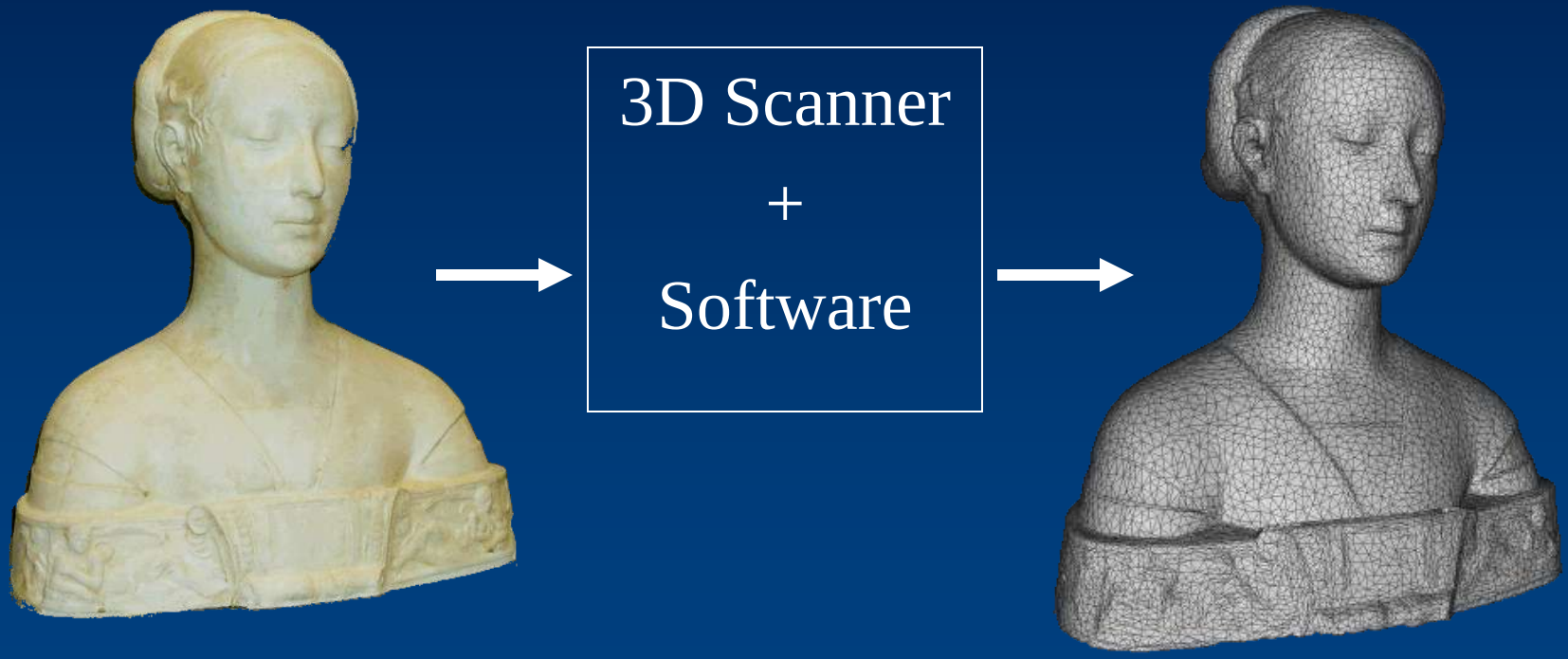
A low cost 3D scanner based on structured light

C. Rocchini, P. Cignoni,
C. Montani, P. Pingi, R. Scopigno

Introduction

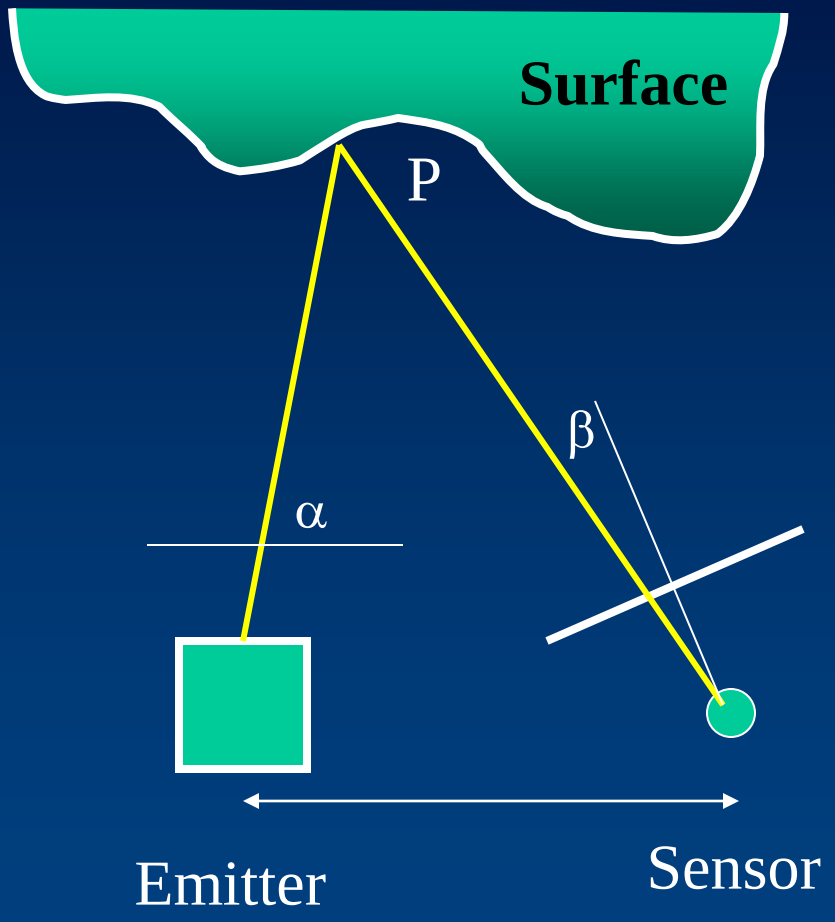


Characteristics

- Use only consumer technology:
  - Low cost hardware
  - Fast technological development
- Good accuracy and resolution:
  - Sufficient for Cultural Heritage acquisition
  - Better than “shape from shading” or “silhouette” (but not than laser scanner)
- Easiness of use:
  - Suitable for the Cultural Heritage “people”

