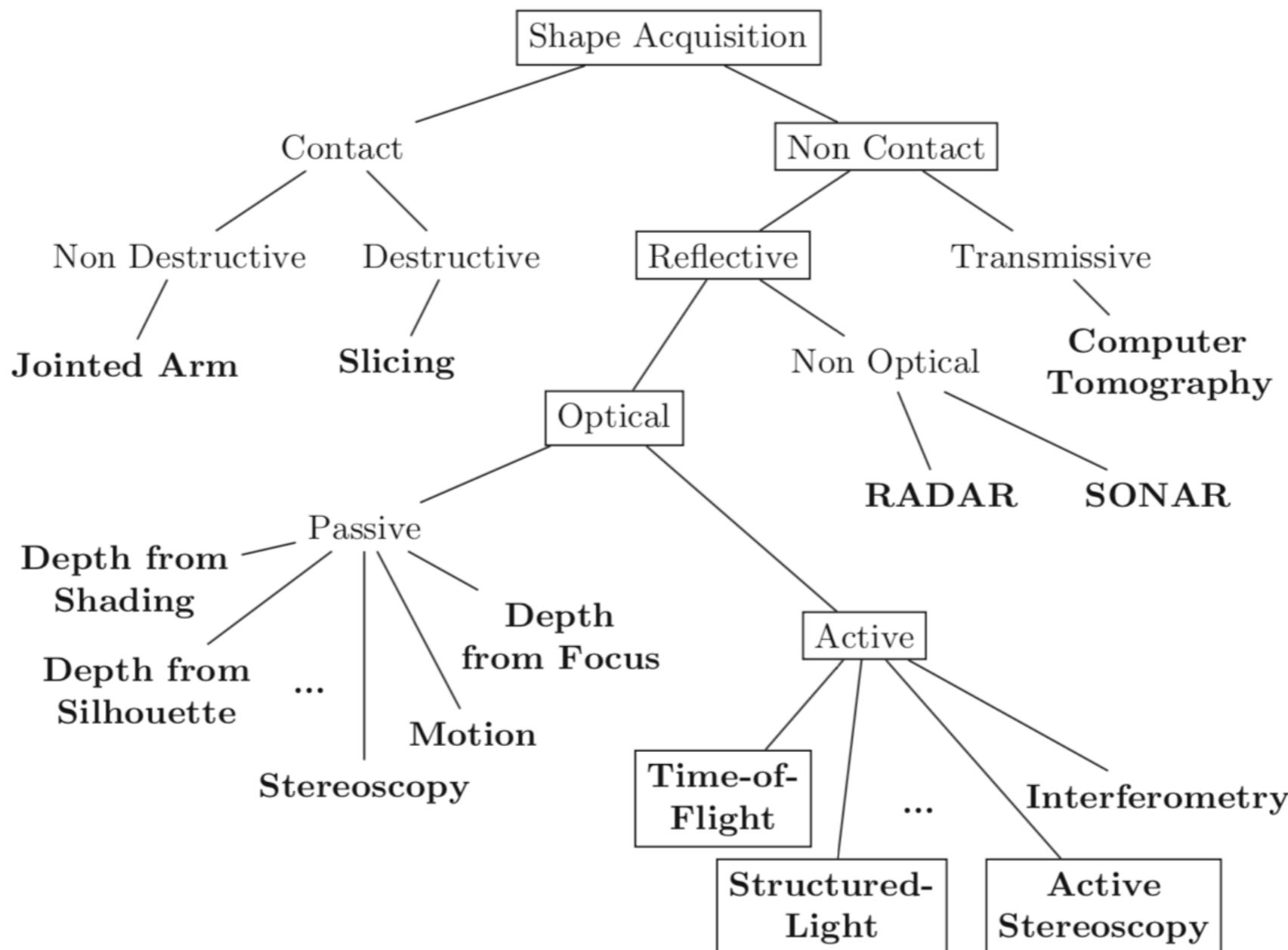


# 3D Camera Introduction

Jiandong Huang  
Dec, 2019

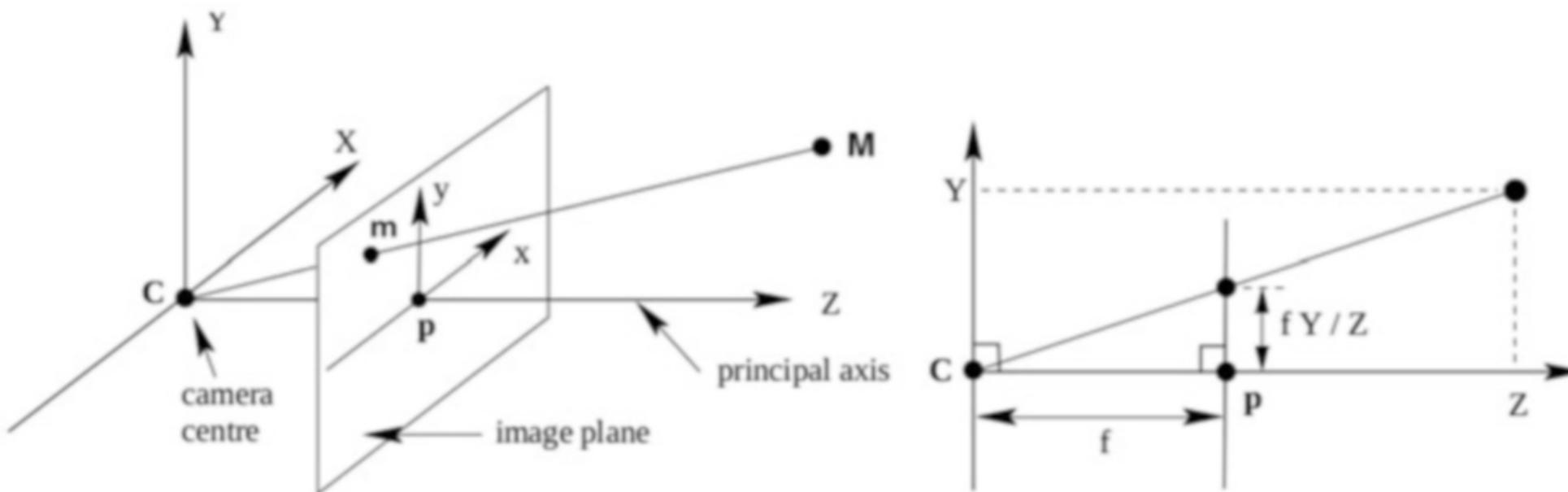
