Soft 3D Reconstruction for View Synthesis

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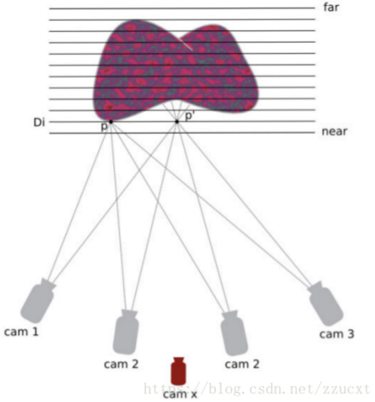
Objective

Assuming that our cameras are calibrated and we have known the intrinsic parameters and projection matrix of these cameras, the main task in this paper[2] aims to render a virtual view based on 3D reconstruction obtained from given inputs images.



Overview

1. Soft 3D Reconstruction from given views
   - Initial depth estimation
   - Soft 3D Reconstruction
2. Image Synthesis for virtual view
   - Soft View Synthesis

Initial depth estimation

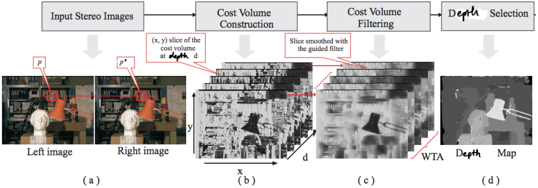


Figure: (a) Input stereo images. (b) Cost volume construction. Each (x, y) slice holds the dissimilarity costs at a given depth value d. (c) Cost volume filtering. Filtering is applied on each of the (x, y) slices using the guided filter[1]. (d) Depth selection. For each pixel, we select the depth of lowest costs in the smoothed volume of (c).

Three main steps:

- Cost Volume Construction
- Cost Volume Filtering
- Depth Selection

Cost Volume Construction

For a reference view with neighborhood views, we construct an array of shape $(rows, cols, DispRange)$, where the value $C(p, d)$ for pixel $p = (x, y)$ at depth d is obtained by measuring the dissimilarity between pixel p of the reference image and pixel p' of neighbor image.

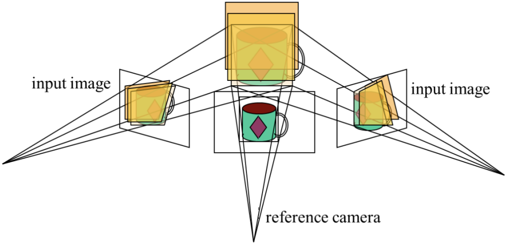


Figure: Sweep Plane

Measuring Dissimilarity

$$C(p,d) = \alpha Min(T_c, M(p,d)) + (1-\alpha) Min(T_g, G(p,d)) \tag{1}$$

where α balances the color and gradient terms, T_c, T_g are color and gradient truncation values. In equation (1), color absolute difference $M(p,d)$ is expressed as:

$$M(p,d) = \sum_{i=0}^{i=3} |I^i_{ref}(p) - I^i_{neighbor}(p^{'})| \tag{2}$$

where $I^i(p)$ denotes the value of the *ith* color channel(RGB)at pixel p. Similarily, gradient absolute difference $G(p,d)$ is computed by:

$$G(p,d) = |\nabla_x(I_{ref}(p)) - \nabla_x(I_{neighbor}(p^{'}))| \tag{3}$$

where $\nabla_x(I(p))$ denotes the gradient in x direction computed at pixel p in image I.

Cost Volume Filtering

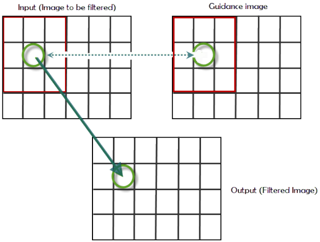


Figure: Guidance image and guided image

$C^{'}(p, d)$, the filtered cost value at pixel p and slice d:

$$C^{'}(p, d) = \sum_{q} W_{p,q}(I)C(q, d) \tag{4}$$

where the guidance image is the reference color image and the guided image is an (x, y) slice of the cost volume.

