Refraction Wiggles for Measuring Fluid Depth and Velocity from Video
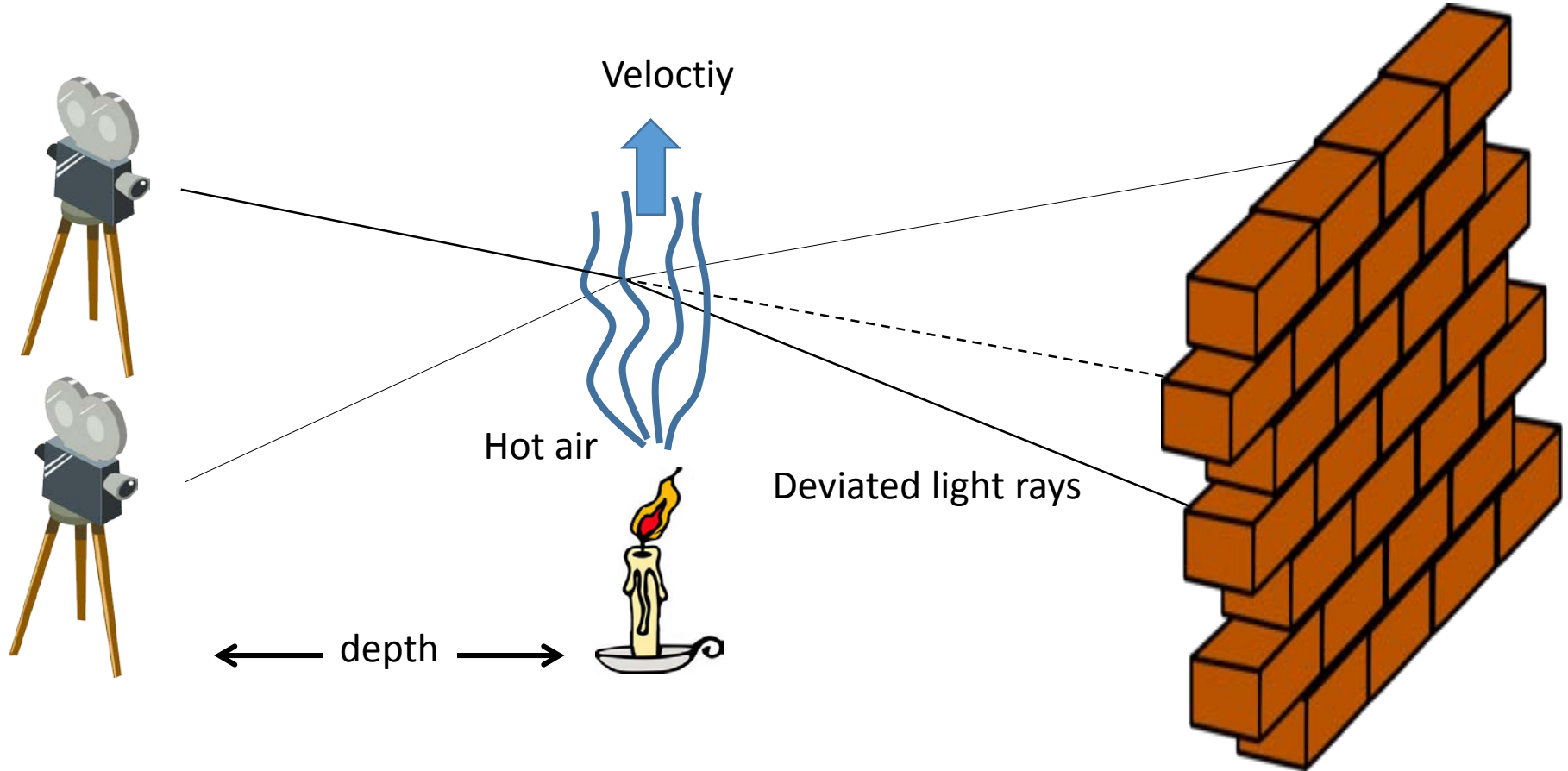
Tianfan Xue[1], Michael Rubinstein[2,1], Neal Wadhwa[1], Anat Levin[3],

Fredo Durand[1], and William T. Freeman[1]

[1]MIT CSAIL   [2]Microsoft Research   [3]Weizmann Institute

CSAIL

Microsoft Research

Weizmann Institute of Science

Measure refractive flow velocity and depth from natural videos

Veloctiy

Hot air

Deviated light rays

depth

- **Single camera**: measure the velocity of air
- **Stereo camera**: measure the depth of air

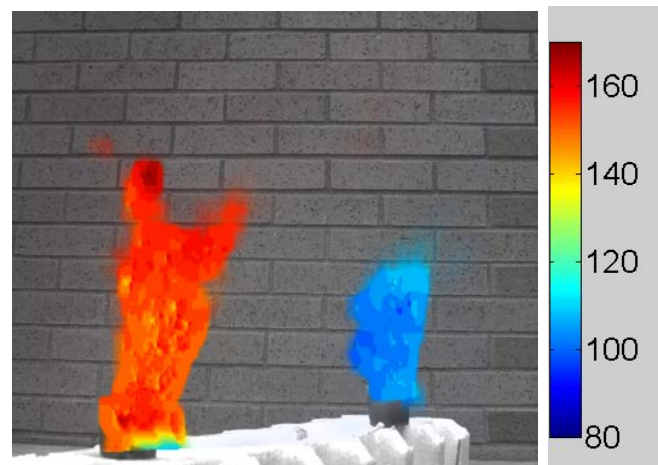# Flow Velocity and Depth Recovered from Videos

Input (right view)

Refractive flow

Motion of air (our result)

Refractive Stereo

Input (left view)

Disparity map of air (out result)

Outline

- **Introduction and related work**
- Algorithm:
  - Wiggle features
  - Measure fluid depth
  - Measure fluid velocity
  - Probabilistic formulation
- Experimental results

