TSBB21, Lecture: Range cameras 3B

- Binary or Gray-coded patterns
- Fringe patterns
- Demonstration of a modern “Sheet-of-light” camera with triangulation: SICK Ruler 3000

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Repetition: Different range camera principles

- I) Triangulation and passive stereo
- II) Active light and triangulation
  - a) “Single spot” with triangulation
  - b) “Sheet-of-light” with triangulation
  - c) “Structured light” with triangulation
    - c1) Simple grid pattern
    - c2) Microsoft Kinect 1 (Random dot pattern)
    - c3) Binary or Gray-coded patterns (Range camera 3 lecture)
    - c4) Fringe patterns (Range camera 3 lecture)
- III) Time-of-flight
  - a) Light pulse and time measurement, LIDAR (light+RADAR)
  - b) Time-of-flight camera. Amplitude modulated light. (For outdoor applications, this is called Flash LIDAR, which is a confusing name.) (Also in Range camera 2 lecture)
    - Sinusoidal wave and phase shift measurement.
    - “Rectangular” pulse. Measure three short intervals.

- i) Stationary scene or moving scene
- ii) Scanning or stationary light

Structured light with triangulation and Gray-coded patterns

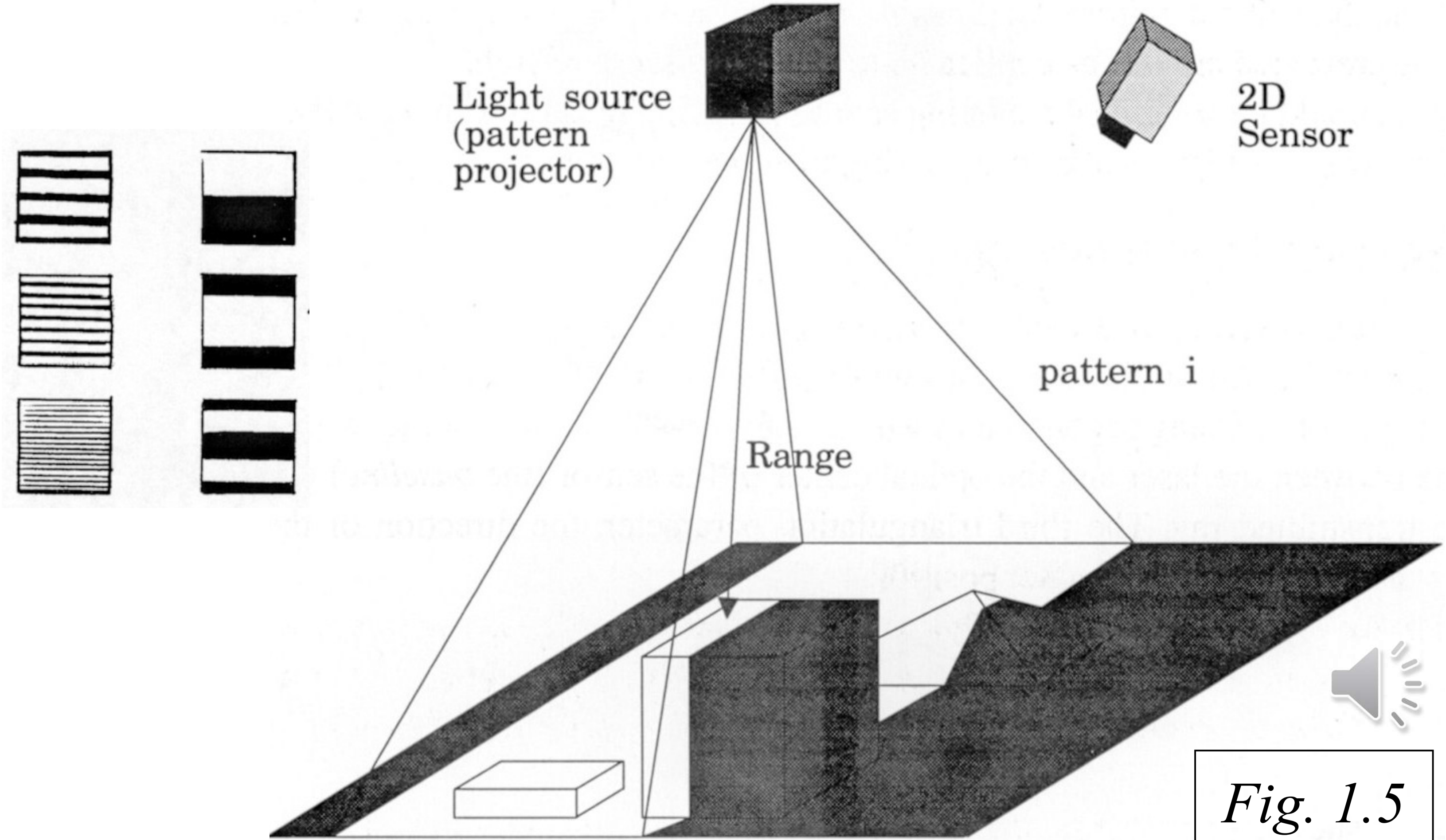


Fig. 1.5

Gray coded patterns instead of ”sheet-of light”?

The logN binary images can be combined to one image with coded positions in every pixel. Consequently N different codes are possible.

Advantage: logN patterns instead of N sheet-of-light positions!