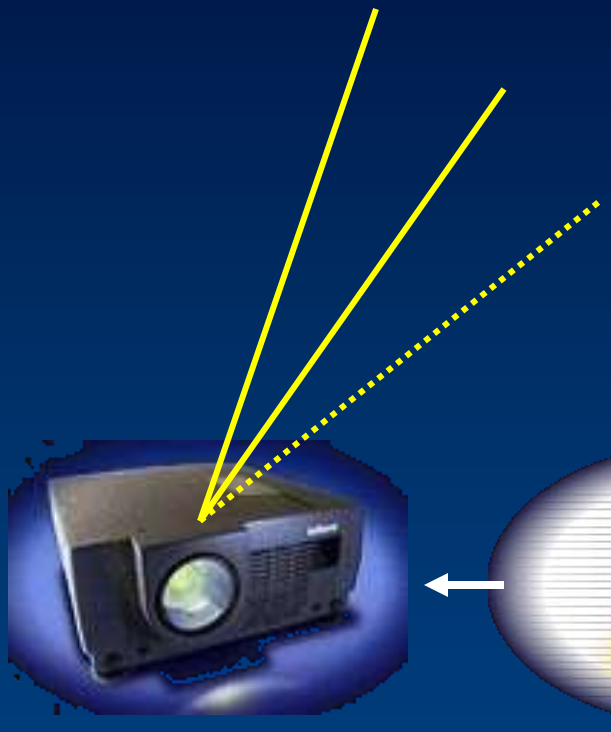
Stripe 3D-Scanner Scheme

1. The emitter generates a reference signal
2. The signal hits the surface
3. The sensor gets the signal position
4. The surface position is computed by triangulation



Our solution

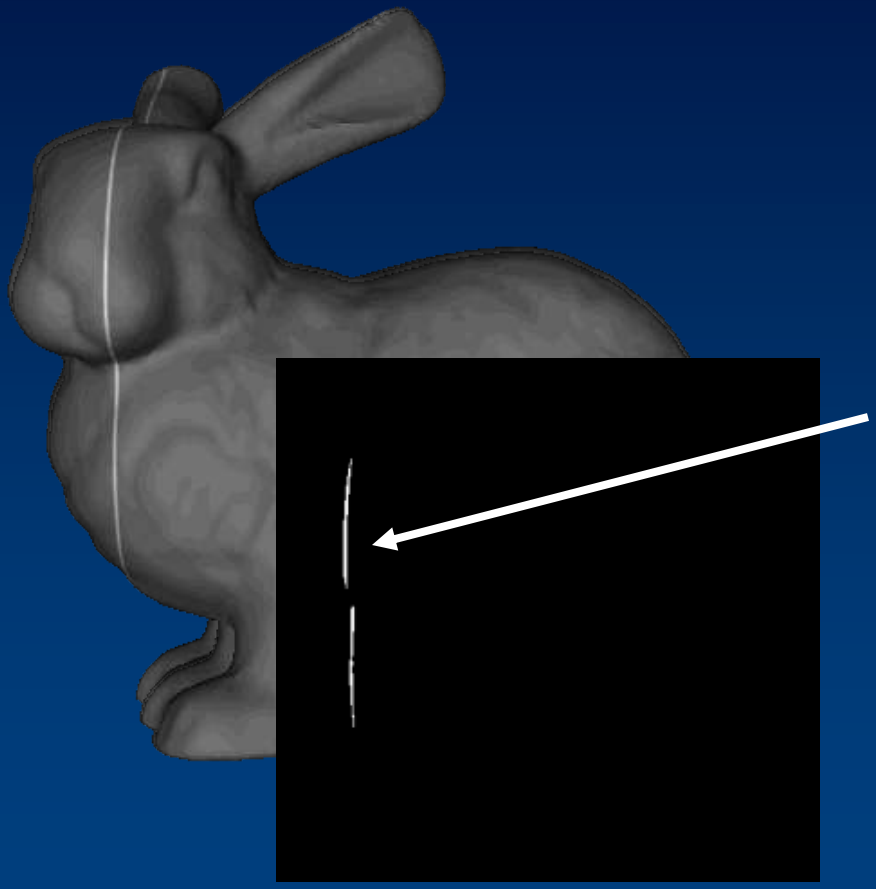
A computer drives a standard video projector (emitter) and a consumer digital photo camera (sensor).



