Slow Flow

Exploiting High-Speed Cameras for Accurate and Diverse Optical Flow Reference Data

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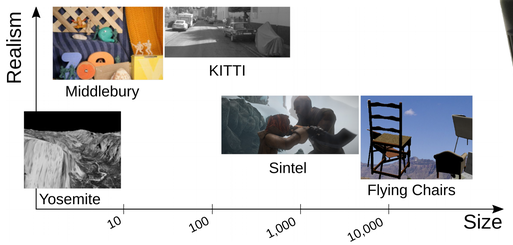
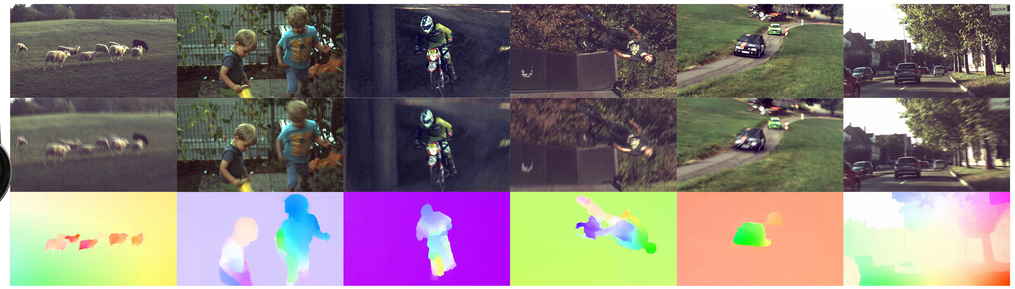
Code and dataset available
www.cvlibs.net/projects/slow_flow/

Motivation

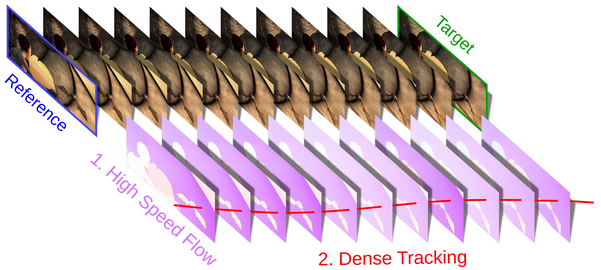
- Real datasets limited in **size** and **diversity**
- Lack of optical flow sensor to obtain ground truth
- Are synthetic datasets **realistic** enough?





Idea

Create reference data from high speed sequences



Challenges

- Accumulation of errors (drift)
- Tracking through occlusions

1. High Speed Flow

Continuous-Discrete Optimization

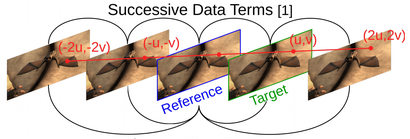
$$E(\mathbf{F},\mathbf{O}) = \int_\Omega \underbrace{\psi^{\mathcal{D}}(\mathbf{F}(\mathbf{p}),\mathbf{O}(\mathbf{p}))}_{\text{Data Terms}} + \underbrace{\psi^{\mathcal{S}}(\mathbf{F}(\mathbf{p})) + \psi^{O}(\mathbf{O}(\mathbf{p}))}_{\text{Spatial Smoothness}} d\mathbf{p}$$

Flow, Occlusion

Data Terms

$$\psi^{\mathcal{F}}(\mathbf{F}(\mathbf{p}),\mathbf{O}(\mathbf{p})) = \underbrace{\mathbf{O}(\mathbf{p})\cdot\psi^{\mathcal{B}}(\mathbf{F}(\mathbf{p})) \quad + \quad (1-\mathbf{O}(\mathbf{p}))\cdot(\psi^{\mathcal{F}}(\mathbf{F}(\mathbf{p}))-\tau)}$$

Successive Data Terms [1]



Reference Data Terms [1]

Improving in Occlusions

Reference | Symmetric | Forward | Occlusion Reasoning

[1] Wang et al. Estimating optical flow by integrating multi-frame information. JISE 2008

