Unsupervised Flow Refinement near Motion Boundaries

Shuzhi Yu, Hannah H. Kim, Shuai Yuan, Carlo Tomasi

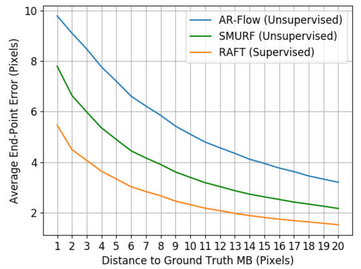
Department of Computer Science, Duke University

BMVC 2022

Introduction

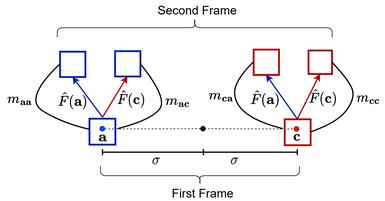
- The **average** End-Point Errors (EPEs) of top flow estimators can be as accurate as sub-pixels
- Flow estimates worsen near Motion Boundaries (MB), for both supervised and unsupervised estimators (right plot)
- Our goal is to improve the flow estimates near MBs under unsupervised setting
- We first detect MBs and then refine flow near them

Plots of the errors of the flow estimates as a function of the distance to MBs, on the Sintel dataset

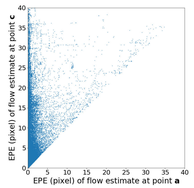


Method – Motion Boundary Detection

- Input: Three consecutive frames, and forward and backward flow estimates (from middle frame) by an unsupervised flow estimator
- Detects MBs by a hysteresis thresholding method from three feature maps: Image edge map, motion discrepancy map, proposed map of invalid smooth motion
- Map of invalid smooth motion: Different matching costs for patch *a* and patch *c* where the motion should not be smooth



Observation 1: Changes of appearance of the blue patch is more consistent with the blue motion than with the red motion, vice versa.



Observation 2: The estimation errors of flow on the two sides are asymmetric. Point *a* and *c* reside on the two sides of a MB.

Result

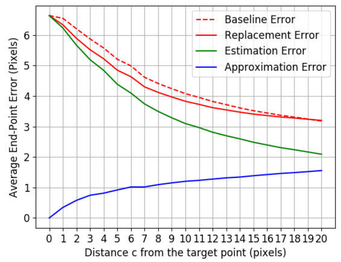
- Our method consistently outperforms the baseline (BL) method with different input flows

		SMURF [41]			AR-Flow [24]			LDOF [3]		
		Flow (EPE)	BL (F1)	Ours (F1)	Flow (EPE)	BL (F1)	Ours (F1)	Flow (EPE)	BL (F1)	Ours (F1)
Sintel	Clean	2.01	70.3	**74.5**	2.79	53.1	**64.3**	4.18	54.8	**59.2**
	Final	2.87	63.5	**67.4**	3.73	48.5	**57.1**	6.25	46.7	**51.2**

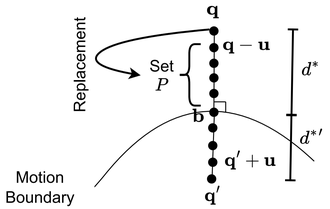
Table 1: F_1-score for **MB estimation** with different input flow estimates, compared with the baseline method (BL). SMURF [41] and AR-Flow [24] are two top unsupervised flow estimators, and LDOF [3] is a top classical flow estimator.

Method – Flow Refinement

- Input: Estimated flow map and detected MBs
- Replace the flow estimates near MBs with those away MBs
  - ❖ A better replacement flow may exist away MBs



Two types of replacement errors, namely estimation error and approximation error. On average, replacing flow is fruitful (red solid line is below the red dashed line), on the Sintel dataset.



Only the flow estimates on one side of a MB may be replaced. That side has smaller true motion.

Result

- Our refinement method consistently improve the flow estimates in set *P*

Input Flow	Dataset	Input Flow AEPE	Replaced Points			
			% of MB points	Init AEPE	Our AEPE	↓
LDOF [3]	Clean	4.18	51.02	12.81	**10.84**	15.38%
	Final	6.25	33.24	13.68	**11.28**	17.54%
	KITTI	19.63	-	44.95	**43.76**	2.65%
ARFlow [24]	Clean	2.79	48.13	9.52	**7.90**	17.02%
	Final	3.70	34.16	8.96	**7.42**	17.19%
	KITTI	3.46	-	19.29	**18.62**	3.47%
SMURF [41]	Clean	2.03	61.28	5.47	**5.17**	5.48%
	Final	2.90	39.98	5.71	**4.72**	17.34%
	KITTI	1.94	-	15.35	**14.69**	4.30%

Table 3: The average EPE and average EPE improvement with our replacement method near our estimated MBs on the flow estimates by different flow estimators. Note the ARFlow uses 3 frames to estimate the flow. About 1% of all MPI Sintel pixels are true MB points. This information is unknown for KITTI, which has sparse ground truth flow.

Ablation Study

- Our proposed map of invalid smooth motion (M_{ism}) identifies false negative MB detections, highlighted by red circles

Figure 4: MB detection samples with our method and the baseline on Sintel (clean) with SMURF input. Main differences are highlighted by red ovals.

- Edge map (M_e) and map of invalid smooth motion complement each other

	Baseline (Map M_{md})	+Map M_e	+Map M_{ism}	Ours (+M_e+M_{ism})
Clean	70.3	39.7	49.7	**74.5**
Final	63.5	42.5	54.2	**67.4**

Table 2: Performance of MB detection (F_1) of our proposed hysteresis scheme with different map combinations. Input flow is estimated by SMURF [41].

- Qualitative study of flow replacement
  - ❖ The flow estimates in set *P* (red vector) are perturbed by the front moving objects
  - ❖ The replacement flow away from MBs are less perturbed and the replacement makes improvement

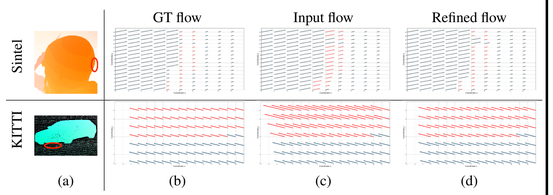


Figure 5: Two examples of flow (quiver plots with flow down-scaled by 70) before and after replacement on set *P* (red vectors). Input flow is from SMURF [41]. On these two patches, replacement decreases the AEPE from 24.62 to 3.40 pixels per frame for the Sintel example and from 33.23 to 16.87 pixels per frame for the KITTI example.

Conclusion and Future Work:

- The proposed method both detects MBs and improves flow estimates near them
- It exploits the fact that the error in taking flow estimates from some wrong point may be smaller than the error caused by proximity to a MB
- Limitation: The benefit of replacing flow is bounded
- Future work may directly tackle the estimation error near MBs