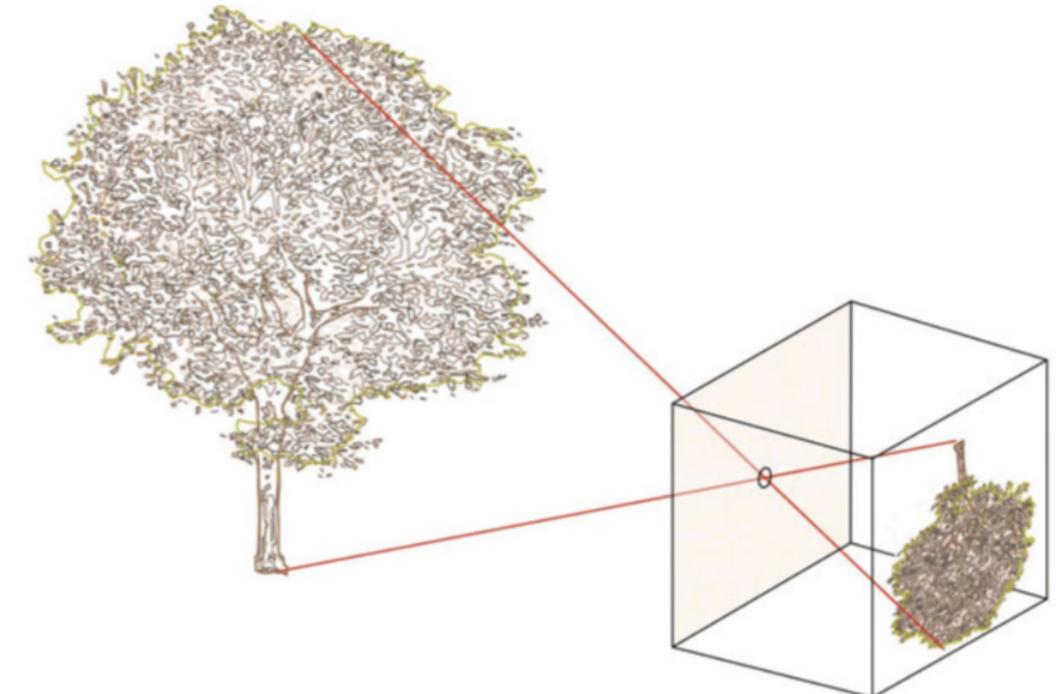
# Intuition

- Traditional Camera: lack of geometrical information (depth estimation)
- Taxonomy for 3D reconstruction techniques