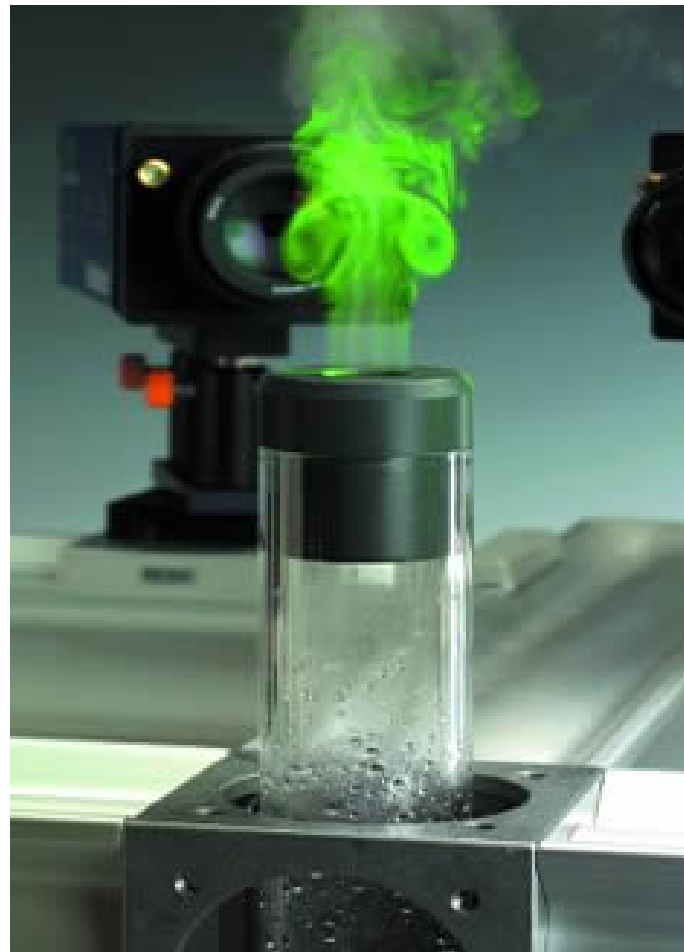# Potential Applications for fluid motion estimation
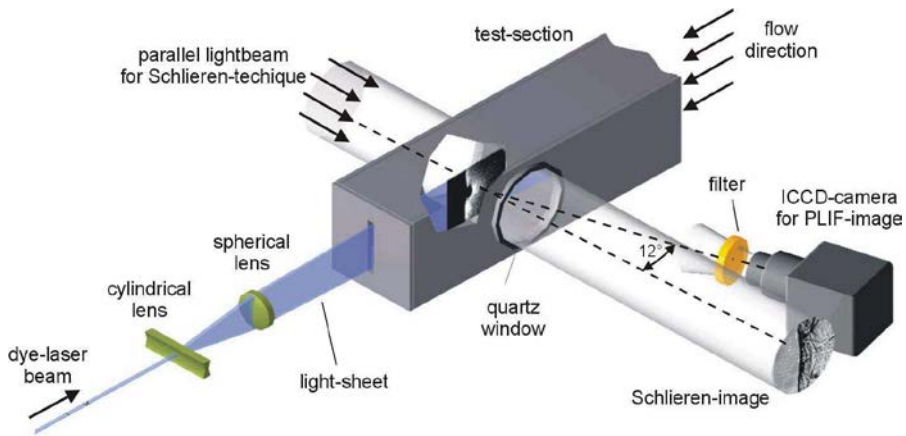

Aircraft scheduling

Toxic gas detection

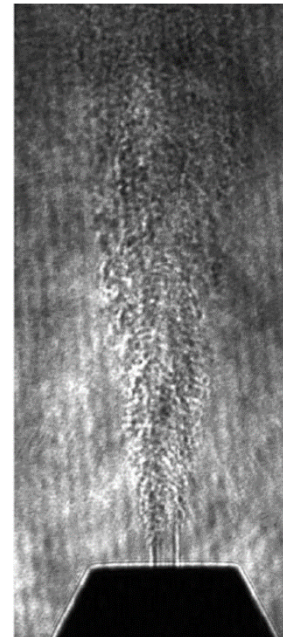# Related work

Particle Image Velocimetry (PIV)

Related work

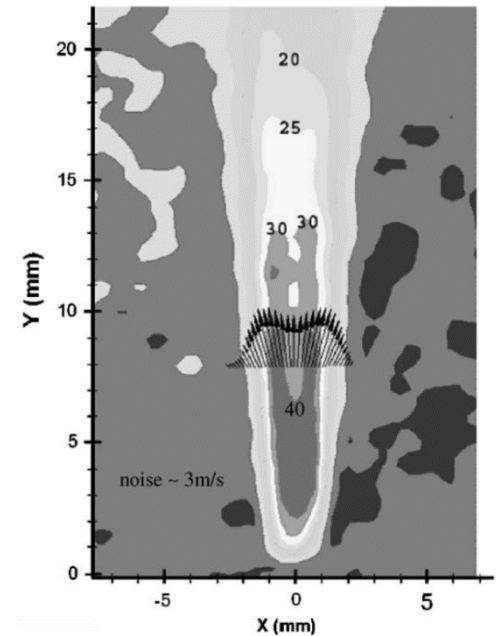Tracer-based method (1): Schlieren photography
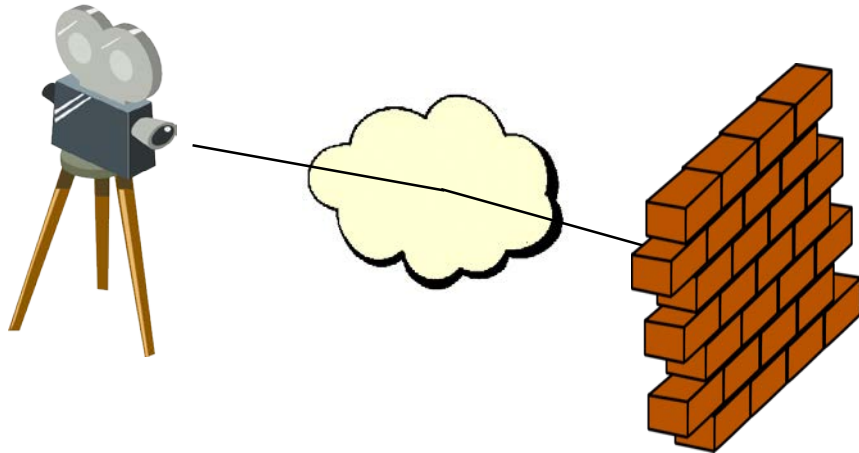

Schlieren setup

Schlieren image

Schlieren PIV
[Jonassen et al., *Schlieren PIV*, 2006]

Image from: http://www2.galcit.caltech.edu/EDL

Related work

Tracer-based method (2): Background Oriented Schlieren (BOS)

