Structured Light Based Reconstruction Under Local Spatial Coherence Assumption

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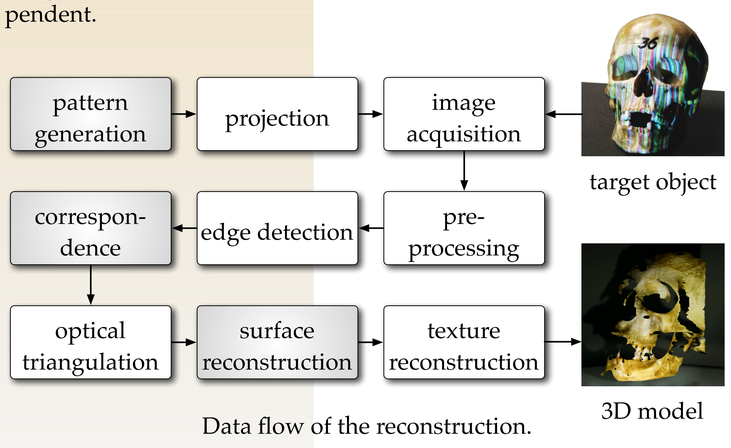
Range Scanning Pipeline

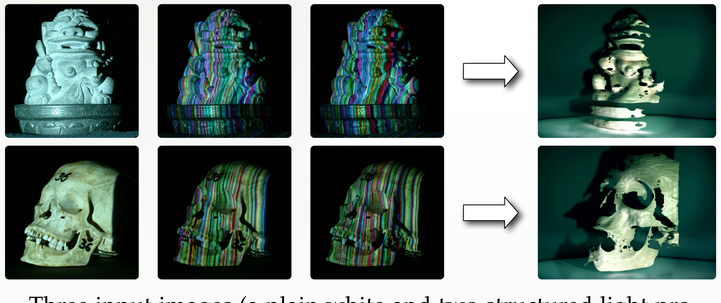
Objectives

- **Speed:** To use very few acquisitions to perform reconstruction.
- **Robustness:** To ensure robustness against high frequency shapes and inappropriate reflection properties.
- **Accuracy:** To make use of the full projector and camera sampling capabilities for the highest resolution.
- **Flexibility:** To allow the projection and acquisition image resolutions to be independent.

Our minimalistic projector-camera based 3D scanner uses a time-coded color structured light.



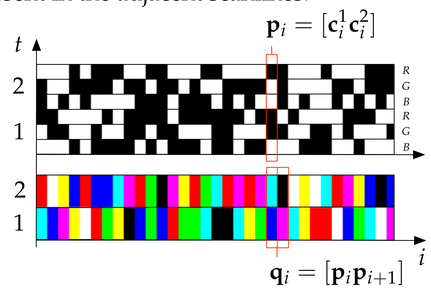
Data flow of the reconstruction.



Three input images (a plain white and two structured light projections) are required for each of the above reconstructions.

A Spatio-temporal Pattern

- **Local Spatial Coherence Assumption**
  - Horizontal: Two adjacent stripe boundaries in a camera scanline correspond to adjacent projected stripe boundaries.
  - Vertical: Stripe boundaries detected in any camera scanline are also present in the adjacent scanlines.

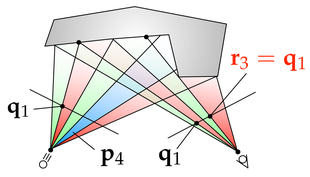


- **Spatio-temporal stripe sequence**: $\mathbf{P} = [\mathbf{p}_1 \dots \mathbf{p}_n]$, where t stripes accumulated over time form a stripe color combination $\mathbf{p}_i = [\mathbf{c}_i^1 \dots \mathbf{c}_i^t]$ and $\mathbf{c}_i^j \in \{0,1\}^3$ is the RGB-color of frame j
- **Properties of P**
  - Detectable stripe boundaries:

$$\forall i \in \{1,\dots,n-1\} : \mathbf{p}_i \neq \mathbf{p}_{i+1}$$

  - Time varying stripe boundaries:

$$\forall i \in \{1,\dots,n-1\} \exists t_1, t_2 : t_1 \neq t_2 \,, \quad [\mathbf{c}_i^{t_1} \mathbf{c}_{i+1}^{t_1}] \neq [\mathbf{c}_i^{t_2} \mathbf{c}_{i+1}^{t_2}]$$



As $\mathbf{p}_4$ is completely occluded, $\mathbf{r}_3$ can be falsely corresponded to $\mathbf{q}_1$.