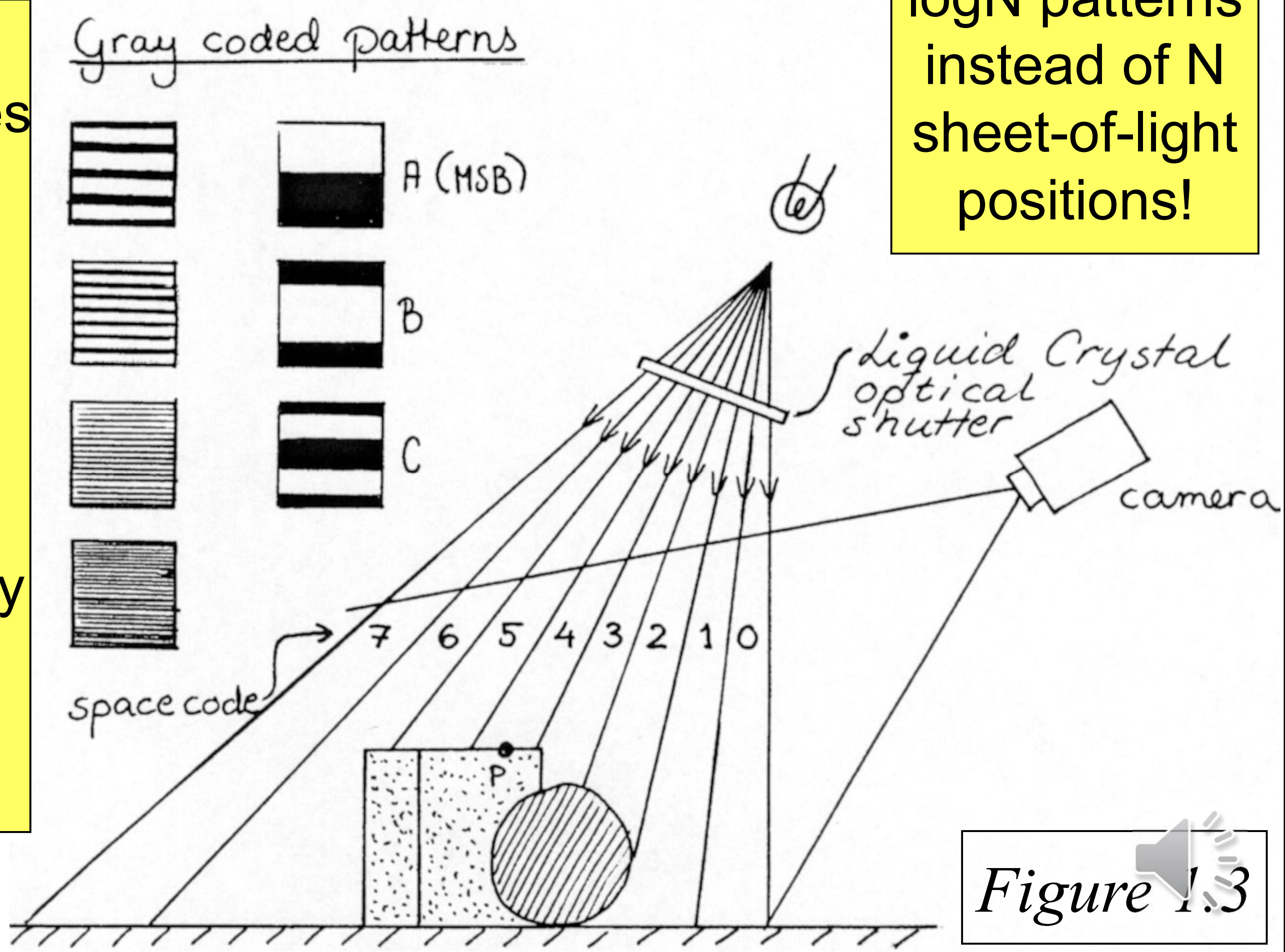


Figure 1.3

Why Gray code instead of binary code?

Normal binary code	Gray code
0 0 0	1 0 0
0 0 1	1 0 1
0 1 0	1 1 1
0 1 1	1 1 0
1 0 0	0 1 0
1 0 1	0 1 1
1 1 0	0 0 1
1 1 1	0 0 0

Advantage: Because only one binary position changes at the time in the Gray code, one error does not give a big effect.