BOS setup
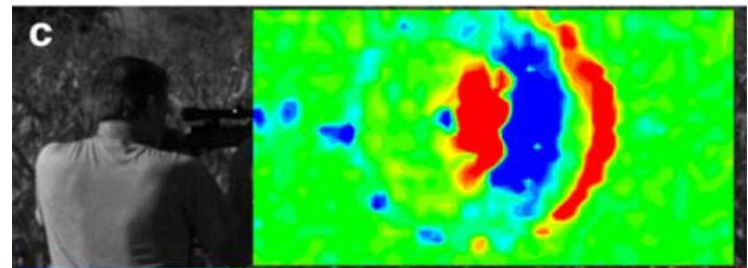
BOS image

Related works
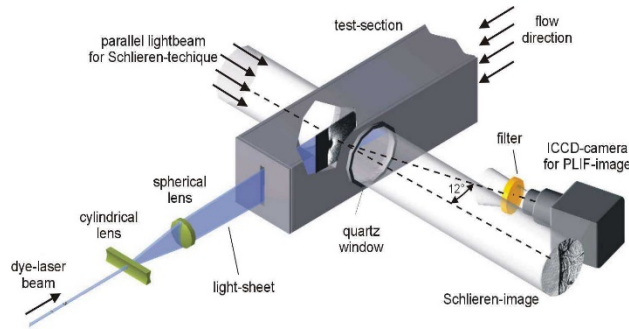
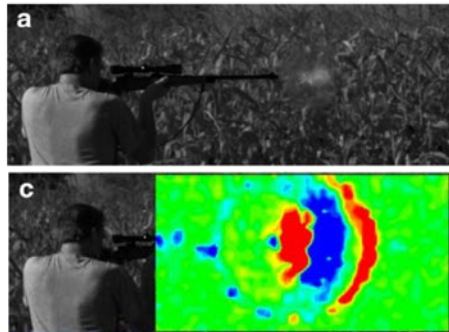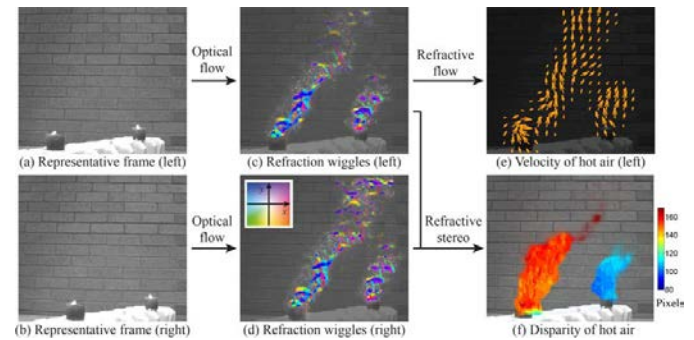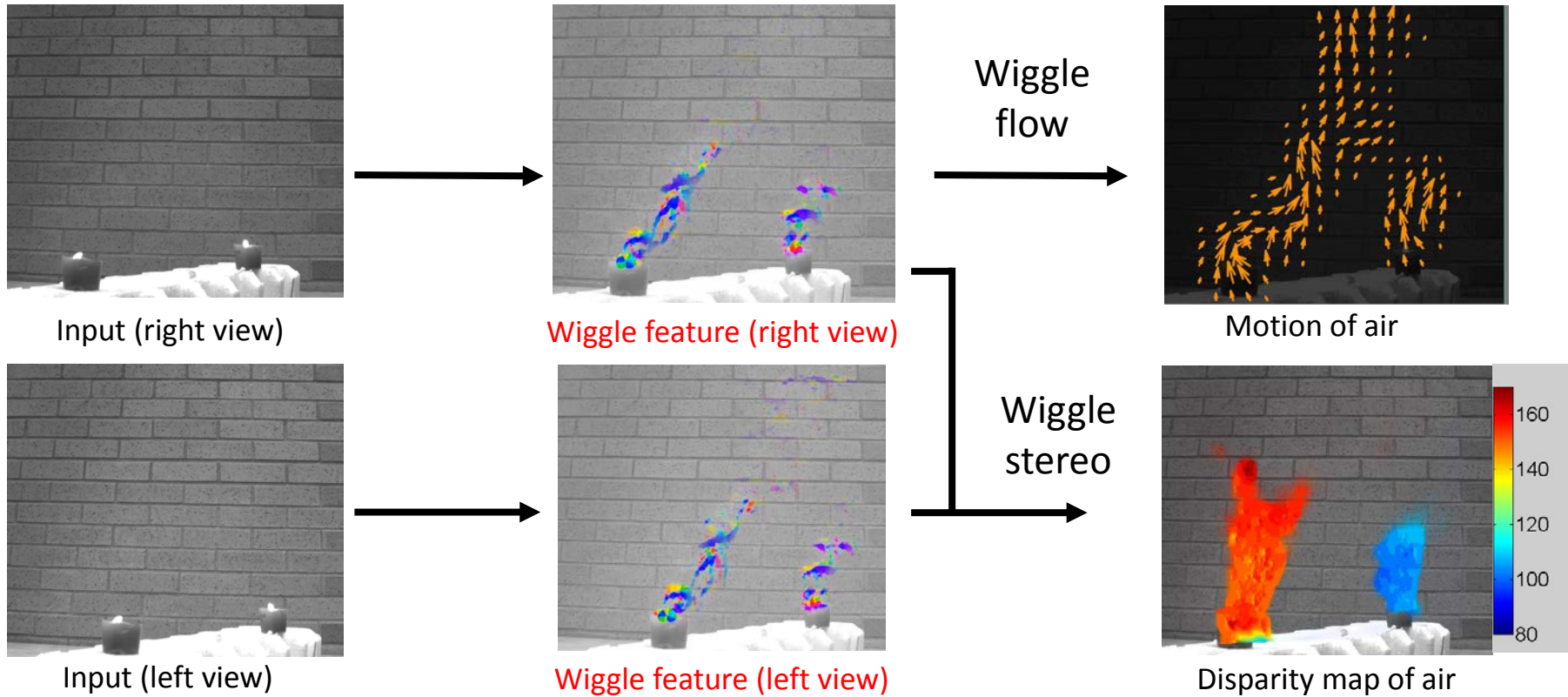|	Visualization	Visualization and Measurement
Complicated Setup	 Schlieren	 Particle Image Velocimetry (PIV) Schlieren PIV
Simple Setup	 Background Oriented Schlieren (BOS)	 Wiggle Stereo and Wiggle Flow
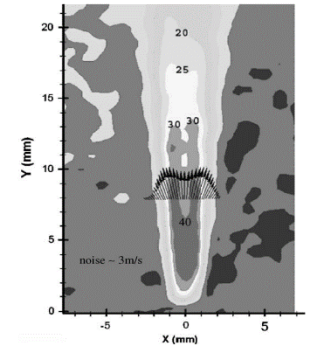
Outline

- Introduction and related work
- **Algorithm:**
  - **Wiggle features**
  - Measurement of fluid depth
  - Measurement of fluid velocity
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- Experimental result

Outline of the algorithm

Input (right view)

Wiggle feature (right view)

Wiggle flow

Motion of air

Input (left view)

Wiggle feature (left view)

Wiggle stereo

Disparity map of air

Wiggle features

- Wiggle features are the distortion of background pattern due to the change of refraction