2. Dense Tracking

Pixel Trajectories, Visibility

$$E(\mathcal{H}_*,\mathcal{V}_*) =$$

$$\lambda^{\mathcal{D}_A}\sum_{t<s}\psi^{\mathcal{D}_A}_{ts}(\mathbf{H}_t,\mathbf{V}_t,\mathbf{H}_s,\mathbf{V}_s) \quad \text{Appearance Data Term}$$

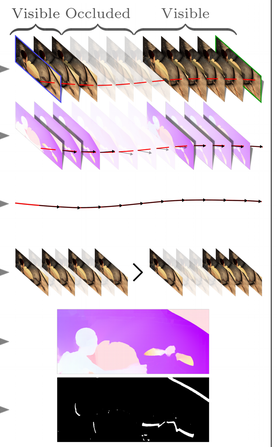
$$+\lambda^{\mathcal{D}_F}\sum_{s=t+1}\psi^{\mathcal{D}_F}_{ts}(\mathbf{H}_t,\mathbf{V}_t,\mathbf{H}_s,\mathbf{V}_s) \quad \text{Flow Data Term}$$

$$+\lambda^{\mathcal{F}_T}\sum_{\mathbf{p}\in\Omega'}\psi^{\mathcal{F}_T}_{\mathbf{p}}(\mathbf{h}_\mathbf{p}) \quad \text{Temporal Flow Smoothness}$$

$$+\lambda^{\mathcal{V}_T}\sum_{\mathbf{p}\in\Omega'}\psi^{\mathcal{V}_T}_{\mathbf{p}}(\mathbf{v}_\mathbf{p}) \quad \text{Temporal Visibilty Smoothness}$$

$$+\lambda^{\mathcal{F}_S}\sum_{\mathbf{p}\sim\mathbf{q}}\psi^{\mathcal{F}_S}_{\mathbf{pq}}(\mathbf{h}_\mathbf{p},\mathbf{h}_\mathbf{q}) \quad \text{Spatial Flow Smoothness}$$

$$+\lambda^{\mathcal{V}_S}\sum_{\mathbf{p}\sim\mathbf{q}}\psi^{\mathcal{V}_S}_{\mathbf{pq}}(\mathbf{v}_\mathbf{p},\mathbf{v}_\mathbf{q}) \quad \text{Spatial Visibilty Smoothness}$$



Particle Belief Propagation

- Discretization of the solution space
- Data-driven proposal generation scheme
- Linear spatial and temporal extrapolation in occlusions

Validation

Sintel High Speed Dataset

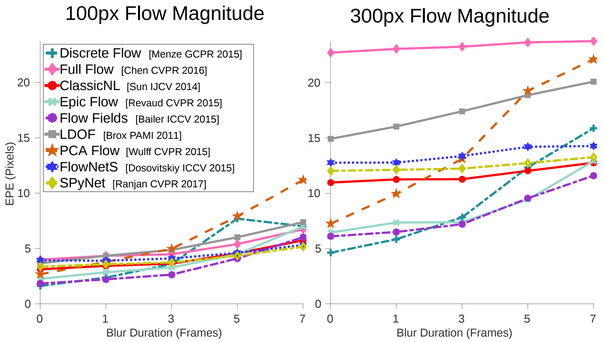
Methods	Visible (Edges)	Occluded (E.)
Epic Flow (24fps)	2.45 (10.10)	16.54 (20.68)
Epic Flow (Accu. 144fps)	1.04 (4.41)	17.09 (18.44)
Slow Flow (Accu. 144fps)	**0.78** (4.43)	15.24 (17.28)
Slow Flow (Accu. 1008fps)	1.35 (**2.60**)	19.18 (17.93)
Slow Flow (Full Model)	0.87 (4.65)	**9.45** (**14.28**)

Reconstruction Dataset

Flow Magnitude	100	200	300
Epic Flow	1.54	9.33	25.11
Slow Flow	**1.47**	**3.47**	**5.13**

Real-World Benchmark

Input Image | High Frame Rate | Low Frame Rate



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