$W_{p,q}$ is expressed as follows:

$$W_{p,q} = \frac{1}{|\omega|^2} \sum_{k:(p,q)\in\omega_k} (1 + (I_p - \mu_k)^T (\Sigma_k + \epsilon U)^{-1} (I_q - \mu_k)) \quad (5)$$

Here, Σ_k and μ_k are the covariance matrix and mean vector of image I in the window ω_k with size (r, r), centered at pixel k. The number of pixels in this window is $|\omega|$, ϵ is a smoothness parameter, I_i, I_j and μ_k are 3 x 1(RGB) vectors.

Depth Selection

Once the cost volume slices are filtered as $C^{'}$, for each pixel, we select the depth of lowest costs in the smoothed volume $C^{'}$:

$$d_p = argmin_{d \in D} C^{'}(p, d) \tag{6}$$

where D represents the set of all allowed depths.

Soft 3D Reconstruction

Problems:

- One type of uncertainty is between neighboring pixels within a single image.
- Another type of uncertainty is across different views, e.g, multiple depth maps from different views do not always agree with each other about commonly visible points.

Solutions:

- Consider each pixels depth as a distribution originating from its neighborhood in the depth map rather than a single depth.
- Construct a vote volume to aggregate the consensus at each point in space.

$$VoteVal_{\mathrm{raw}}(x, y, z) = \begin{cases} 1 & z = D(x, y) \\ 0 & otherwise \end{cases}$$

$$VoteConf_{\mathrm{raw}}(x, y, z) = \begin{cases} 1 & z <= D(x, y) \\ 0 & otherwise. \end{cases}$$

Consensus and Visibility Function

- **Filtered vote volume**

$$VoteVal(x,y,z) = \sum_{(\hat{x},\hat{y})\in W(x,y)} w(x,y,\hat{x},\hat{y})\, VoteVal_{\text{raw}}(\hat{x},\hat{y},z)$$

$$VoteConf(x,y,z) = \sum_{(\hat{x},\hat{y})\in W(x,y)} w(x,y,\hat{x},\hat{y})\, VoteConf_{\text{raw}}(\hat{x},\hat{y},z),$$

- **Consensus function(array)**

$$Consensus'(x,y,z) = \frac{\sum_{k\in M} VoteVal_k(x'_k,y'_k,z'_k)}{\sum_{k\in M} VoteConf_k(x'_k,y'_k,z'_k)}$$

- **Soft Visibility Function(array)**

$$SoftVis(x,y,z) = max(0, 1 - \sum_{\hat{z}\in Z, \hat{z}<z} Consensus(x,y,\hat{z})).$$

Soft View Synthesis

- Calculate consensus volumes and then soft visibility volumes for all input views.
- Calculate interpolation weight $W_k()$ for each input view based on the geometry relation with synthesized view.
- In the synthesized view's reference, the color at a 3D point is interpolated from the input images $I_k()$:

$$Color_{\text{synth}}(x, y, z) = \frac{\sum_k SoftVis_k(x'_k, y'_k, z'_k) W_k(x'_k, y'_k) I_k(x'_k, y'_k)}{\sum_k SoftVis_k(x'_k, y'_k, z'_k) W_k(x'_k, y'_k)}$$

Soft View Synthesis

- The geometry(consensus) in front of the synthesized view is smoothly interpolated from our input views using our weights $W_k()$:

$$Consensus_{\text{synth}}(x, y, z) = \sum_k W_k(x'_k, y'_k) Consensus_k(x'_k, y'_k, z'_k)$$

- Once we have $Consensus_{synth}$, we then obtain $SoftVis_{synth}$ by:

$$SoftVis(x, y, z) = max(0, 1 - \sum_{\hat{z} \in Z, \hat{z} < z} Consensus(x, y, \hat{z}))$$

- Define $CC()$ as consensus clamped to the remaining ray visibility:

$$CC(x, y, z) = min(Consensus_{\text{synth}}(x, y, z), SoftVis_{\text{synth}}(x, y, z))$$

- Synthesized image

$$I_{\text{synth}}(x, y) = \frac{\sum_{z \in Z} Color_{\text{synth}}(x, y, z) CC(x, y, z)}{\sum_{z \in Z} CC(x, y, z)}$$

Conclusion

Contributions:

- A fast, local stereo methods can produce high quality view synthesis results.
- Vote-based representation is proposed, which provides visibility estimates to perform per-pixel view selection and improve depth edges in depth estimation, and provide soft visibility weights in synthesis.

Limitation: Geometry is reconstructed directly in volumes, so memory consumption increase linearly with depth precision, which limits the amount of free view-point movement away from the source views.

References

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