Solid Background

Time $t + 1$

Refractive object

Image plane

Time t:
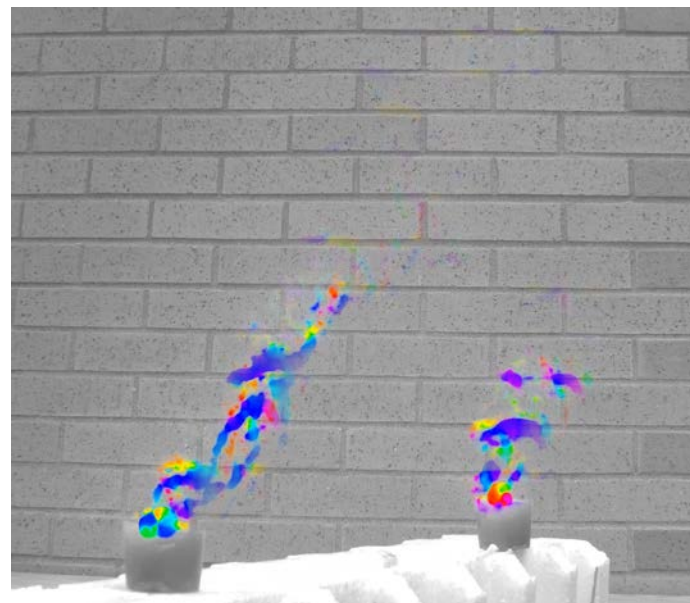
Time $t + 1$:
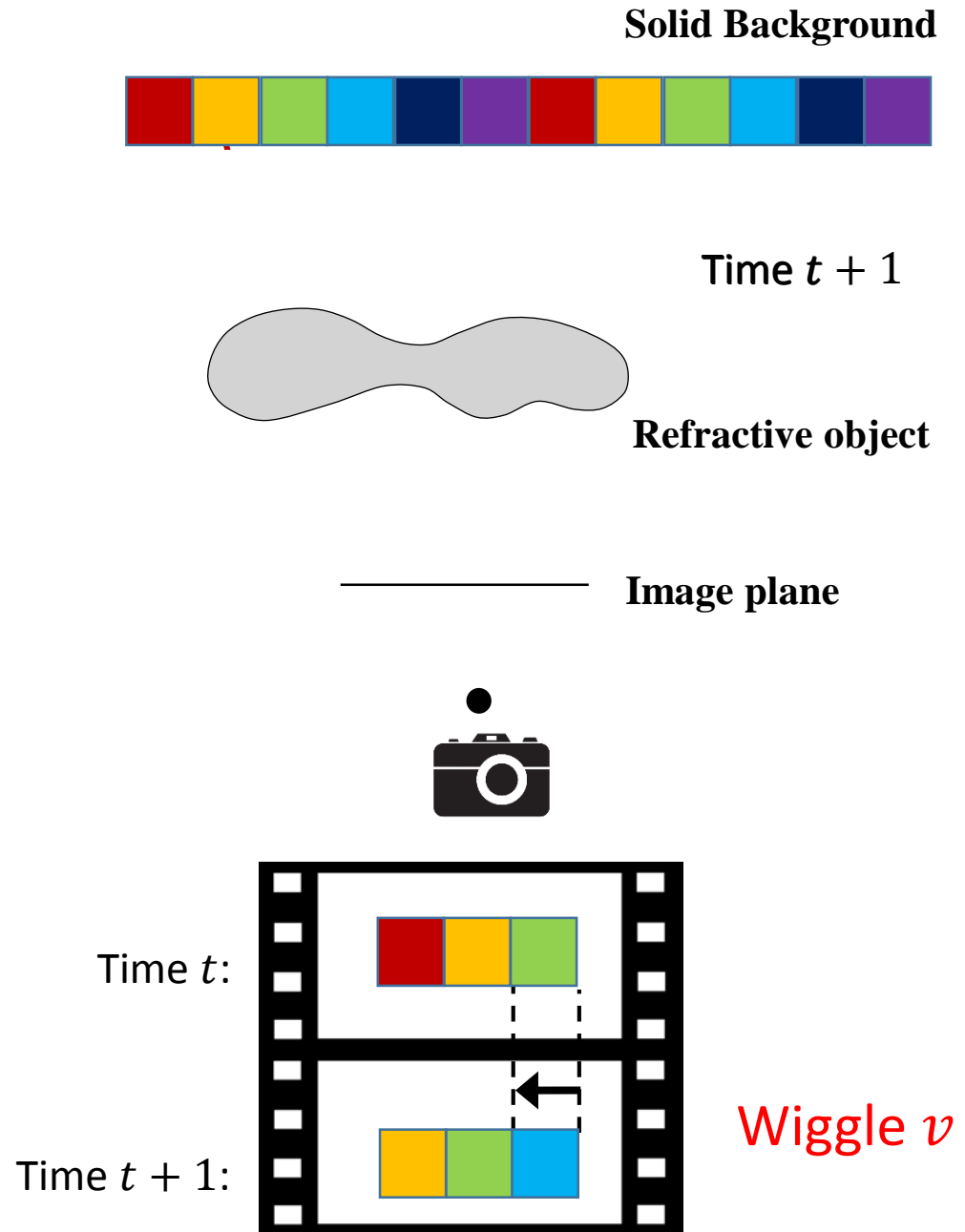
Wiggle v

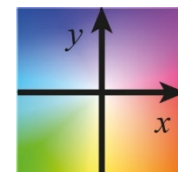# Example of Wiggle Features

Input

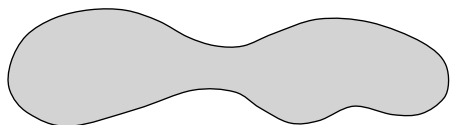Optical
flow

Wiggle feature

Outline

- Introduction and related works
- **Algorithm:**
  - Wiggle features
  - **Measurement of fluid depth**
  - Measurement of fluid velocity
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- Experimental results

Fluid Stereo should fuse *wiggle motions*, not image intensities
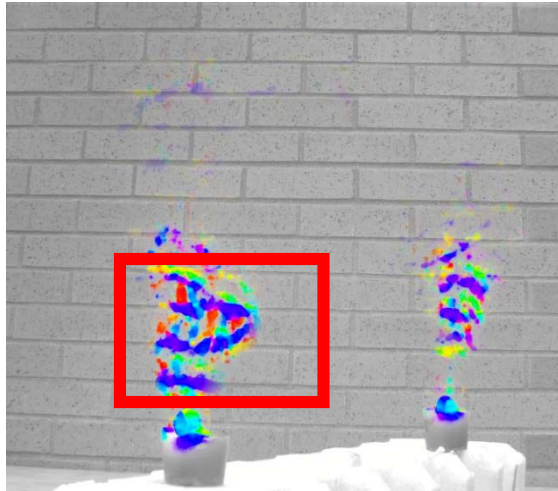
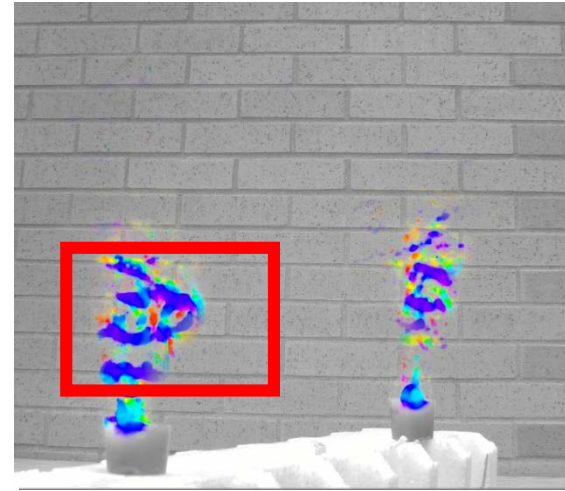Match intensities to find surface depths

Solid Background

Please refer to our paper for the proof of wiggle constancy

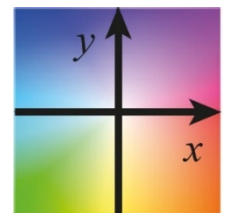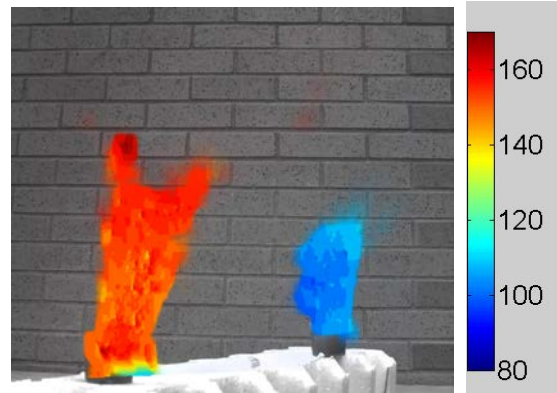# Example of Refractive Stereo