Emitter

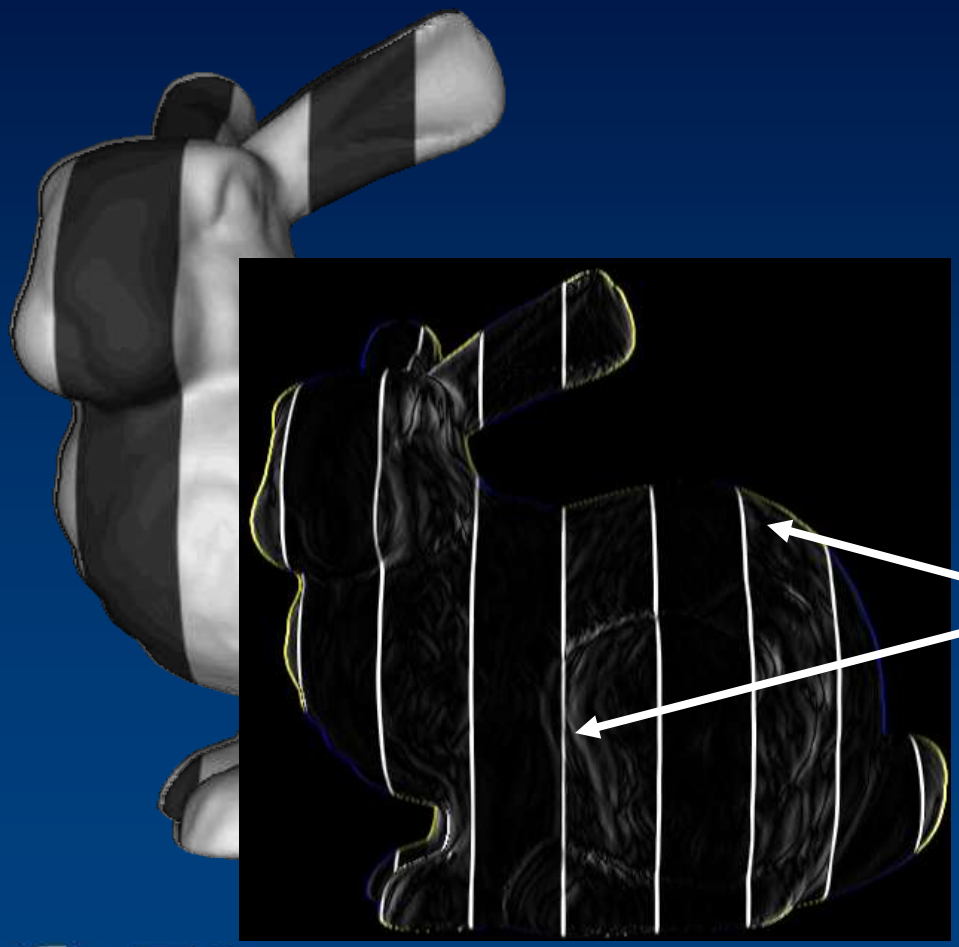
Sensor

Pattern generation for laser scanners



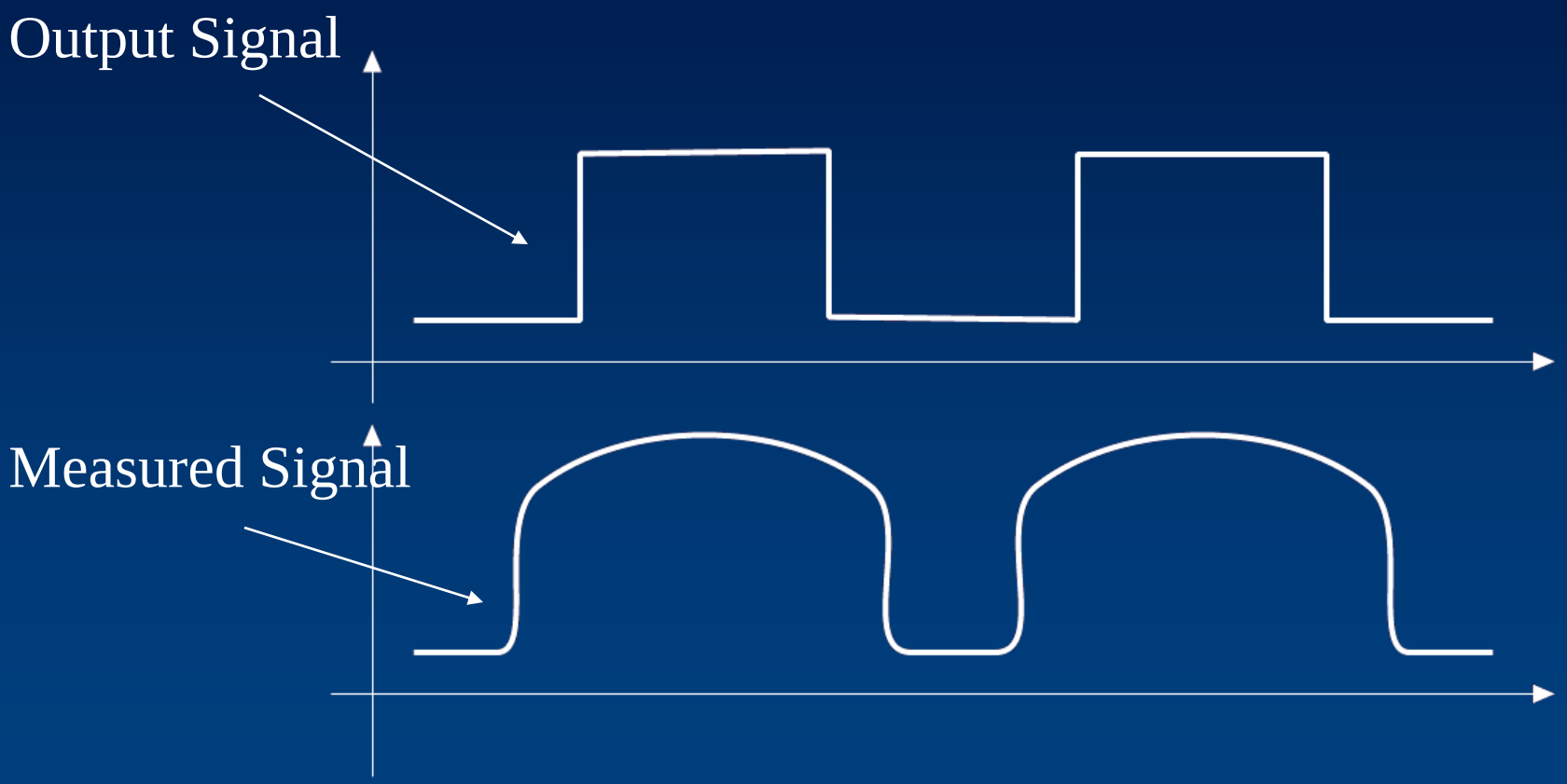
- The laser scanner generates a single line.
- All the points of the line in the image are detected by looking for the brightest pixels.
- (The signal is time-coded).

