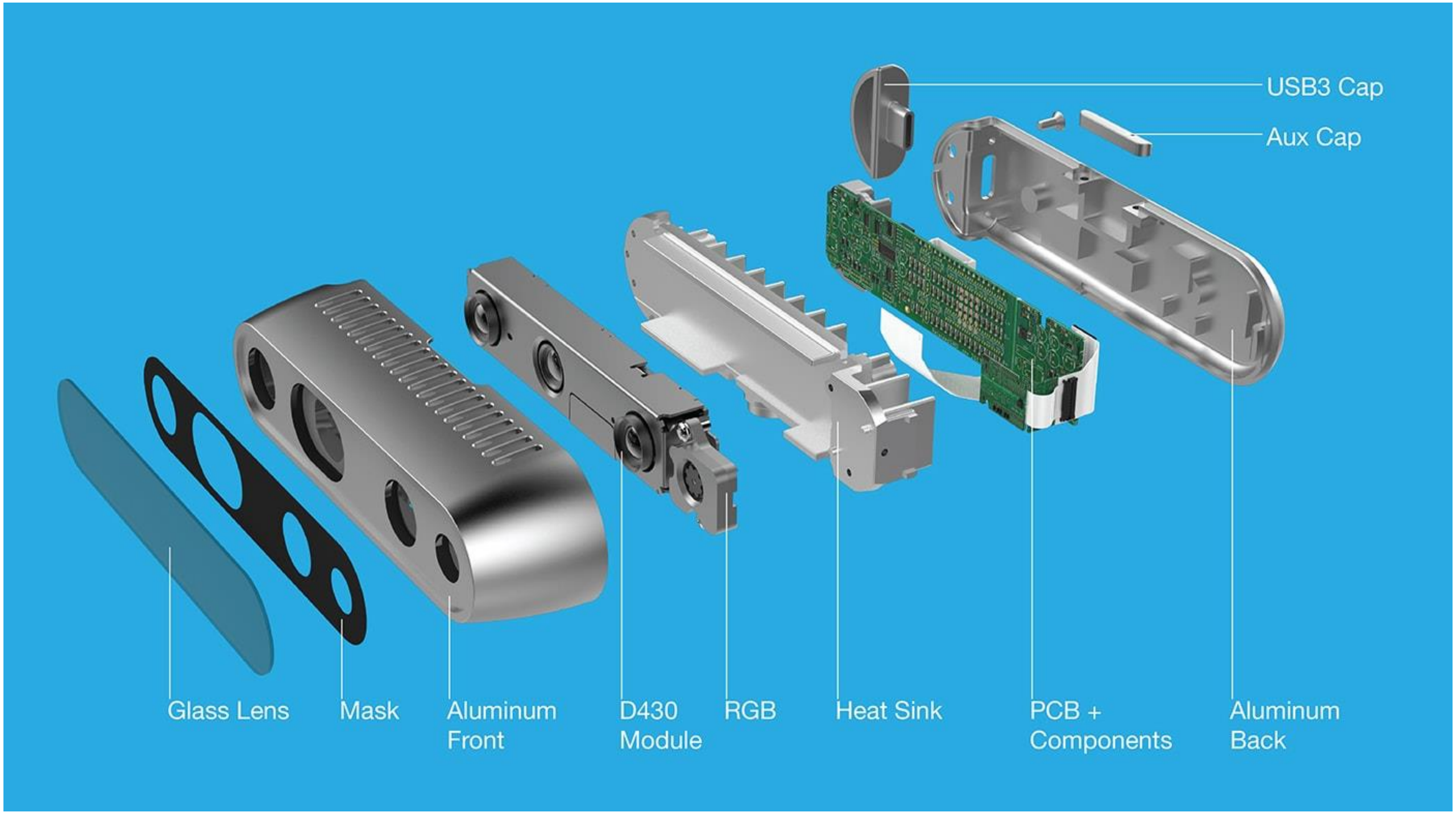
- The smallest 3D sensor right now
- For embedded system