Refractive wiggle
(left view)

Refractive wiggle
(right view)

Disparity of Air
(from stereo fusing
wiggle features)

Outline

- Introduction and related work
- **Algorithm:**
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  - Measurement of fluid depth
  - **Measurement of fluid velocity**
  - Probabilistic formulation
- Experimental results

Fluid Flow should match of the wiggle features between neighboring frames (the flow of the flow)
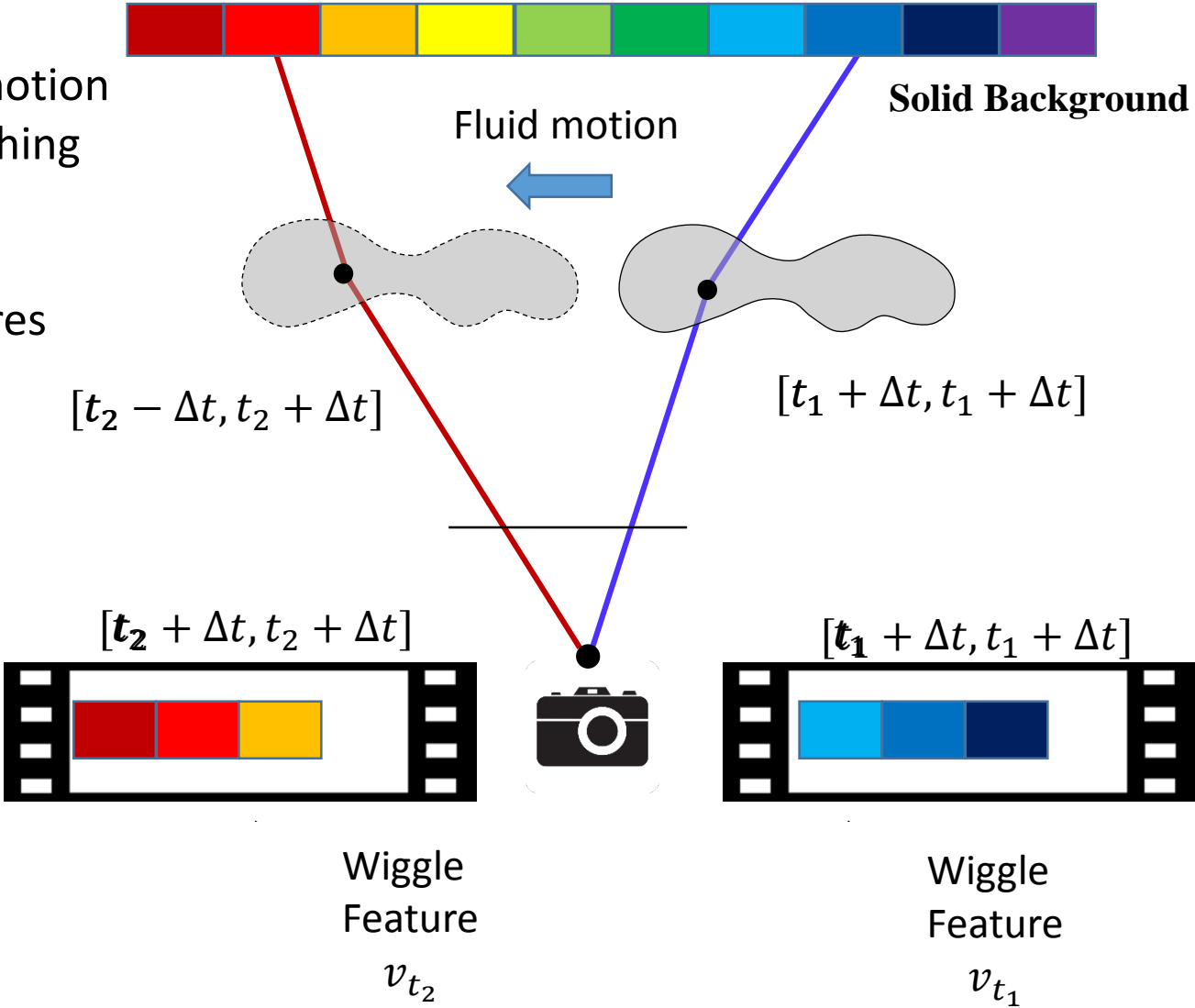
- We cannot find the motion from t_1 to t_2 by matching intensities

Fluid motion

Solid Background

t_2

t_1

t_2

t_1
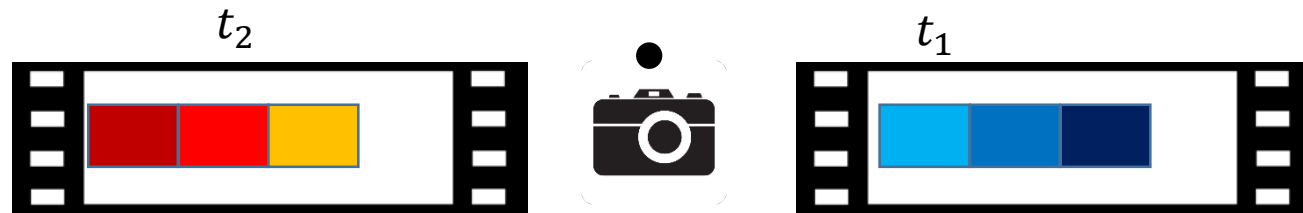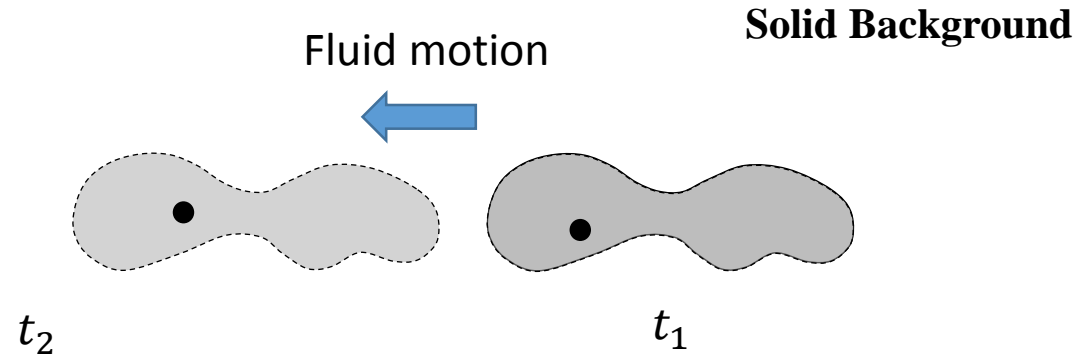
Fluid Flow should match the wiggle features between neighboring frames (the flow of the flow)