# The theoretical foundation

- Camera model:
- Pinhole model



**Fig. 2.3** *Left:* Frontal pinhole camera representation. *Right:* Trigonometrical representation

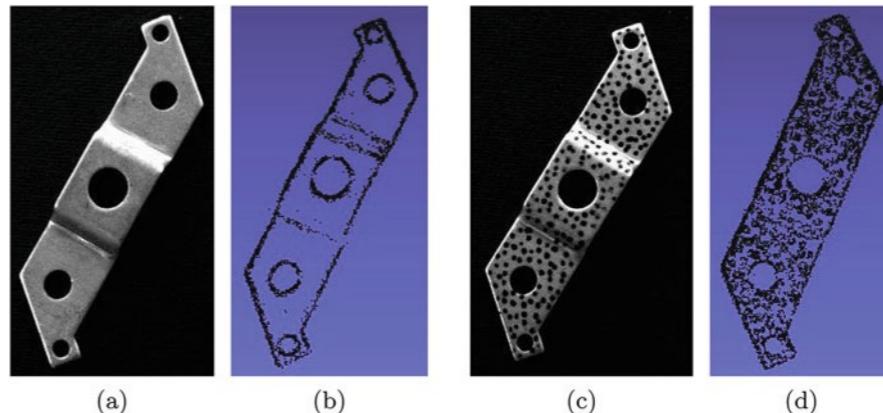
- Light –(camera)–>photo-diodes, ccd, cmos –(photo-voltaic effect)–>electric signal –(sampled to 8 or 24 bits)–>digital images

## Dense Stereoscopy

Finds homologous keypoints to triangulate by detecting features and matching them coherently.

1. Feature-based matching
2. Correlation-based matching

## Active Stereoscopy



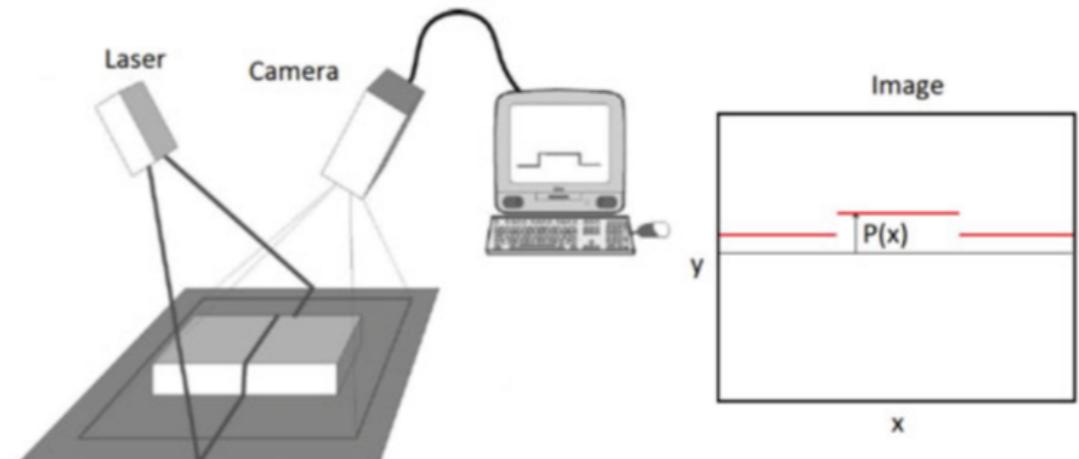
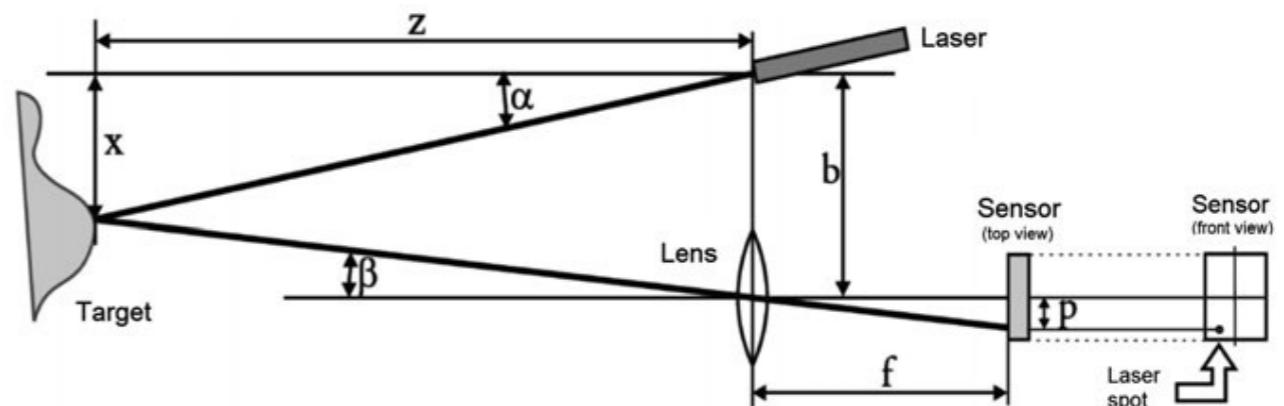
## Structured-Light