Pattern generation for non-laser scanners

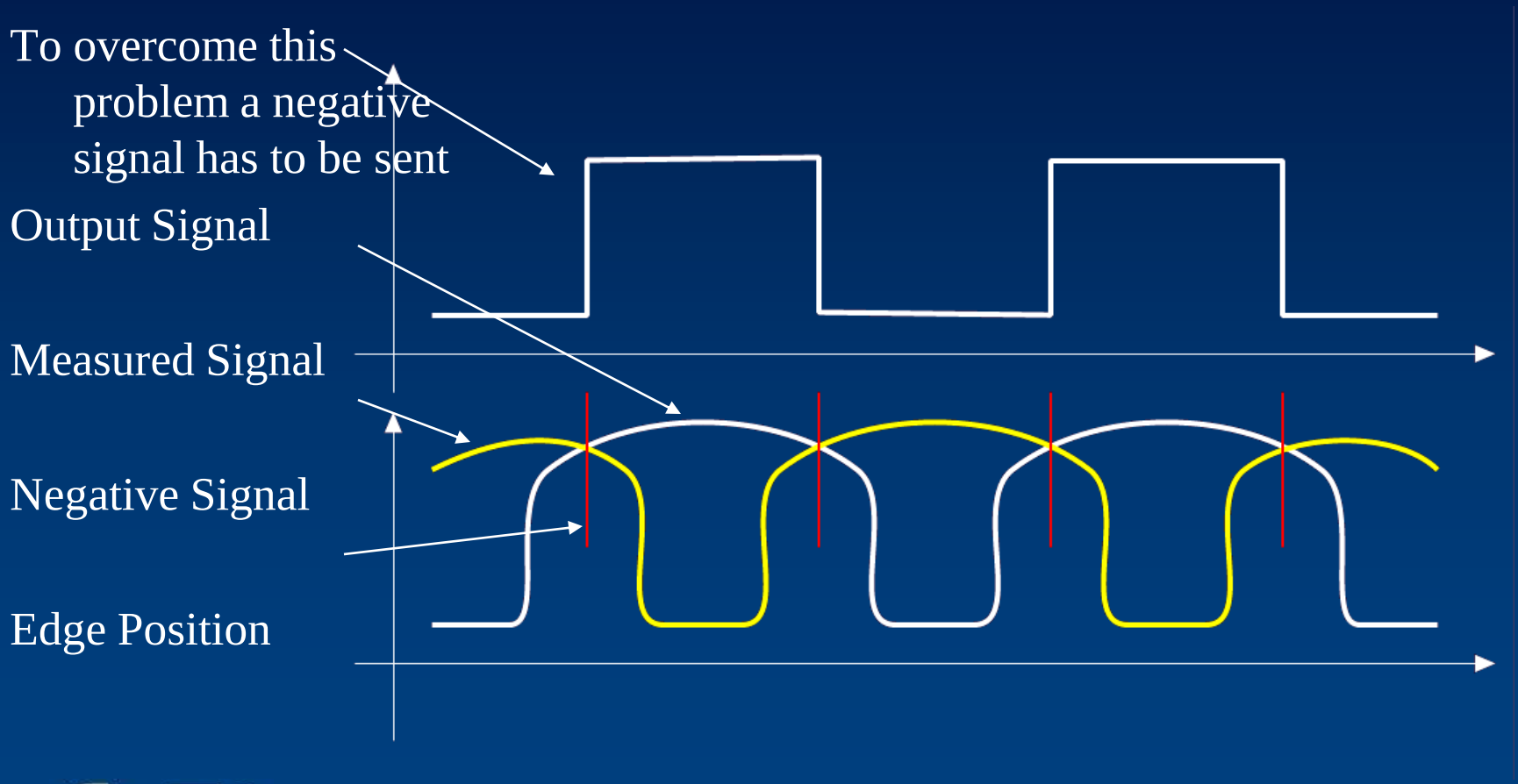


- A structured light scanner generally uses a set of stripes. The set generates a binary code.
- The sample points are obtained by looking for the edges of the stripes.
- (The signal is space-coded)

A problem with non-laser systems: CCD White Expansion



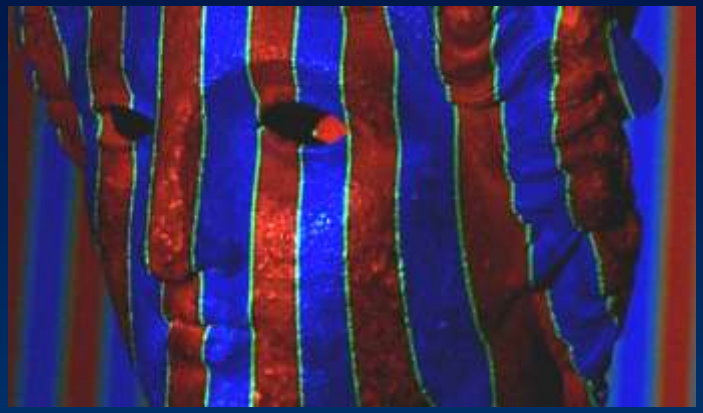
White Expansion: Negative Pattern



Our Pattern …

- …Uses Color
  - Consumer video-projectors and photo-cameras support colors.
  - Color enhances the information of the signal.
- … Combines lines and stripes
  - Lines for geometry detection (like laser scan)
  - Stripes for space coding (like others stripe scanner).

Pattern Sample



RGB Generated Pattern

Green Component: Stripe Position

Blue, Red Components: Binary Code (for the next stripe)

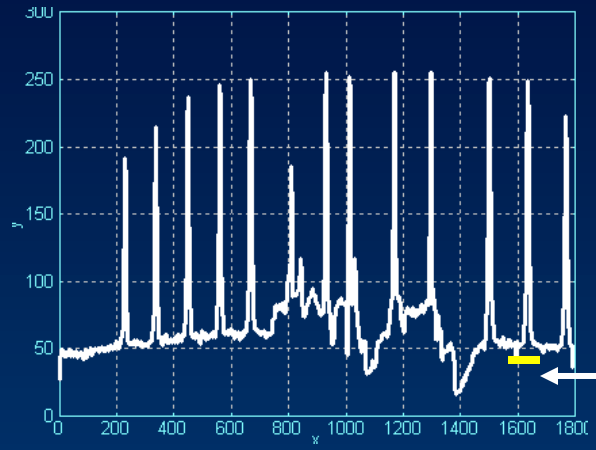
Space coding

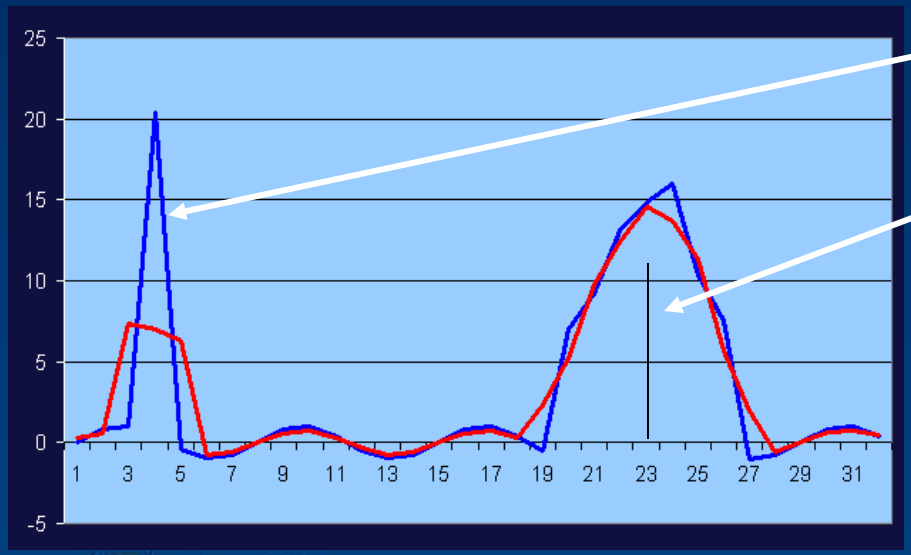
A set of binary patterns generates the space code.

Advantages of hybrid pattern

- More precision and robustness: line detection overcomes edge detection.
- Generation of negative patterns is not needed (50% of the scanning time).
- It takes advantage of the color information (consumer devices are color devices).