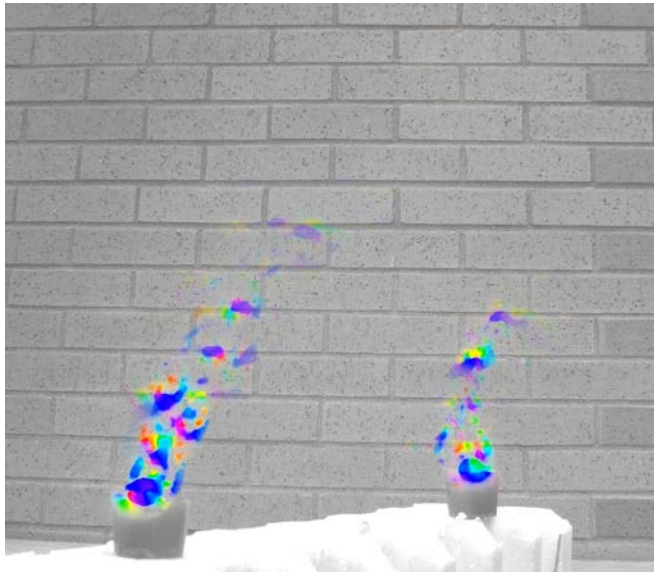- We cannot find the motion from t_1 to t_2 by matching intensities
- But we can find it by tracking wiggle features

Solid Background

Fluid motion

$[t_2 - \Delta t, t_2 + \Delta t]$

$[t_1 + \Delta t, t_1 + \Delta t]$

$[\boldsymbol{t_2} + \Delta t, t_2 + \Delta t]$

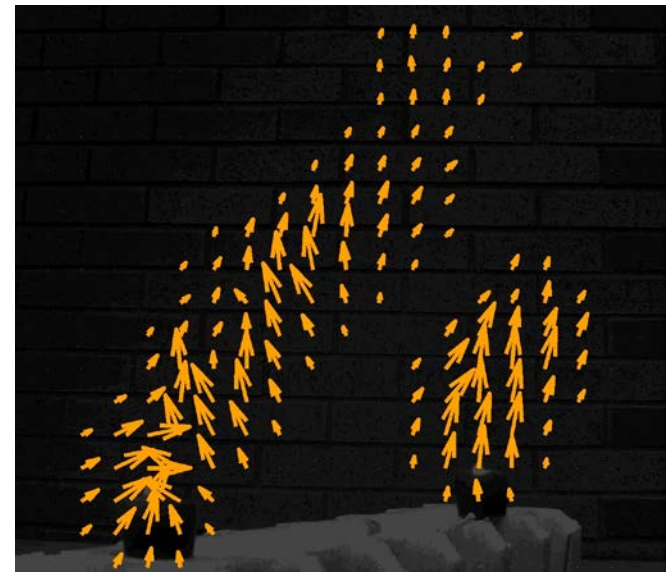$[\boldsymbol{t_1} + \Delta t, t_1 + \Delta t]$

Wiggle Feature v_{t_2}

Wiggle Feature v_{t_1}

Example of Refractive Flow

Input video

Optical flow →

Velocity of air flow

Brightness Constancy vs. Wiggle Constancy

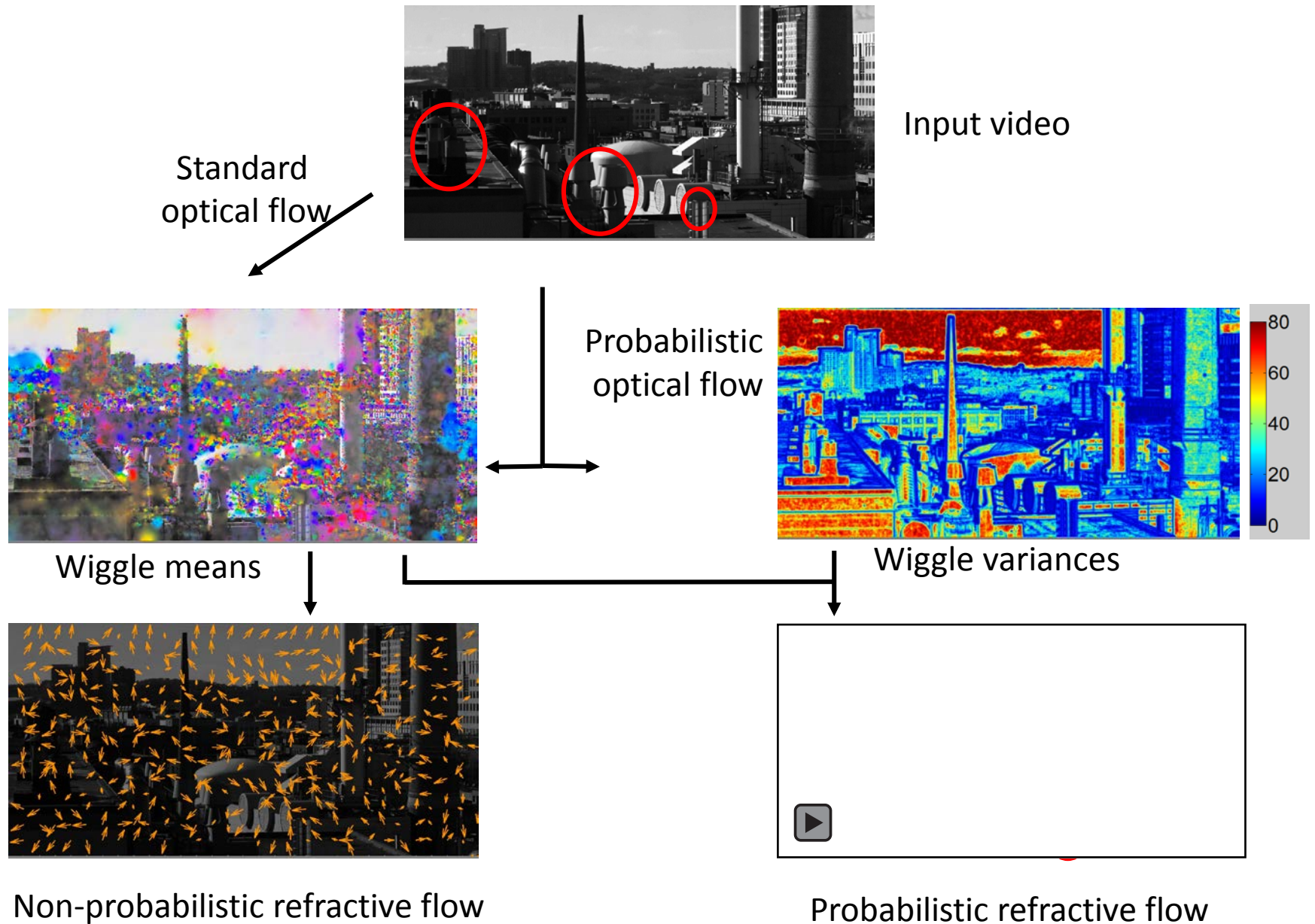|	Brightness constancy	Wiggle constancy
Solid Object Stereo	✔	✘
Solid Object Flow	✔	✘
Refractive Object Stereo	✘	✔
Refractive Object Flow	✘	✔

Outline

- Introduction and related work
- **Algorithm:**
  - Wiggle features
  - Measurement of fluid depth
  - Measurement of fluid velocity
  - **Probabilistic formulation**
- Experimental Results

Probabilistic Optical Flow to Calculate Wiggle Features

Why a robust, probabilistic formulation is needed:

The wiggle feature is small (in the order of 0.1 pixel), so it is easily overwhelmed by the noise.