  - Globally unique pairs of close stripes:

$$\forall i,j,k,l \in \{1,\dots,n\}, \quad 1 \leq |i-j| \leq d, 1 \leq |k-l| \leq d : \quad [\mathbf{p}_i \mathbf{p}_j] = [\mathbf{p}_k \mathbf{p}_l] \;\Rightarrow\; (i=k) \wedge (j=l)$$

→ An exhaustive search yields a sequence of unique stripe boundaries: $\mathbf{Q} = [\mathbf{q}_1 \dots \mathbf{q}_{n-1}]$, where $\mathbf{q}_i = [\mathbf{p}_i \mathbf{p}_{i+1}]$ represents a single stripe boundary.

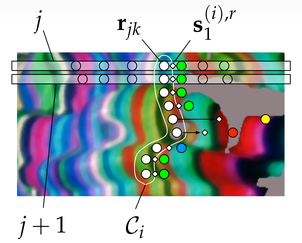
- **Benefits**
  - Two projections exhaust the full projector resolution using one pixel wide stripes.
  - Ambiguous correspondences due to high frequency occlusions can be avoided.

Correspondence

- The kth acquired stripe boundary in row j:

$$\mathbf{r}_{jk} = [\mathbf{a}_{jk} \mathbf{a}_{j,k+1}] \in [0,1]^{6t} \,, \quad j = 1,\dots,r \,,\; k = 1,\dots,m_j \,,$$

where $\mathbf{a}_{jk}$ and $\mathbf{a}_{j,k+1}$ are the left and right acquired color combinations adjacent to the stripe boundary



- **Algorithm**
  1. Assign each $\mathbf{r}_{jk}$ to a cluster $\mathcal{C}_i$ so that every $\mathcal{C}_i$ contains at most one $\mathbf{r}_{jk}$ from each row j.
  2. Determine the set of left and right side medial axis colors of $\mathcal{C}_i$:

$$\mathcal{S}_i^{\mathrm{l}} = \{\mathbf{s}_1^{(i),\mathrm{l}}, \dots, \mathbf{s}_{q_i}^{(i),\mathrm{l}}\} \quad \text{and} \quad \mathcal{S}_i^{\mathrm{r}} = \{\mathbf{s}_1^{(i),r}, \dots, \mathbf{s}_{q_i}^{(i),r}\} \;.$$

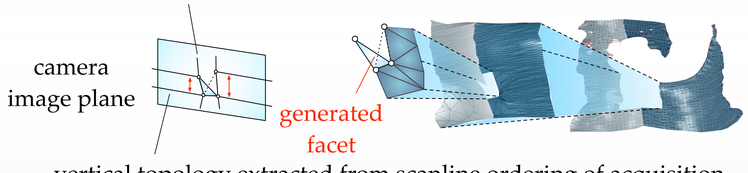
  3. Compute left and right side medians of $\mathcal{C}_i$:

$$\tilde{\mathbf{s}}_i := [\text{median}\, \mathcal{S}_i^{\mathrm{l}} \;\; \text{median}\, \mathcal{S}_i^{\mathrm{r}}] \;.$$

  4. Assign all $\mathbf{r}_{jk} \in \mathcal{C}_i$ to $\tilde{\mathbf{s}}_i =: \tilde{\mathbf{s}}_{jk}$.
  5. For each row j, determine, for all k, the closest pairs $(\tilde{\mathbf{s}}_{jk}, \mathbf{q}_i)$ until no more matches are possible.
- **Benefit:** Exploitation of *expressiveness* of colors located at stripe medial axes and *robustness* of those located at the vicinity of stripe boundaries, which are less susceptible to spatial discontinuities, undetected and overdetected stripe boundaries

Surface Reconstruction

horizontal topology extracted from correspondence data



vertical topology extracted from scanline ordering of acquisition

- Recovery of a topologically consistent manifold surface that is insensitive to noise, outliers, and anisotropic sampling density
- Filling of undesired holes under local spatial coherence assumption