Abstract

- Binocular Stereo algorithms use correspondence to derive depth information. In practice they will use a smoothing term to compensate for smoothly shaded areas where correspondence fails. Such a term usually assumes (fronto-parallel) piecewise planar surfaces.
- In areas with a known shading model shape-from-shading (SfS) can be used to derive per-pixel orientation information, modelling the surface as being curved rather than planar.
- Our goal is to integrate these two sources of information, depth from stereo and orientation from SfS. The aim is to generate results better than either approach alone.
- We work with disparity from stereopsis and change-in-disparity calculated from SfS. Using Gaussian belief propagation of a Gaussian-Markov random field we find the MAP estimate of the disparity.
- Stereopsis and SfS are performed with dedicated algorithms. A Lambertian reflectance model is assumed for SfS, with per-segment albedo estimated using an initial surface estimate derived from stereopsis alone. A single known light source is assumed.
- We compare the results for two scenes with ground truth, in each case running the algorithm using SfS information. A qualitative improvement is also observable.

Integration with Belief Propagation

- We integrate the disparity and differential of disparity together with belief propagation on a Gaussian-Markov random field.
- The algorithm runs this step twice, first with the differential of disparity set to zero, making it a smoothing operation; and a second time with the SfS calculated disparity differentials.
- Belief propagation iteratively passes messages representing probability distributions between nodes. In our case these represent the distribution on disparity for individual pixels:

\[ m_{st}^{(n)}(x) = \alpha \prod_{(x,y) \in A} m_{st}^{(n-1)}(x) \]

\[ m_{st}^{(n)}(x) \] - message from node t to node s at iteration n.
\[ \psi_{st}(x,y) \] - compatibility between nodes, parametrised by SfS.
\[ \psi_{st}^{(n)}(x,y) \] - disparity provided by Stereo Algorithm.

- Gaussian distributions may be represented as:

\[ \psi_c(x,y) = \exp \left( \frac{1}{2} (x - \mu)^2 \right) \]

the disparity provided by stereopsis may then be represented as:

\[ \psi_s(x,y) = \psi_c(x,y) \]

if the change in disparity between two adjacent pixels is \( \Delta d \), and \( P_{st} \) is a precision which reflects the accuracy of the surface normal, then a compatibility function can be given by:

\[ \psi_{st}(x,y) = \exp \left( -\frac{1}{2} (x - \mu)^2 \right) \]

- We can define:

\[ n_t = n_s + \sum_{(x,y) \in A} P_{s\mu} \]

and from the above define the messages passed between adjacent nodes:

\[ m_{st}^{(n)}(x) = \phi[P_{st}, P_{st}] \]

\[ P_{st} = \frac{P_{s\mu} + \frac{1}{2}(P_{s\mu} - P_{st})}{P_{st} + \frac{1}{2}(P_{s\mu} - P_{st})} P_{s\mu} \]

after a sufficient number of iterations the final disparity may be calculated:

\[ \mu(t) = \frac{1}{n^2_S} \sum_{(x,y) \in A} m_{st}(x) \]

Integration with Shape-from-Shading

- We have shown a relatively simple method of combining stereopsis and SfS. The combined results are shown to be quantitatively better where the SfS works. The output is also perceptually better.
- The quality of SfS, mostly due to albedo estimation, and the ability of the stereopsis to handle smoothly shaded areas appear to be limiting factors. Improved algorithms, probably with greater integration, are required.
- Requiring knowledge of the lighting is a major restriction.
- Orientation sources other than SfS could be considered.

Method

Integration (With Fronto-Parallel Planes Assumption)

- The Integration process is detailed to the right.
- The Stereo Algorithm uses dynamic programming to provide a dense disparity map.
- Segmentation uses the mean shift algorithm.
- Albedo Estimation estimates an albedo for each segment. It uses the irradiance map and smoothed stereo result to calculate per-pixel albedo.
- Shape from Shading is a hard cone constraint and is initialised from the smoothed stereo result. It uses the boundary constraint.

Results

The table gives a quantitative analysis. The first number is the average error for inliers; the second is the percentage of outliers. An outlier is defined as a disparity that deviates more than 8 pixels from ground truth.

Conclusions

- We have shown a relatively simple method of combining stereopsis and SfS. The combined results are shown to be quantitatively better where the SfS works. The output is also perceptually better.
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