Probabilistic Refractive Flow:

Input video

Standard optical flow

Probabilistic optical flow

Wiggle means

Wiggle variances

Non-probabilistic refractive flow

Probabilistic refractive flow

Outline

- Introduction and related work
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  - Measurement of fluid velocity
  - Probabilistic formulation
- **Experimental Results**

Evaluate the refractive flow on simulated sequence

- We simulate a fluid flow with known velocity, and test it on three different backgrounds.
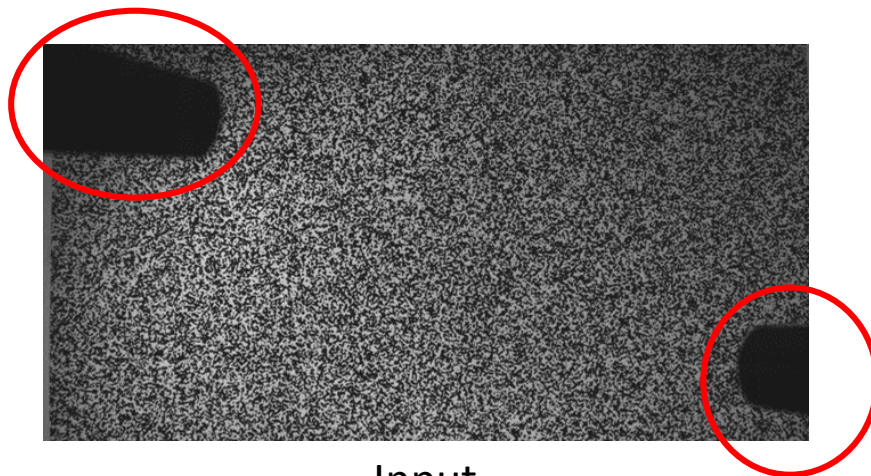
- Error drops when temperature increases
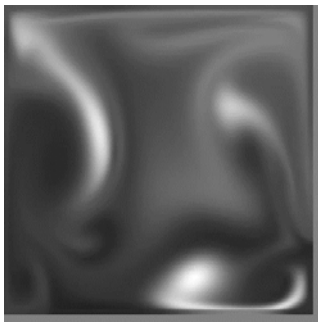
Simulated fluid density
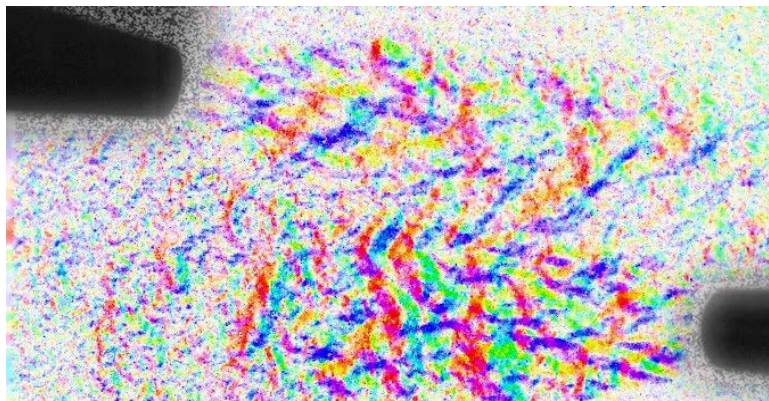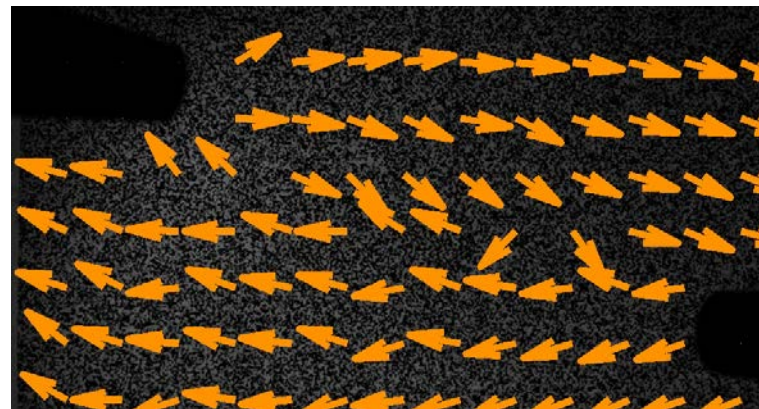[Stam et al. **Stable Fluid** 2004]
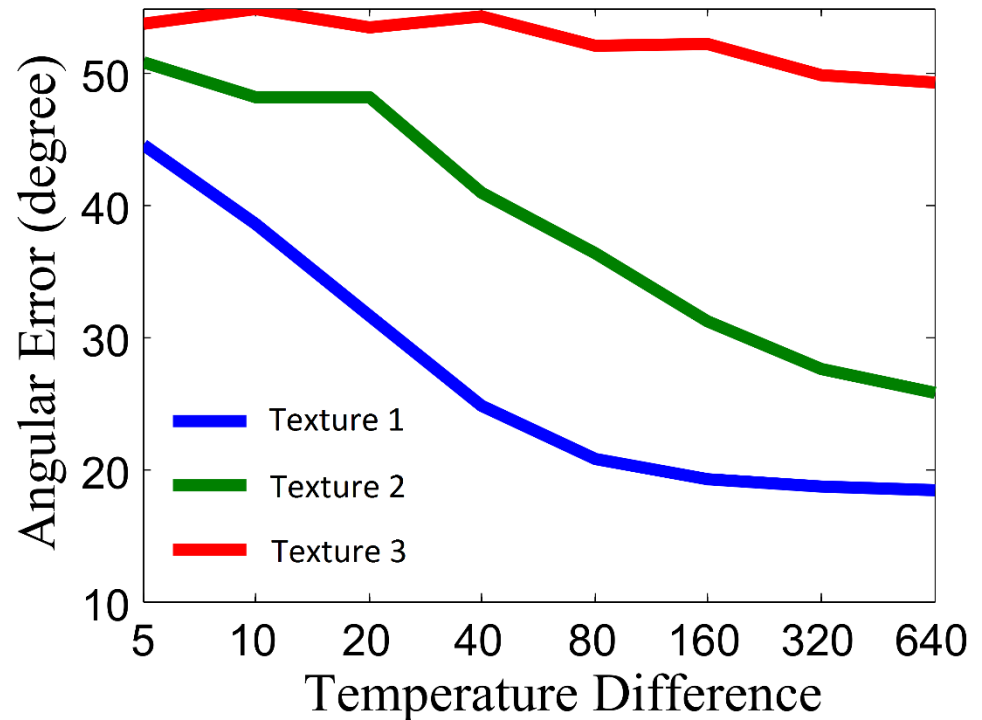
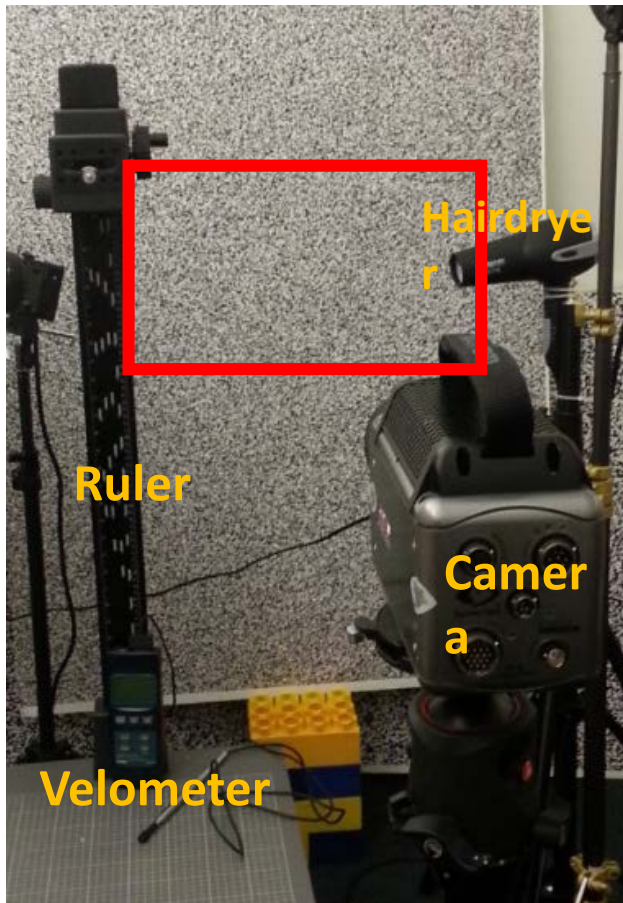Background texture