Detection of patterns

- Background offset
- Local thresholding
- Complementary patterns

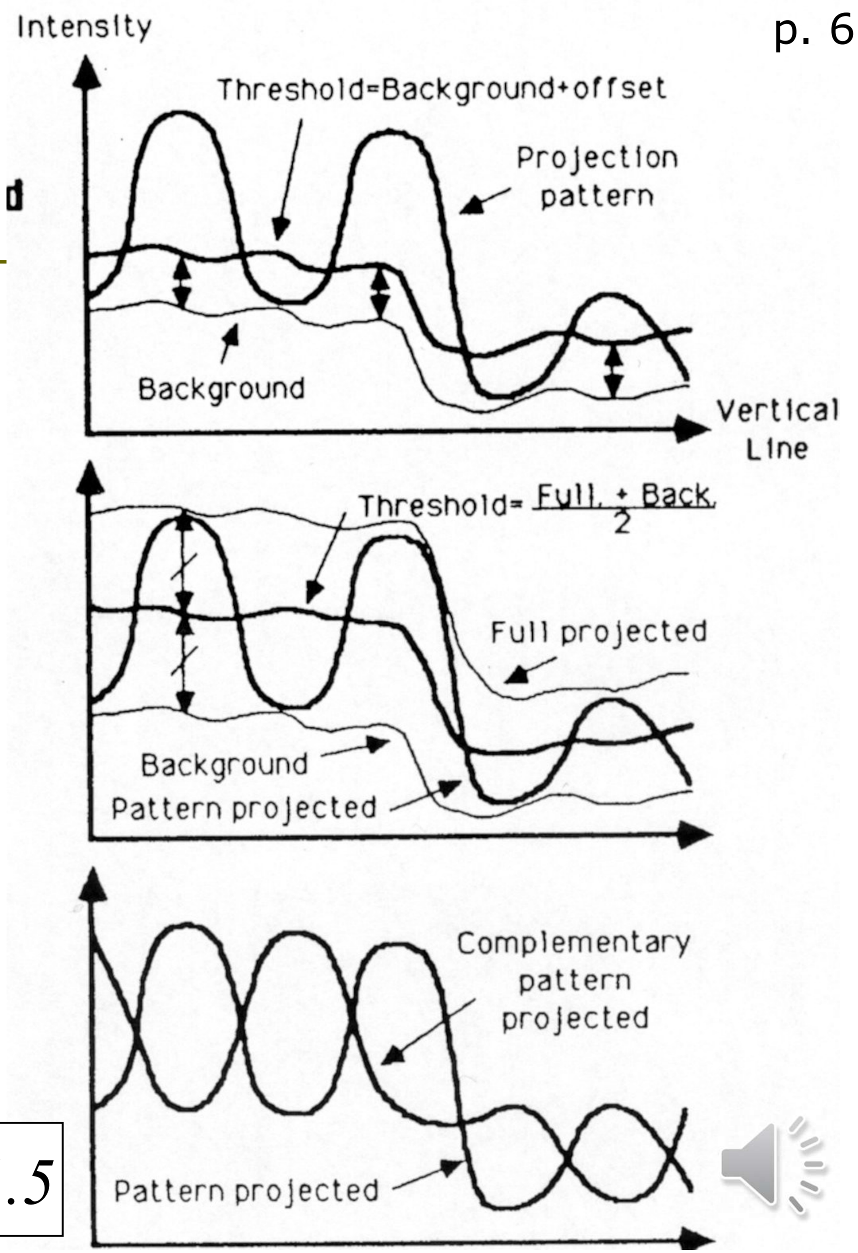
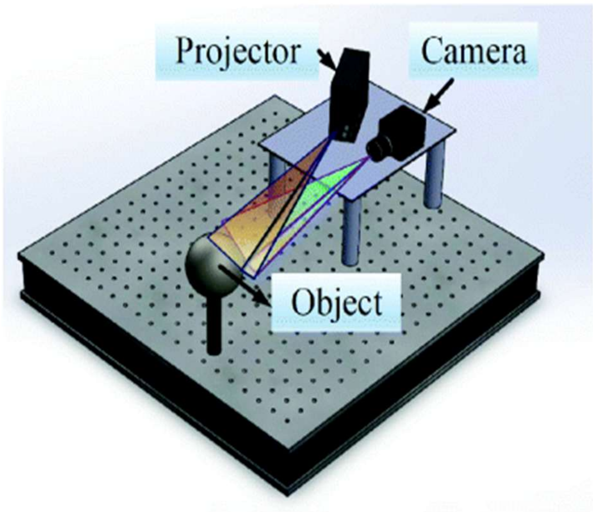


Figure 1.5

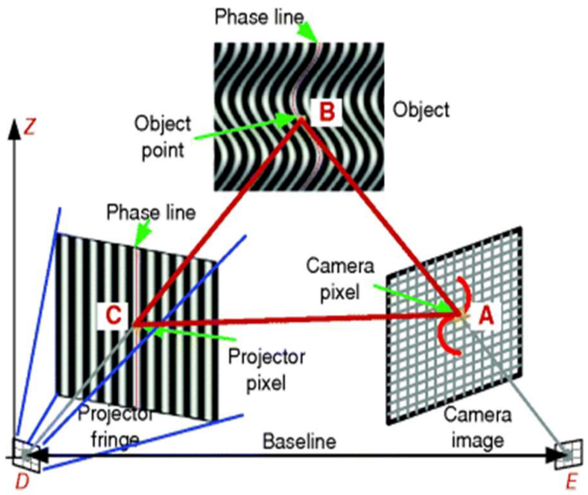
Structured light with trian-gulation and fringe patterns

This is one version. There exist variants.