- single camera + a laser projector.
- projects a codified pattern

$$z = \frac{b}{\tan(\alpha) + \tan(\beta)}$$

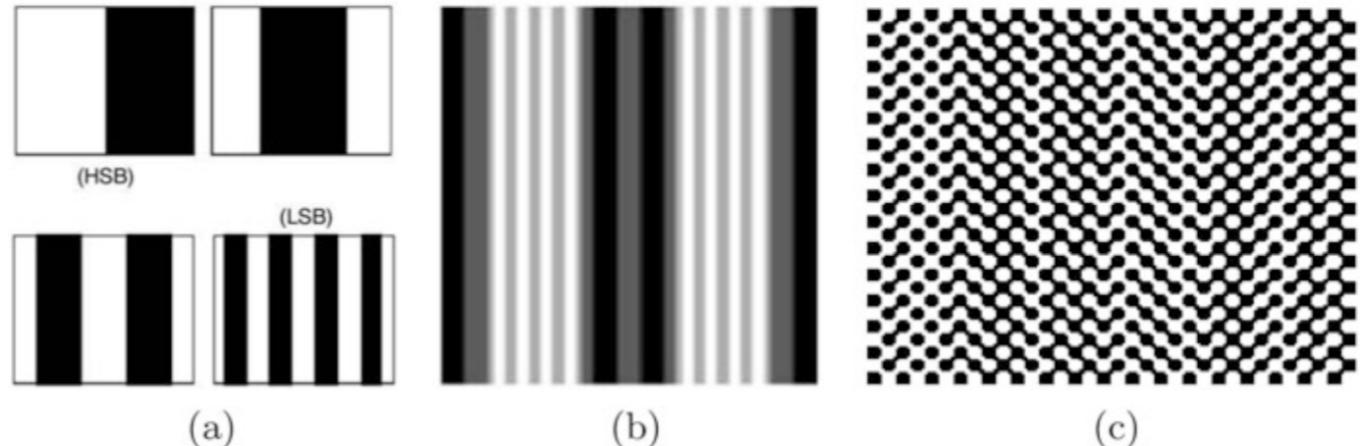
$$x = z \cdot \tan(\alpha)$$

- can be extend in a laser blade setting



## Structured-Light

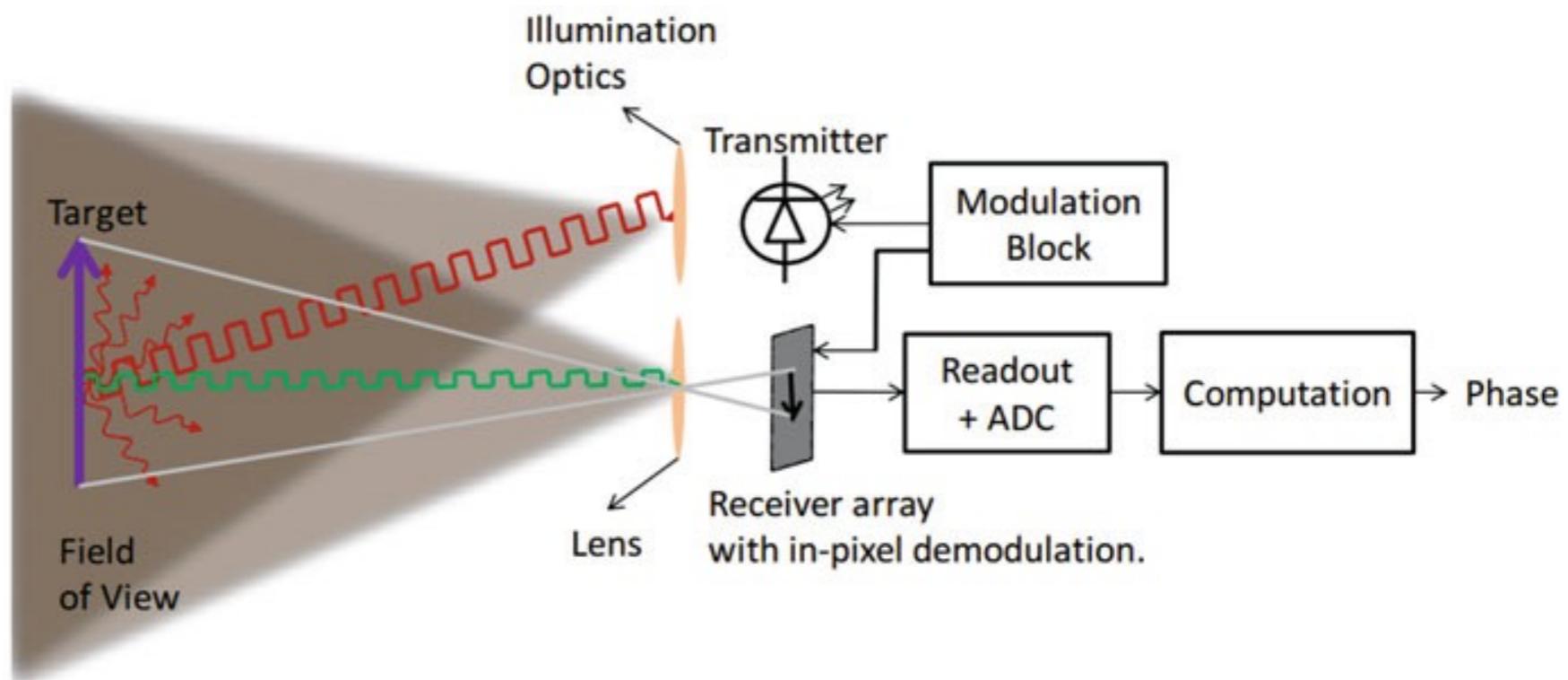
- Also project 2D pattern: time-coded, color-coded or spatially-coded
- (a) Time-Multiplexing
- (b) Direct coding
- (c) Spatial Neighborhood or Speckle Structured