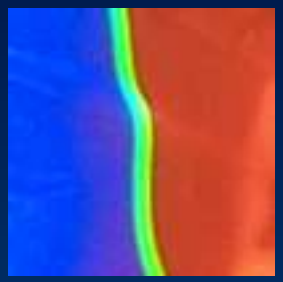
Finding the line position

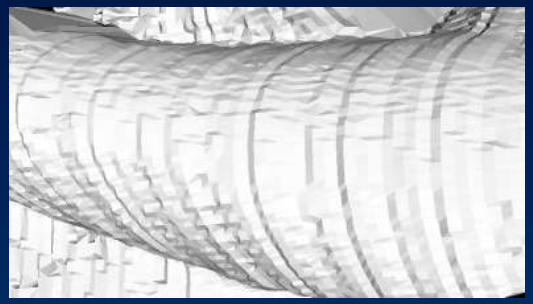




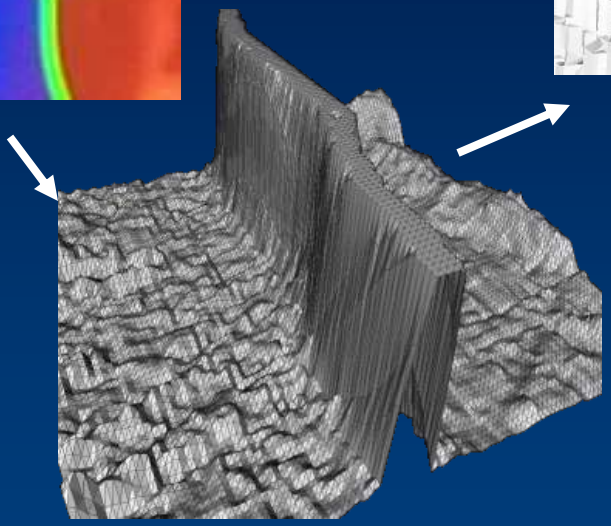
1. Take the signal from the camera (green component)
2. Select an interval using the space coding (red-blue)
3. Filter the signal to remove noise (red line).
4. Compute the barycentre of the local maximum (with sub pixel accuracy).