Google Project Tango

- https://www.google.com/atap/projecttango/
  - https://www.youtube.com/watch?v=Qe10ExwzCqk
- PrimeSense PSX1200 Capri PS1200 3D sensor SoC
- With InvenSense MPU-9150 motion tracking device
- Depth: 320×180@5FPS (?)
- RGB: a 4MP rear-facing RGB/IR camera, a 180° field of view rear-facing fisheye camera

Intel RealSense

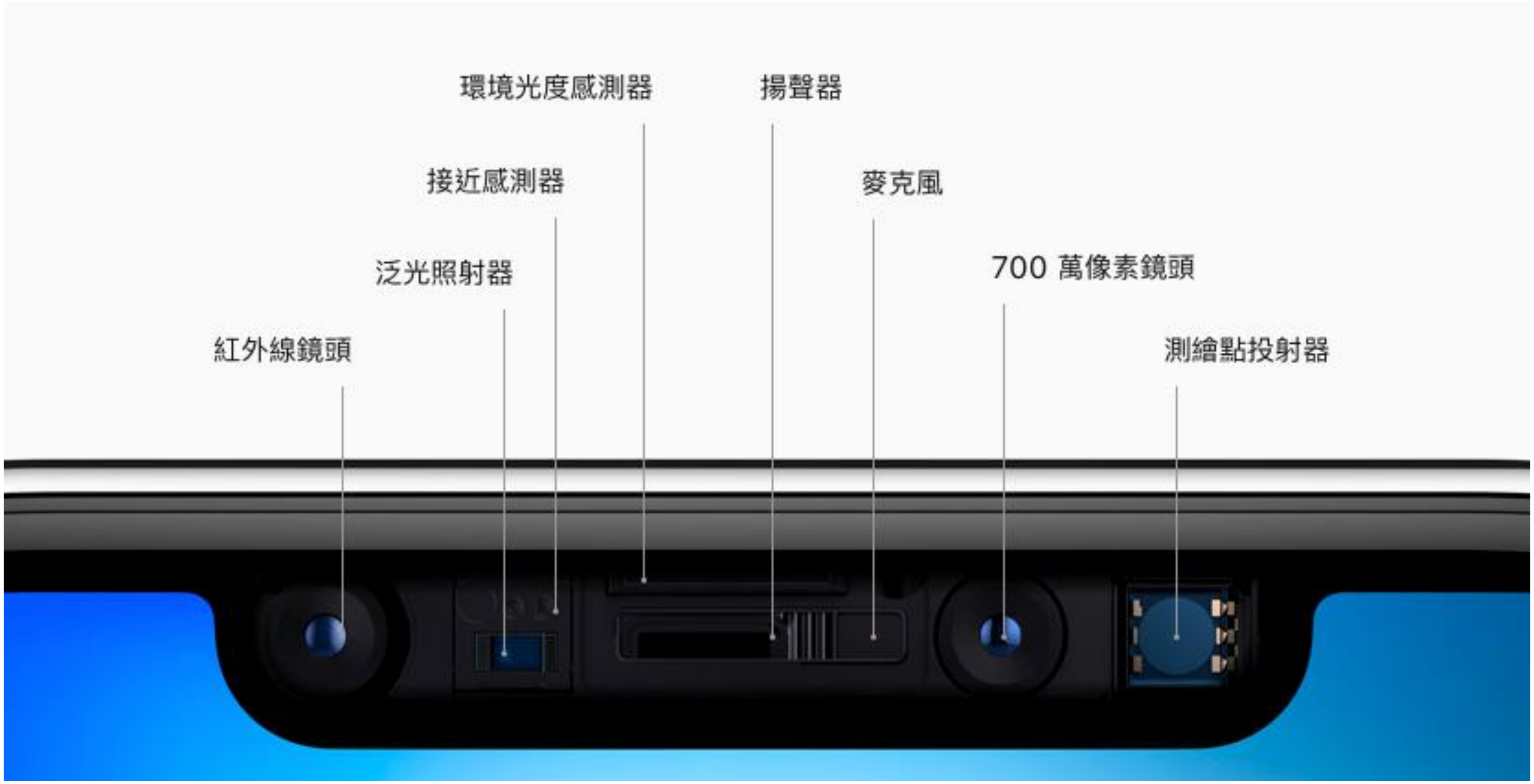


[Intel]