## Depth by Time-of-Flight

- IR or Near Infra-Red (NIR) light

$$d = \frac{c * \Delta t}{2}$$

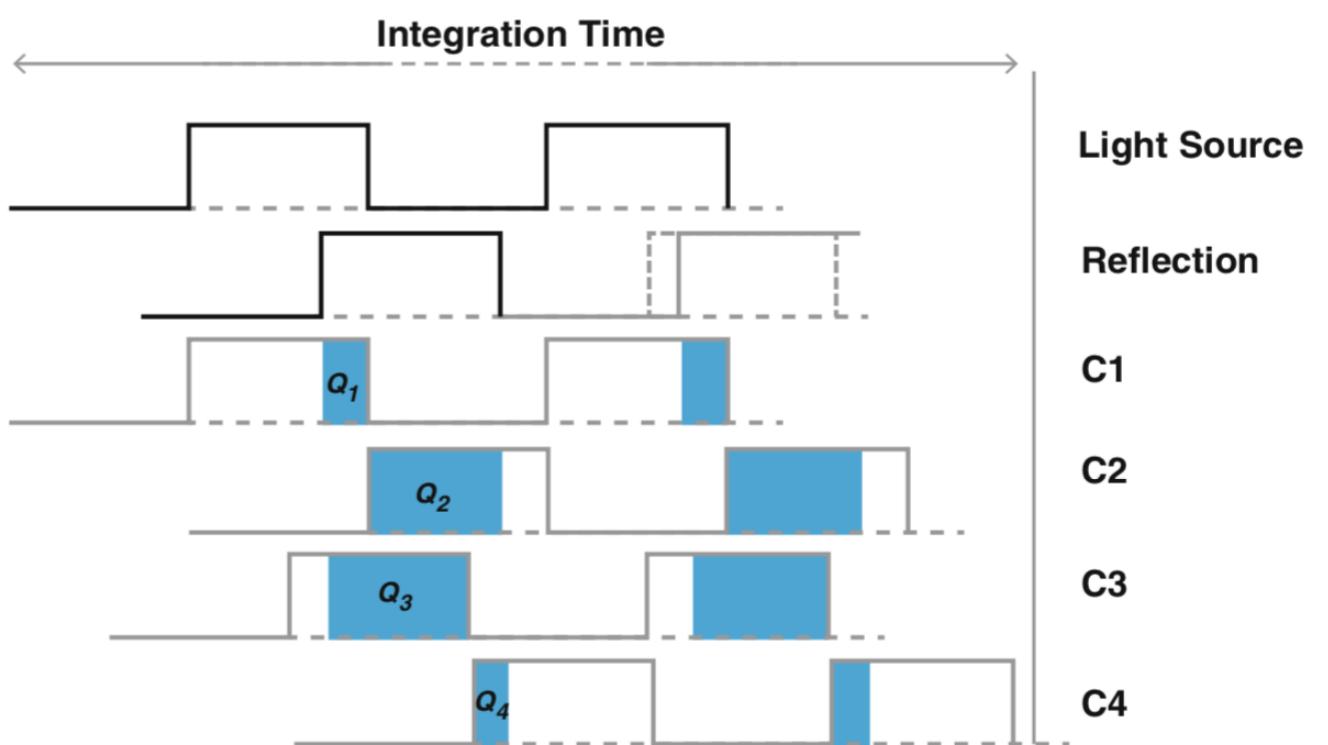


- Use either pulsed-modulation or Continuous-Wave (CW) modulation

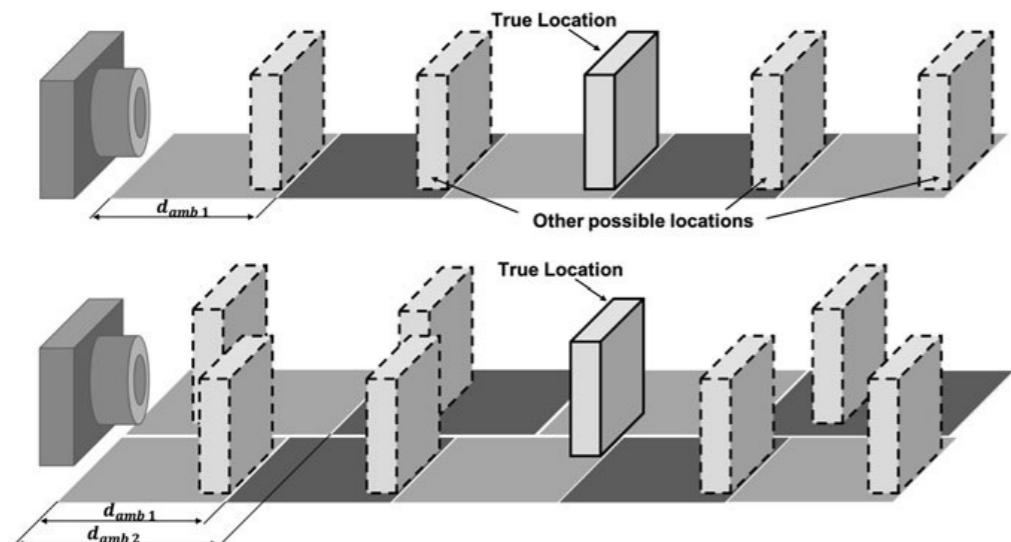
## Depth by Time-of-Flight

$$d = \frac{c * t_{int}}{2} \cdot \frac{Q_2}{Q_1 + Q_2}$$