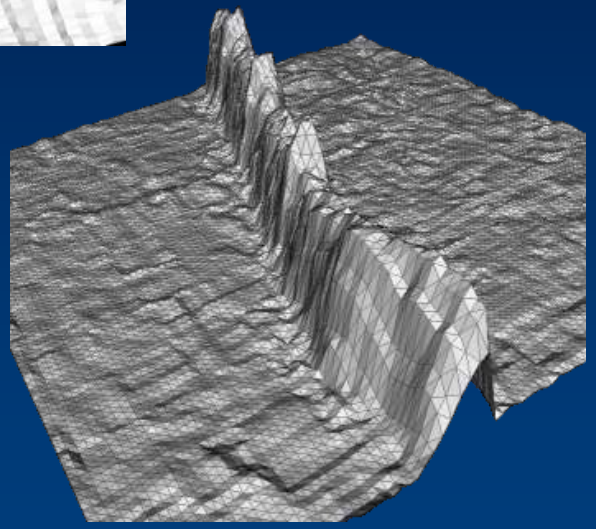
The Overexposure Problem





Noisy Geometry





Overexposed Signal

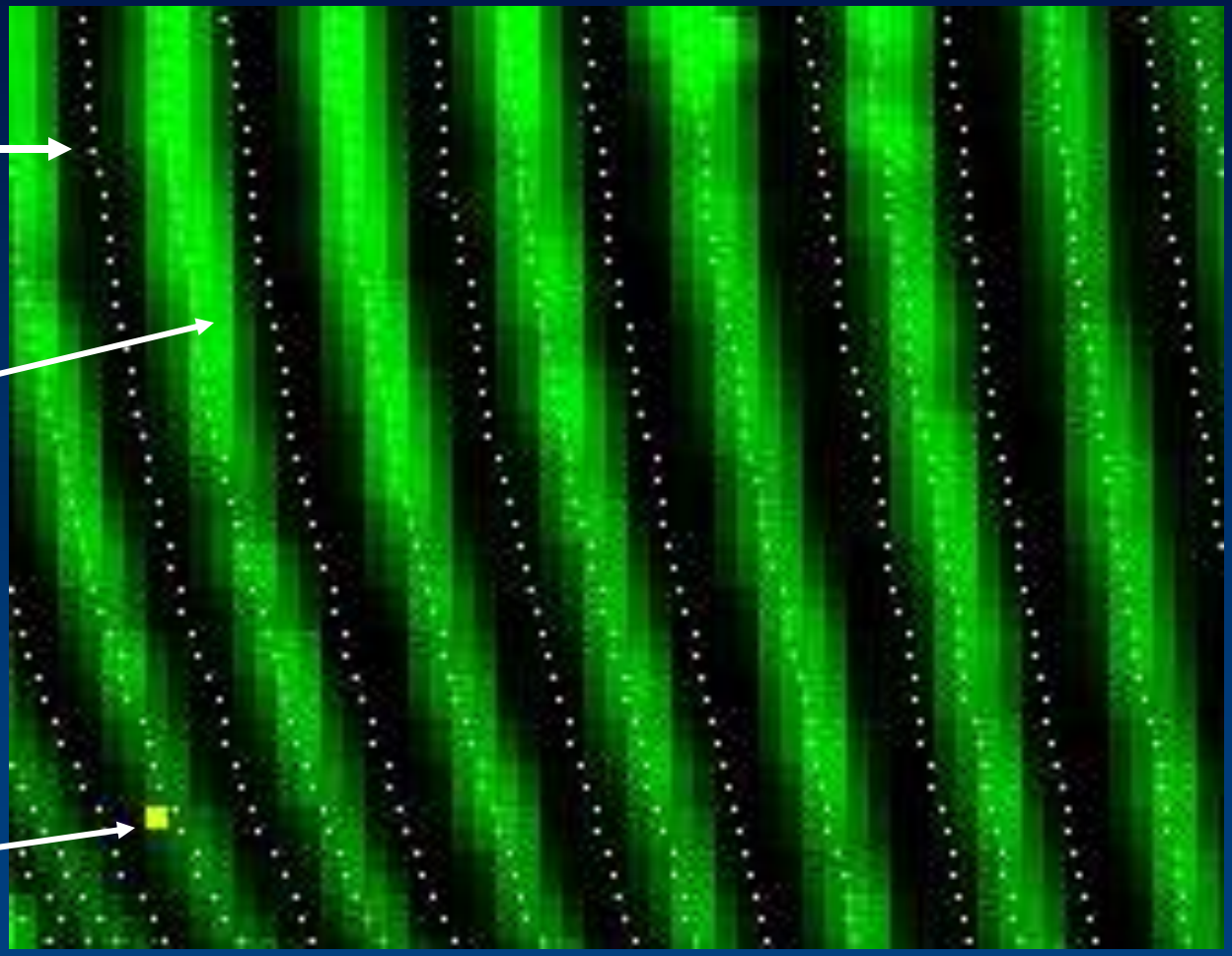
Good Signal

Example of sub pixel accuracy

Sampled Points

Projected Pattern

Photocamera Pixel Dimension

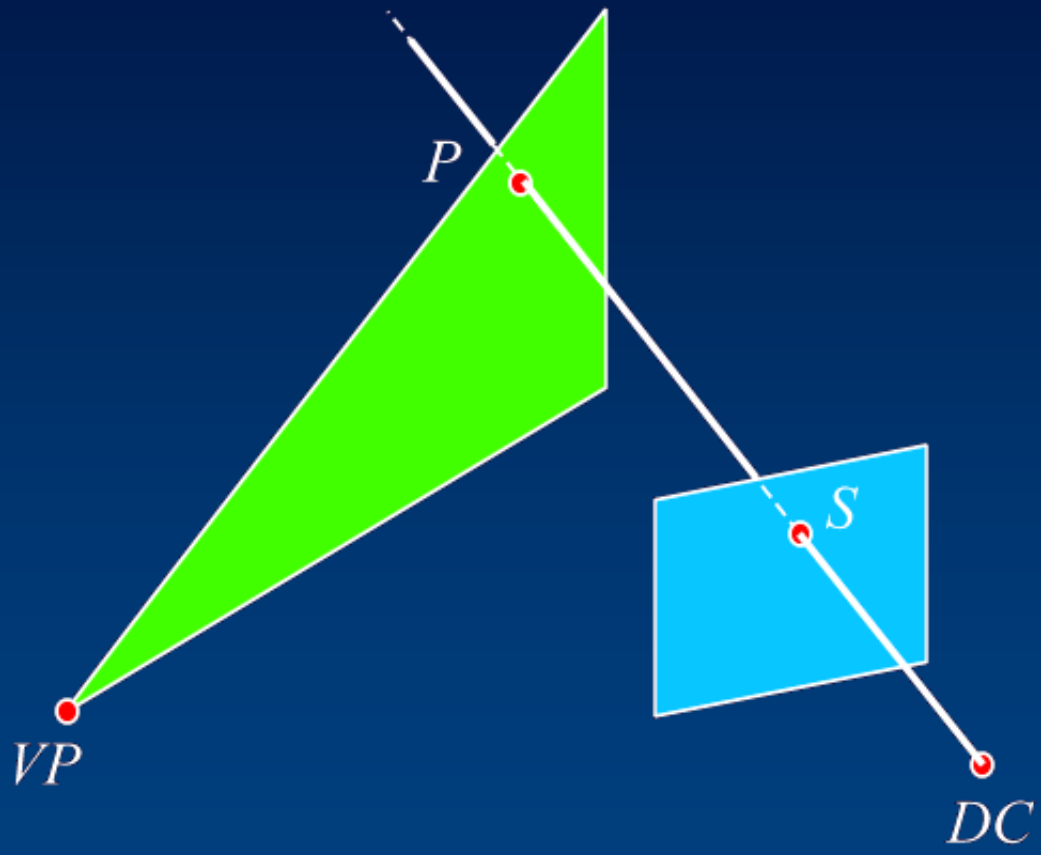


Computing the 3D point

Given…

- The video projector plane VP,
- The digital camera center DC,
- The sampled picture point S,

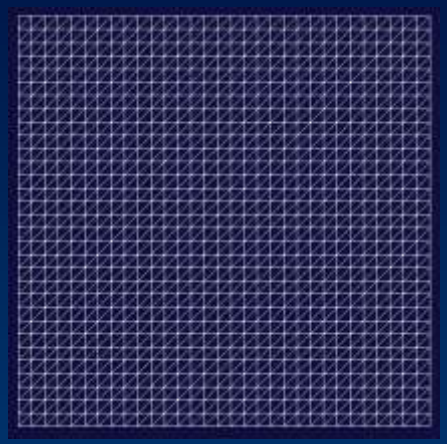
We may compute the 3D position of the real Point P by triangulation

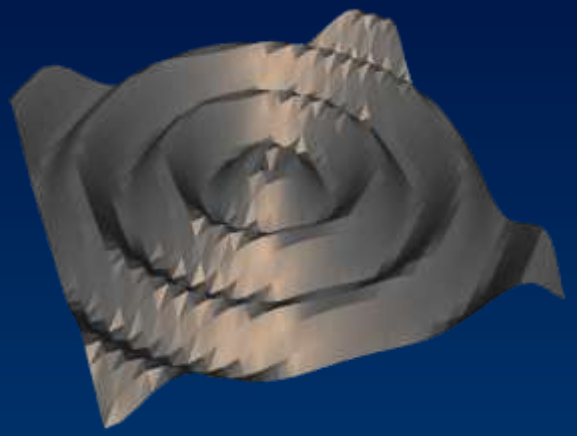


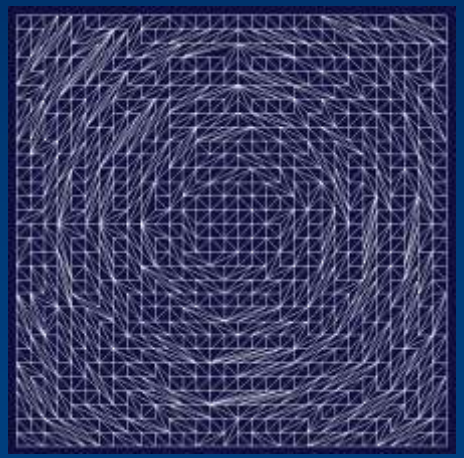
From points to surface

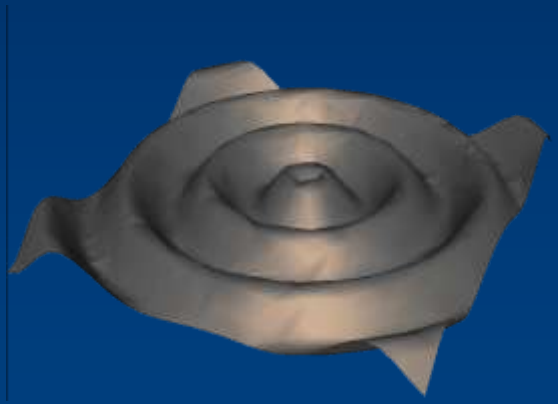
At the end of the scanning process, points are triangulated.