Intel RealSense: D435i

- Intel RealSense Module D430 + RGB CameraVision
- DepthDepth Technology: Active IR Stereo
- Minimum Depth Distance (Min-Z): 0.105 m
- Depth Output Resolution & Frame Rate: Up to 1280 x 720 active stereo depth resolution. Up to 90 fps.
- RGB Sensor Resolution: 1920 x 1080
- Processor: Intel RealSense Vision Processor D4

Apple FaceID



[Apple]

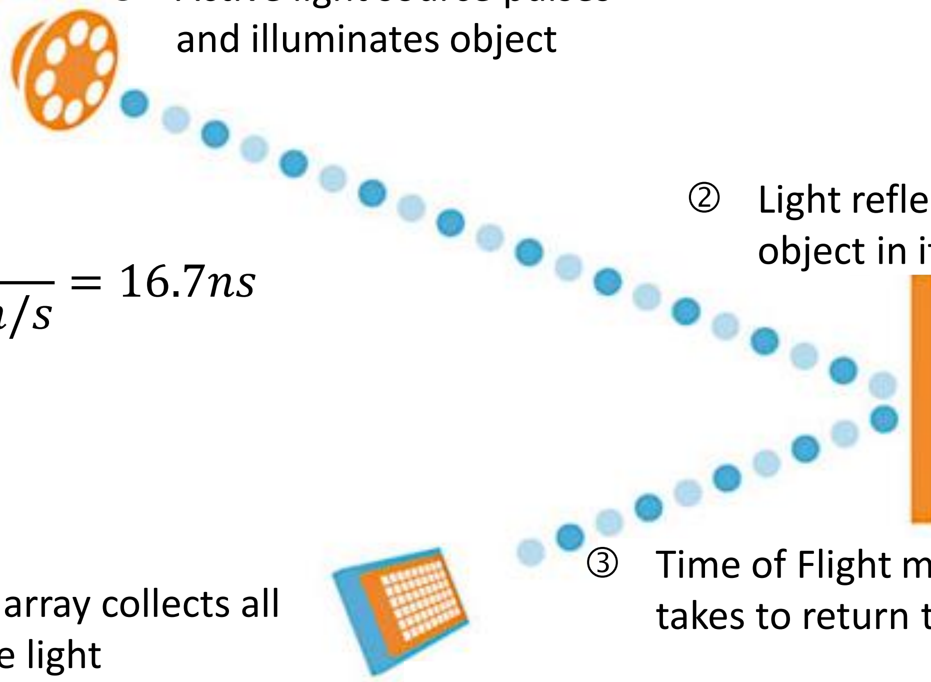
Apple FaceID

Time of Flight

① Active light source pulses and illuminates object

② Light reflects off of any object in its Field of View

$$t = \frac{2d}{c} = \frac{5.0m}{3 \times 10^8 m/s} = 16.7ns$$



③ Time of Flight measures the time it takes to return to the receiver

④ Pixel array collects all active light

Time of Flight

- The emitter unit generates a laser pulse
  - A receiver detects the reflected pulse, and suitable electronics measures the roundtrip travel time of the returning signal and its intensity
- The measurement resolutions vary with the range
  - Large measuring range, it gives excellent results
  - Not suitable for small objects
    - Requires very high speed timing circuitry

Kinect 2

- https://www.youtube.com/watch?v=Hi5kMNfgDS4
  - 3 times the fidelity over Kinect
  - 3DV Systems & Canesta (bought by MS in 2009)
  - Closer IR sensor and illuminator: Less shadow in depth image
- Distance: 0.5-4.5m
- FOV：70°H、60°V
- RGB: 1920x1080@30FPS
- Depth: 512x424@30FPS