- From https://onlinelibrary.wiley.com/doi/full/10.1002/047134608X.W8298
- There are many types of structured patterns (e.g. a simple grid pattern, binary patterns, or Gray-coded patterns.
- Left: illustration of a structured light system containing one projector, one camera, and an object to be captured.
- Right: schematic diagram of a 3D structured light imaging system using fringe pattern projection



(a)

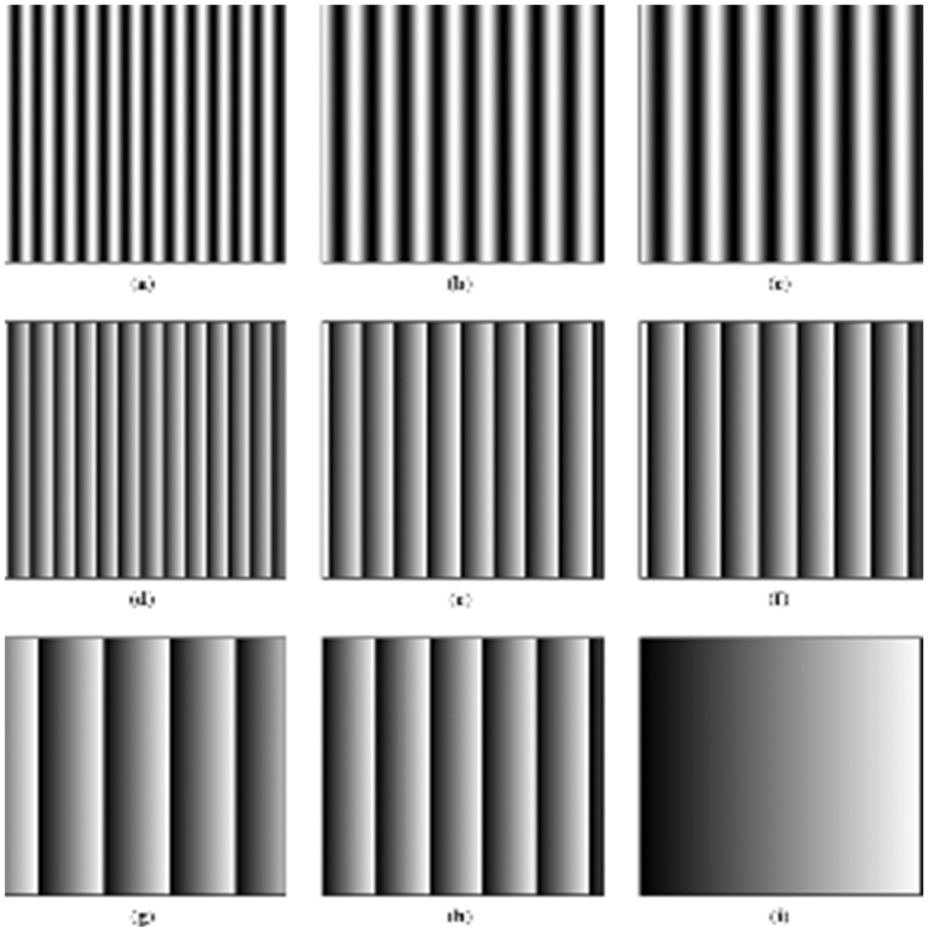


(b)

Sinusoidal patterns = Fringe patterns

- With sinusoidal patterns, pixel-level resolution is possible as intensities vary across the image from point to point at known frequencies and therefore can be differentiated.
- The figure shows 3 sinusoidal patterns with different wavelengths.
- Instead of using intensity values to establish correspondence, phase information is used. One benefit of this is an inherent robustness to surface texture variation.
- Three or more fringe images must be used if robust and accurate measurements are desired.

Multifrequency phase-shifting method



- (a) One fringe pattern (λ_1 = 60 pixels).
- (b) One fringe pattern (λ_2 = 90 pixels).
- (c) One fringe pattern (λ_3 = 102 pixels).
- (d) Wrapped phase φ_1.
- (e) Wrapped phase φ_2.
- (f) Wrapped phase φ_3.
- (g) Equivalent phase difference $\Delta\varphi_{12}$.
- (h) Equivalent phase difference $\Delta\varphi_{13}$.
- (i) Resultant phase $\Delta\varphi_{123}$ that can be used to eventually unwrap φ_1.