- Regular
- Curvature Optimization









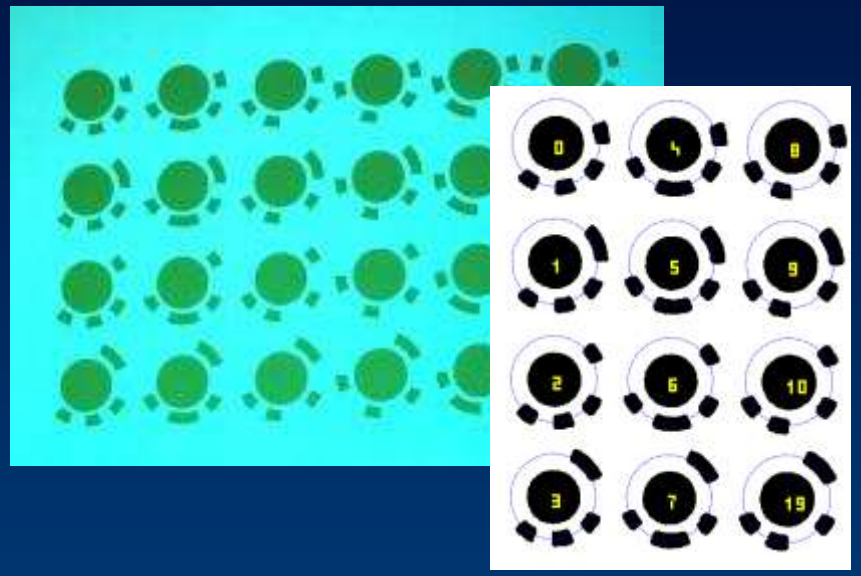
Calibrating the system

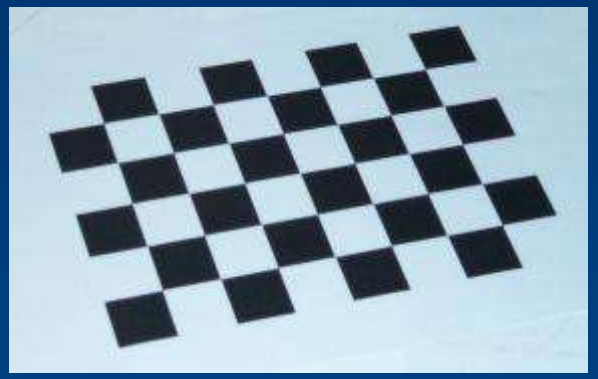
- Camera Calibration
  - Required just once (for given zoom and focus)
  - Detects the camera parameters (focal distance, …)
- Projector Calibration
  - Required just once (for given zoom and focus)
  - Detects the geometry of the planes generated by the vertical pixel lines.
- System Calibration
  - Required just once per system setting
  - Detects the relative position of camera and projector.

Camera Calibration

Performed by the use of a standard method:

- Tsai library + a probe with circular targets and bar codes or …
- Intel CV Library + a chessboard probe

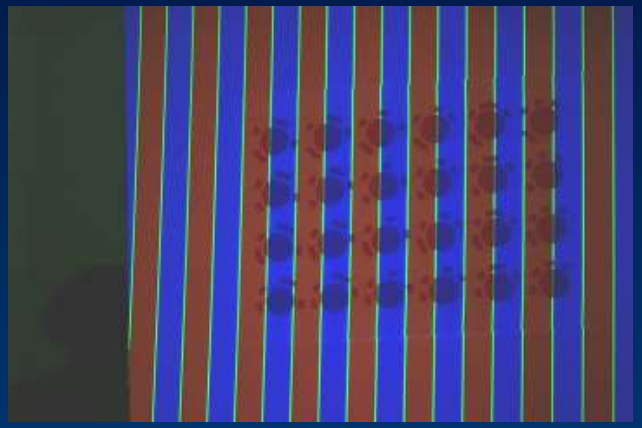


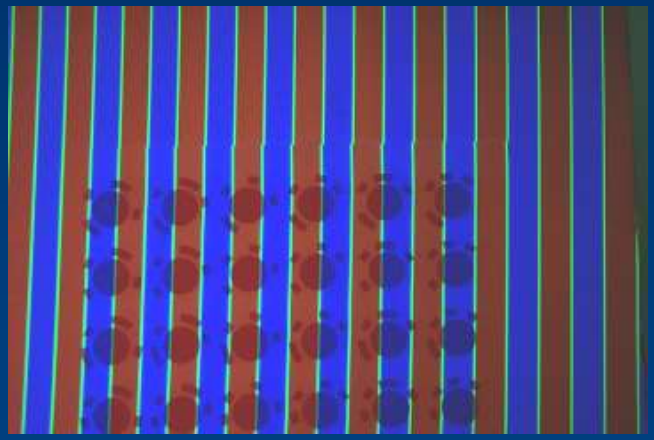


Projector and System Calibration (1/2)

Performed by using the same probe of the camera calibration step:

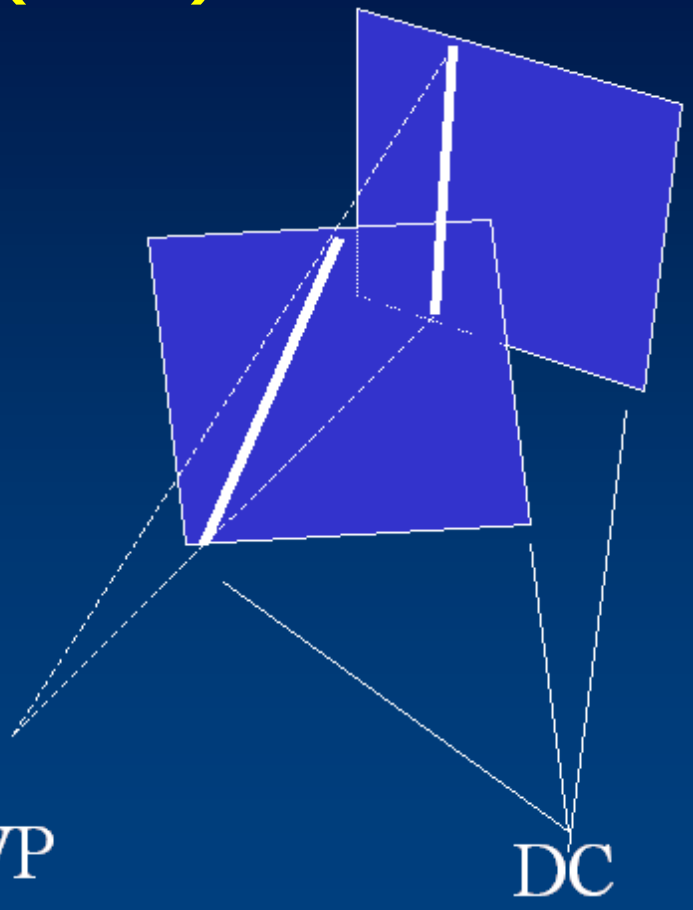
- We first use the targets to compute the probe position and orientation in the camera space.
- Then, we project the stripe pattern over the probe.