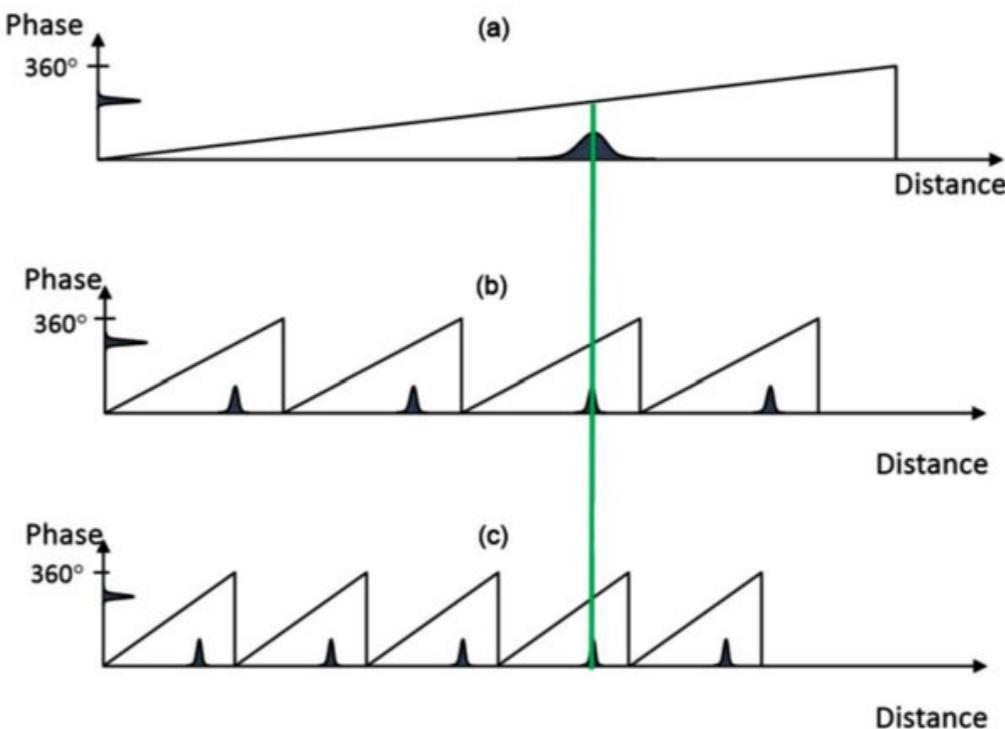
- Advanced TOF systems deploy multi-frequency technologies, combining more modulation frequencies.



2.20 Four phase-stepped samples according to Wyant (1982)



- Single frequency aliasing phenomenon
- Dual frequency extension of the range of measurement