Multifrequency phase-shifting method

- (g) Equivalent phase difference Δφ12:

$$\Delta\varphi_{12} = [\varphi_1 - \varphi_2](\text{mod } 2\pi)$$

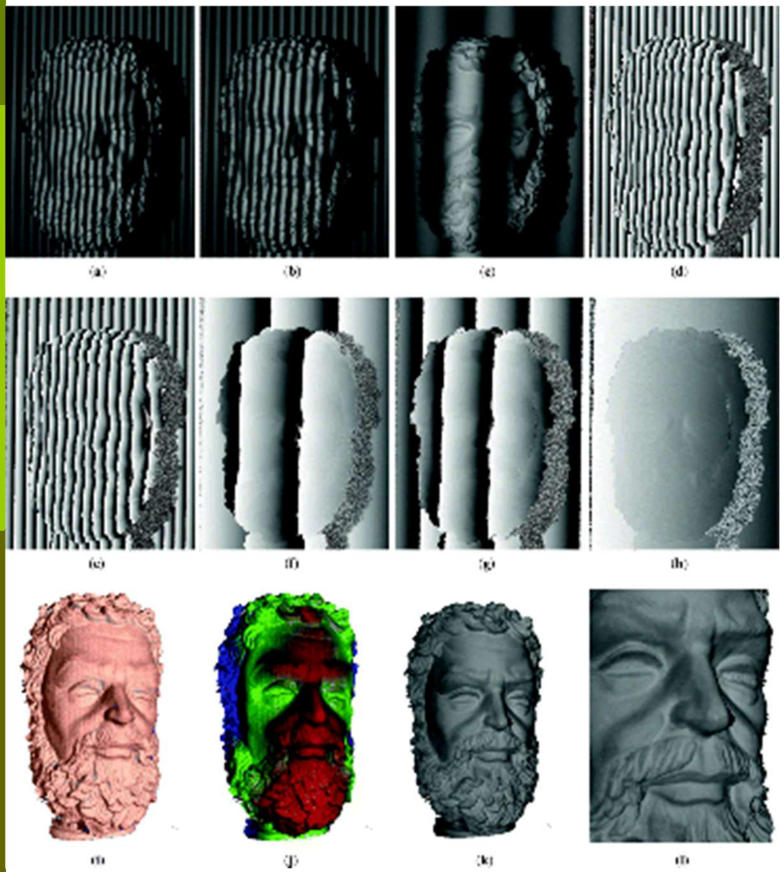
- (h) Equivalent phase difference Δφ13:

$$\Delta\varphi_{13} = [\varphi_1 - \varphi_3](\text{mod } 2\pi)$$

- (i) Resultant phase Δφ123 that can be used to eventually unwrap φ1:

