Low Power Depth Estimation for Time-of-Flight Imaging

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Motivation
- Time-of-flight (TOF) cameras are useful in many mobile applications (e.g. augmented reality, robot navigation) but its illumination source limits battery life
- Our algorithm minimizes the on time of TOF cameras by estimating depth for rigid objects in real-time on a mobile CPU

Rigid Body Motion Estimation

\[
\begin{align*}
\dot{x}_i &= \frac{x_i}{Z_i} \\
\dot{y}_i &= \frac{y_i}{Z_i} \\
\dot{z}_i &= \frac{-x_i y_i}{Z_i}
\end{align*}
\]

3D motion of objects captured by 2D optical flow

\[
t = (U, V, W)^T, \quad \omega = (A, B, C)^T
\]

Rigid body motion is linear and parameterized by translation, \(t\), and angular velocity, \(\omega\)

3D rigid body motion, \(t\) and \(\omega\), can be estimated using 2D optical flow using linear least squares

Depth Map Estimation Algorithm

1. Optical Flow Estimation – Perform block matching at a sparse set of points
2. Rigid Body Motion Estimation – Use RANSAC to iteratively sample optical flow vectors to estimate the rigid body motion
3. Depth Map Reprojection

Algorithm Evaluation

- Sequentially estimate depth map for sequences from [1]
- Evaluate using mean relative error (MRE): \(100 \frac{1}{N} \sum_{i=1}^{N} \frac{|Z_i - \tilde{Z}_i|}{Z_i}\), where \(N\) is the number of pixels, \(\tilde{Z}_i\) is the estimated depth for the \(i\)th pixel, and \(Z_i\) is the ground truth depth
- Achieves median MRE of 0.85% and outperforms competing schemes (Copy and Transfer)

Key Contribution
Lower the power of TOF imaging by 3X while maintaining MRE of 0.85%

References

We thank Analog Devices for funding this work

Energy-Efficient Multimedia Systems Group (www.rle.mit.edu/eems)