## *From Depth Map to Point Cloud*



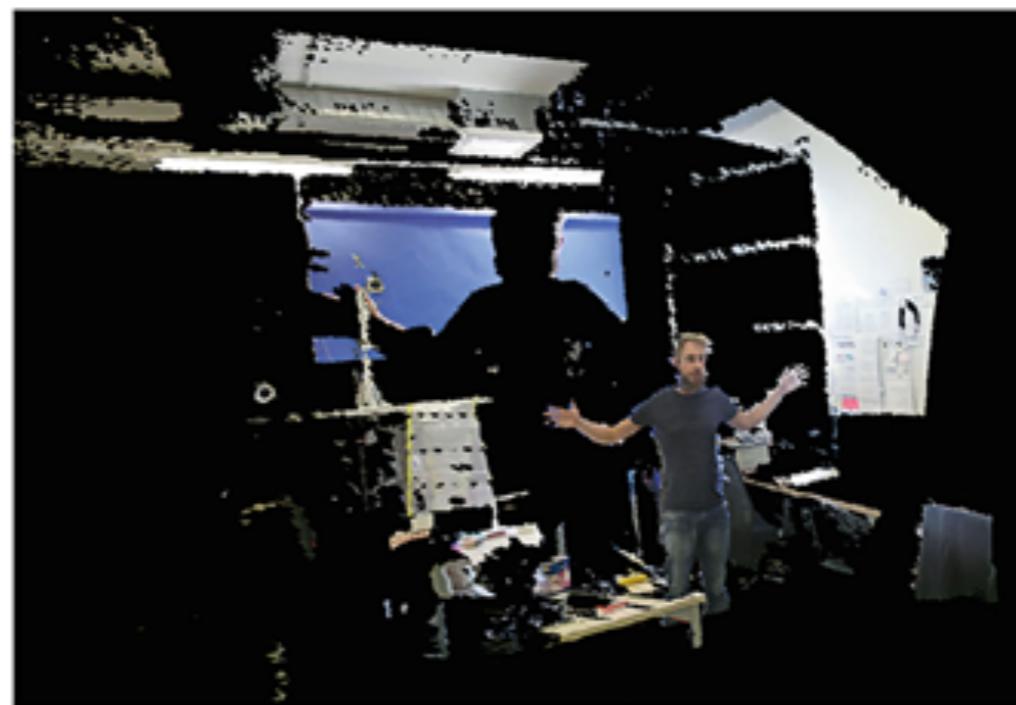
(a) Depth Frame



(b) Point Cloud



(a) Colored depth frame



(b) Colored point cloud

## *State-of-the-Art Devices Comparison*

- PMD Technologies
- They have been famous in the early 2000s for the first TOF devices available for research purposes, such as the PMD CamCube
- More recently, they presented the PMD CamBoard pico flexx

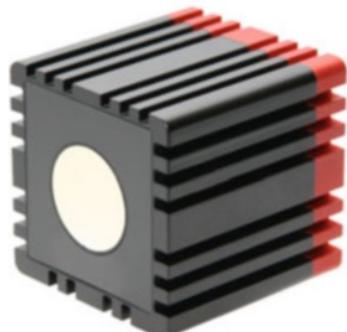


Device	PMD CamCube 2.0
Technology	Time-of-Flight
Range	0 – 13.0 m
Resolution	200 × 200 pix
Frame Rate	up to 80 fps
Field of View	40° × 40°



Device	PMD CamBoard
Technology	Time-of-Flight
Range	0.1 – 4.0 m
Resolution	224 × 171 pix
Frame Rate	up to 45 fps
Field of View	–

- MESA Imaging
- They have been famous in the early 2000s for the first TOF devices available for research purposes, such as the PMD CamCube



Device	MESA SwissRanger 4000
Technology	Time-of-Flight
Range	0.8 – 8.0 m
Resolution	176 × 144 pix
Frame Rate	30fps
Field of View	69° × 56°



Device	MESA SwissRanger 4500
Technology	Time-of-Flight
Range	0.8 – 9.0 m
Resolution	176 × 144 pix
Frame Rate	30fps
Field of View	69° × 55°

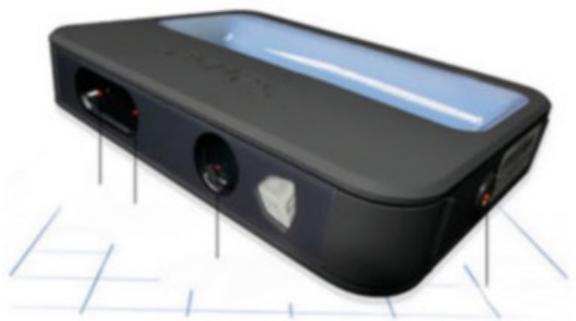
- PrimeSense
- an Israeli company that produce structured-light chips for 3D cameras.
- In 2013, PrimeSense was purchased by Apple.



