Upgrading Optical Flow to 3D Scene Flow through Optical Expansion

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Monocular 3D Scene Motion Estimation

**Problem:** Estimate the 3D motion of dynamic scene elements using a monocular camera.
Monocular 3D Scene Motion Estimation

**Challenge**: Infinite pairs of 3D points correspond to the 2D flow observation.
Monocular 3D Scene Motion Estimation

**Challenge:** Infinite pairs of 3D points correspond to the 2D flow observation.

Prior work
- Motion prior [Kumar et al., ICCV 17, ...]
- Data-driven depth prior [Brickwedde et al., ICCV 19, ...]
Optical Expansion and Motion-in-depth

Change of perceptual size corresponds to change of physical depth.

Upgrading to 3D Scene Flow

(a) with optical flow

(b) optical flow + expansion
Upgrading to 3D Scene Flow

(b) optical flow + expansion

(c) optical flow + expansion + 1st or 2nd depth
Pipeline Overview

Input frame pair

Optical Flow Estimation

Optical Expansion Estimation

Motion-in-depth Correction

Output 3D scene flow
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Input frame pair

Optical Flow Estimation
Optical Expansion Estimation
Motion-in-depth Correction
Output 3D scene flow

Optical Flow Network

Optical flow
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Input frame pair

Optical Flow Estimation

Optical Expansion Estimation

Motion-in-depth Correction

Output 3D scene flow

Optical flow

Dense, local affine warps

Optical Flow Network

Optic Expansion Network

Optical expansion
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- Optical Flow Estimation
- Optical Expansion Estimation
- Motion-in-depth Correction

Input frame pair

Output 3D scene flow

Optical flow

Optical expansion

Dense, local affine warps

Optical Flow Network

Optic Expansion Network

Motion-in-depth Network

Motion-in-depth
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Optical Flow

3D scene flow $t = Z\hat{t}$

Optical expansion
Learning for 3D Scene Flow Upgrade

Multi-task losses for optical expansion and motion-in-depth estimation.
Learning for 3D Scene Flow Upgrade

Training procedure
1. Pre-train with synthetic Scene Flow Datasets [CVPR 2016]
2. Fine-tune on target domain data, KITTI [JPRS 2018].
Learning for 3D Scene Flow Upgrade

Self-supervised training for optical expansion and optical flow estimation.
Application: Monocular Scene Flow

Off-the-shelf monocular depth network

Output 3D scene flow

Motion-in-depth Correction

Optical Expansion Estimation

Optical Flow Estimation

Input frame pair

1st frame

First frame
Application: Stereo Scene Flow

Off-the-shelf stereo matching network

Input frame pair

Output 3D scene flow

1st stereo pair

Optical Flow Estimation

Optical Expansion Estimation

Motion-in-depth Correction
Monocular / Stereo Scene Flow

Input

Relative depth change (motion-in-depth)


SOTA monocular and stereo scene flow performance on foreground objects of KITTI leaderboard.

Application: LiDAR Scene Flow

Input frame pair

Optical Flow Estimation

Optical Expansion Estimation

Motion-in-depth Correction

Output 3D scene flow

1st frame LiDAR
- High-accuracy than state-of-the-art lidar-only methods
- Can be computed before the next LiDAR sweep is captured

Application: Two-frame SFM

Input frame pair → Optical Flow Estimation → Optical Expansion Estimation → Motion-in-depth Correction → up-to-scale 3D flow → Rigid structure
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Inverse depth

Residual error

Iteration 0  Iteration 1  Iteration 5
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Result from MonoDepth2 [3]

Result from COLMAP [2] (two view)

Ours

Residual error

Overlaid two frames [1]

Thanks! More in our paper ...

- Formalism for upgrading 2D optical flow to 3D scene flow

- Optical expansion is the crucial ingredient enabling the above

- If you are using optical-flow-for-X, consider using optical-expansion as well!