$$\Delta\varphi_{123} = [\varphi_{13} - \varphi_{12}](\text{mod } 2\pi)$$

Example of 3D frame capture

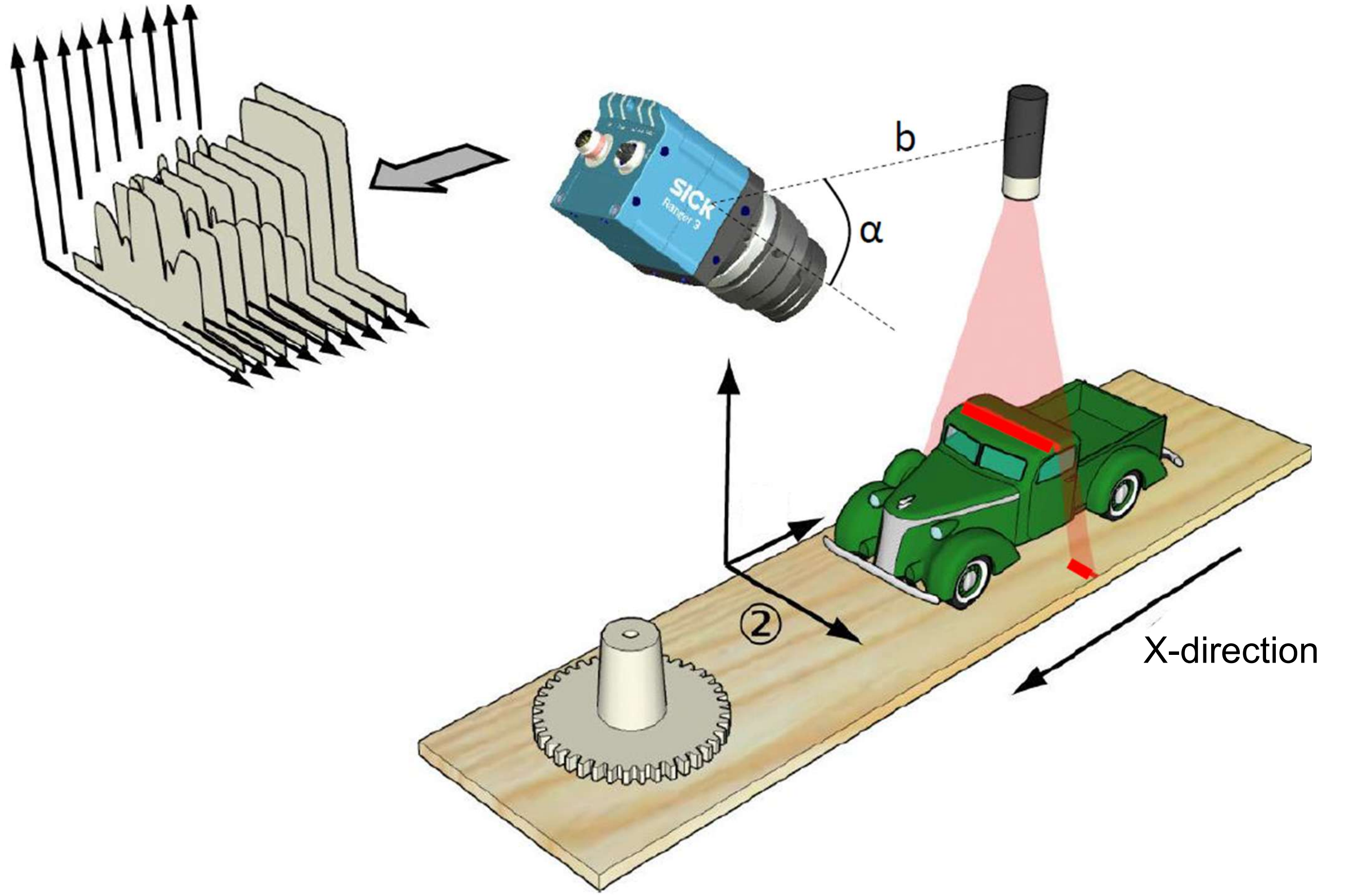


- (a) One fringe pattern (λ1 = 30 pixels).
- (b) One fringe pattern (λ2 = 36 pixels).
- (c) One fringe pattern (λ3 = 231 pixels)
- (d) Wrapped phase φ1.
- (e) Wrapped phase φ2.
- (f) Wrapped phase φ3.
- (g) Equivalent phase difference Δφ12.
- (h) Equivalent phase difference Δφ123 that can be used to unwrap φ1.
- (i) Reconstructed 3D data from the unwrapped φ1 with the application of calibration parameters to recover world coordinates.
- (j) The 3D results colored based on depth value.
- (k) 3D results with texture mapping applied. Can e.g. be the reflected intensity.
- (l) Zoomed-in view.

Demonstration of SICK Ruler3000

- We have got a Ruler3000 from SICK.
- The conveyor table is linearly movable and connected to an encoder so that range profiles are collected at regular intervals Δx. This gives the distance in the x direction in mm.

SICK Ruler3000, principle



SICK Ruler3000: From Sensor image in pixels to world coordinates in mm

- The camera also performs "rectification". This means that resampling (upsampling) is performed to get even distances in the y-direction (width).
- The upsampling is from 2560 pixels to 3200 pixels