Device	ASUS Xtion
Technology	Structured-Light
Range	0.8 – 4.0 m
Resolution	640 × 480 pix
Frame Rate	30 fps
Field of View	57° × 43°



Device	Occipital
Technology	Structured-Light
Range	0.8 – 4.0 m
Resolution	640 × 480 pix
Frame Rate	30 fps
Field of View	57° × 43°



Device	Sense 3D scanner
Technology	Structured-Light
Range	0.8 – 4.0 m
Resolution	640 × 480 pix
Frame Rate	30 fps
Field of View	57° × 43°

- Microsoft Kinect
- releasing the first version of the Kinect used to interact with the Xbox360
- Kinect V1 is build by the company PrimeSense and integrates state-of-the-art algorithm to track up to six human body in a scene



Device	Kinect V1
Technology	Structured-Light
Range	0.8 – 4.0 m
Resolution	640 × 480 pix
Frame Rate	30 fps
Field of View	57° × 43°



Device	Kinect V2
Technology	Time-of-Flight
Range	0.5 – 4.5 m
Resolution	512 × 424 pix
Frame Rate	30 fps
Field of View	70° × 60°

- Kinect V2 is using TOF method instead of Structure Light on V1

- Texas Instrument OPT8140
- The Creative Senz3D and the SoftKinetic DS325 may be the first consumer-oriented TOF cameras.
- They are built by different manufacturer, but the TOF sensor is identical, an OPT8140 provided by Texas Instrument.



Device	Creative Senz 3D
Technology	Time-of-Flight
Range	0.15 – 1 m
Resolution	320 × 240 pix
Frame Rate	60 fps
Field of View	74° × 58°

- Creative Technology is a company based in Singapore
- Senz3D TOF released camera in collaboration with Intel and its Real Sense philosophy.
- Including gesture tracking as well as face detection and recognition



Device	SoftKinetic DS325
Technology	Time-of-Flight
Range	0.15 – 1 m
Resolution	320 × 240 pix
Frame Rate	60 fps
Field of View	74° × 58°

- SoftKinetic is a Belgian company
- In June 2012, the firm presents their SoftKinetic DS325™ TOF device and provides their own gesture recognition software platform, named iisu
- SoftKinetic was bought by Sony Corporation in October 2015

- Google Tango
- In 2014, Google launched the project Tango, a mobile platform that brings augmented reality features to mobile devices like smartphone and tablets.
- The depth sensors are manufactured by OmniVision, a Taiwanese company.
- The tablet embeds a NVIDIA Tegra K1 processor



Device	Google Tango Tablet
Technology	Structured-Light
Range	0.5 – 4 m
Resolution	160 × 120 pix
Frame Rate	10 fps
Field of View	–

- Google also presented a smartphone version of its Tango device, based on a TOF sensor manufactured by PMD Technologies
- In June 2016, Lenovo presented the Phab 2 ProTM, the first consumer-based phone with a 3D camera embedded.
- In August 2017, Asus presented the Zenfone ARTM, based on the same technology.
- As for March 2018, the Google TangoTM Project have been deprecated, in favor of the development of the Google Augmented Reality tool ARCore.



Device	Google Tango Phone
Technology	Time-of-Flight
Range	–
Resolution	–
Frame Rate	–
Field of View	–

- Orbbec
- Orbbec is a company founded in China, manufacturing 3D cameras based on the structured light technology.



Device	Orbbec Astra S
Technology	Structured-Light
Range	0.4 – 2.0 m
Resolution	640 × 480 pix
Frame Rate	30 fps
Field of View	60° × 49.5°

- Intel RealSense
- In 2016, Intel released the SR300 camera module. Based on a system of resonating MEMS mirrors and lenses that diffuse the IR laser in a specific pattern.
- the ZR300 is a R200TM depth camera module Infra-Red (IR) stereo + RGB camera, coupled with a tracking module including a fisheye camera and an IMU.



Device	Intel SR300
Technology	Structured-Light
Range	0.2 – 1.5 m)
Resolution	640 × 480 pix
Frame Rate	30, 60, 90 fps
Field of View	71.5° × 55°



Device	Intel R200
Technology	Active Stereoscopy
Range	0.5 – 6.0m
Resolution	640 × 480 pix
Frame Rate	30, 60, 90 fps
Field of View	59° × 46°



Device	Intel ZR300/Euclid
Technology	Active Stereoscopy
Range	0.5 – 6.0m
Resolution	640 × 480 pix
Frame Rate	30, 60, 90 fps
Field of View	59° × 46°



Device	Intel D415
Technology	Active Stereoscopy
Range	0.16 – 10 m
Resolution	1280 × 720 pix
Frame Rate	30, 60, 90 fps
Field of View	63.4° × 40.4°

- Intel RealSense



Device	Intel D435
Technology	Active Stereoscopy
Range	0.2 – 4.5 m
Resolution	1280 × 720 pix
Frame Rate	30, 60, 90 fps
Field of View	85.2° × 58°

- StereoLabs ZED: Passive Stereo
- Stereolabs is a French company proposing a passive stereoscopic system using only by the natural textures from the scene to infer depth.



Device	StereoLabs ZED
Technology	Passive Stereoscopy
Range	0.5 – 20m
Resolution	up to 4416 × 1242 pix
Frame Rate	up to 100 fps
Field of View	110°(diagonal)