Projector and System Calibration (2/2)

By intersecting (at least) two lines generated from the projector, we can compute the projector plane coordinate in the camera reference system.



Color Acquisition

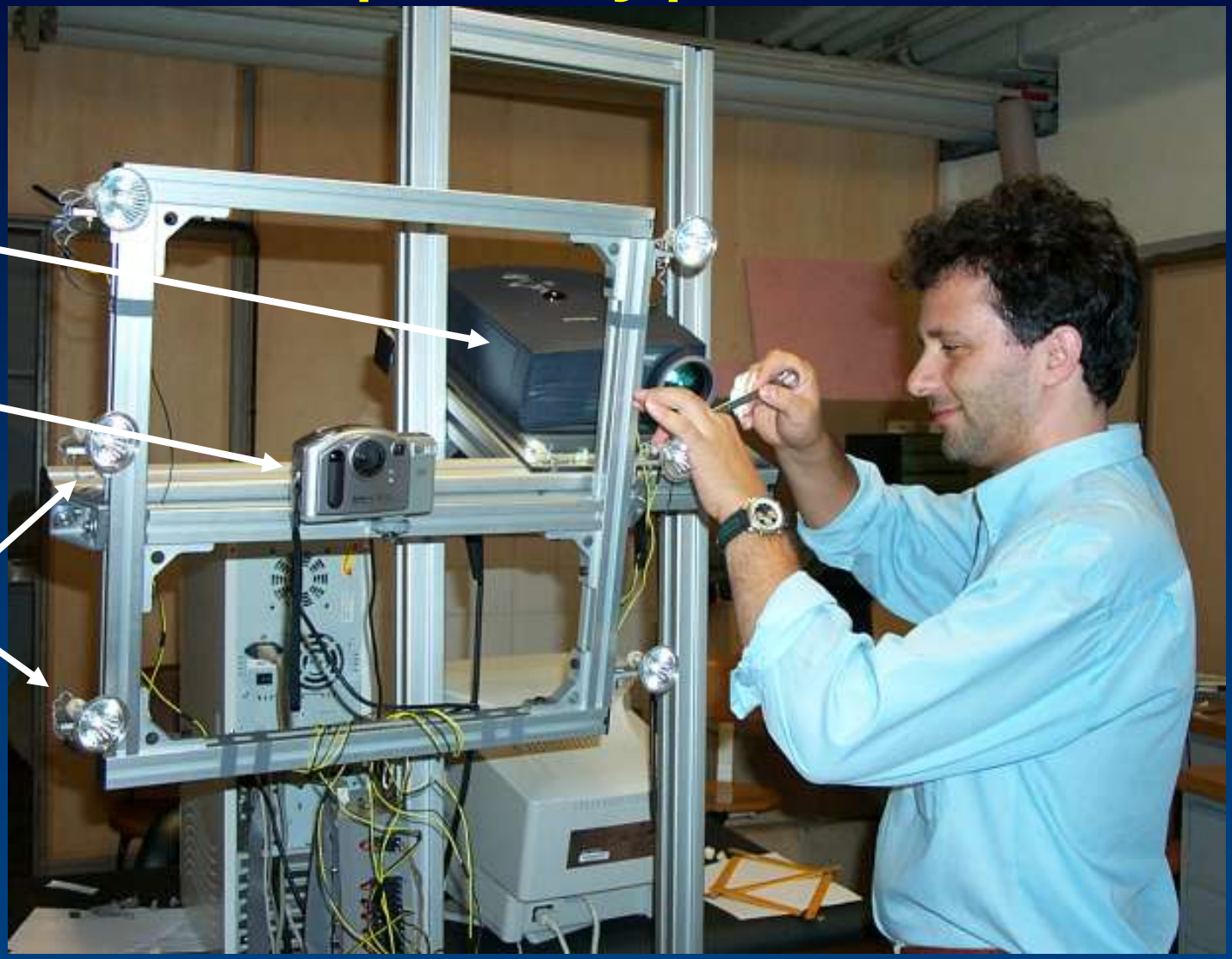
The scanner can also acquire color information:

• by taking a picture with white pattern or…

• by taking a set of pictures using different lights for shading removal.

The geometry is aligned to the color texture by definition.

The prototype



What about the accuracy of the system?

The accuracy depends on:

- The video projector quality
- The photo camera quality
- The calibration accuracy

And, mainly, on

- The scanned material (dark, shiny surfaces are difficult to scan).

Scanner specifications

- Video projector: 1024x768 Digital Light Processor, high contrast.
- Photo camera: consumer digital photo camera 1800x1200 pix, USB connection.

Scanner specifications

- Field of view: 750x500 cm (at 130 cm)
- Depth of view: 130 cm to … (the video projector can’t focusing at lower distance)
- Resolution: 512x768 points
- Accuracy (z axis) : approx. +/- 0,02 cm on white opaque surface, (experimental measurement)
- Scan speed: 180 secs/scan (the photo camera is very slow).

A case study: Minerva of Arezzo

Results: Minerva

Ancient Greek statue of "Minerva di Arezzo"

Florence Archeological Museum

~170 cm high,

146 scans

Results:

Copy of Laurana Bust (1400)

29 Scans,

1 working day

Conclusions

We have presented a new 3D scanner system:

- Based on consumer technology
- It uses a line-stripe hybrid pattern that assures greater precision and speed
- It may acquire also the color information

vcg.iei.pi.cnr.it/~rocchini

rocchini@iei.pi.cnr.it