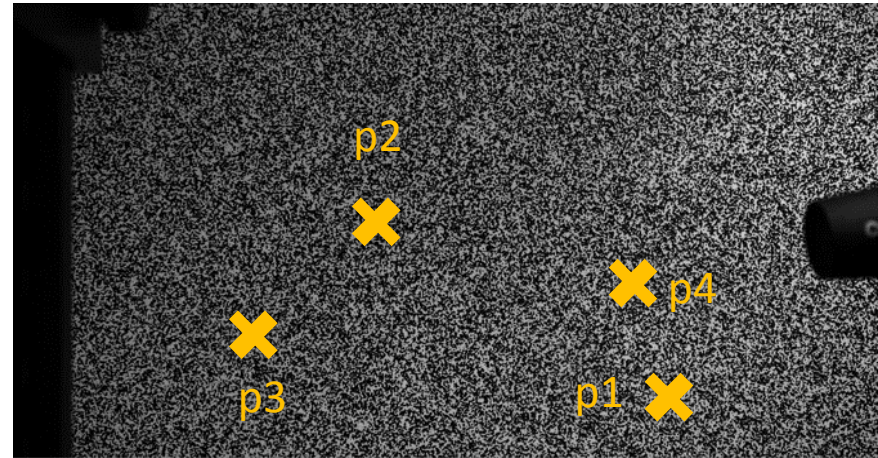# Real Sequence: Hairdryer (1000fps)

Input

Wiggle feature

Flow field of air

Comparison with Velocimeter Measurements

Experiment Setup

Input Video

	p1	p2	p3	p4
By Algorithm (m/s)	0.8	1.4	3.2	12.0
By Velocimeter (m/s)	0.0	0.3	1.4	13.8

Comparison of fluid velocity measurements
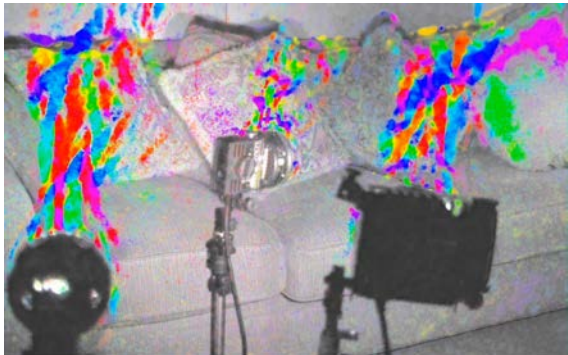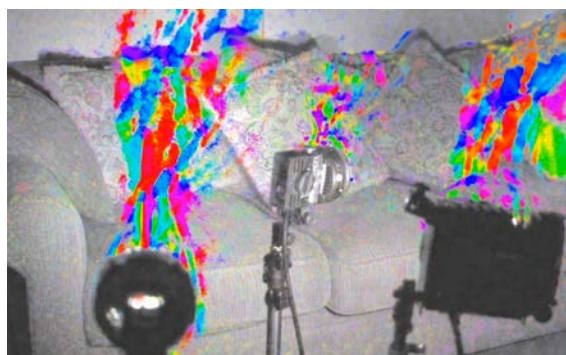
Real Sequence: Lights

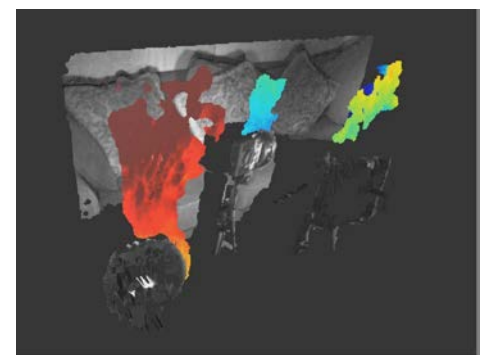
Input (Left view)

Input (Right view)

Disparity map of air flow

Wiggle feature (Left view)
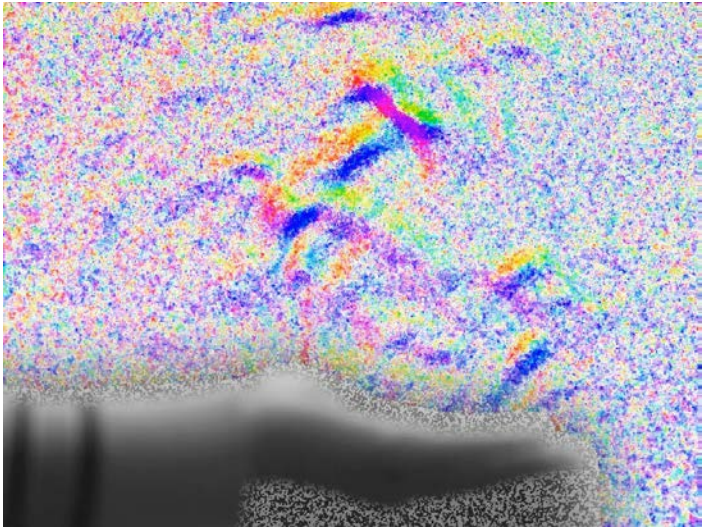
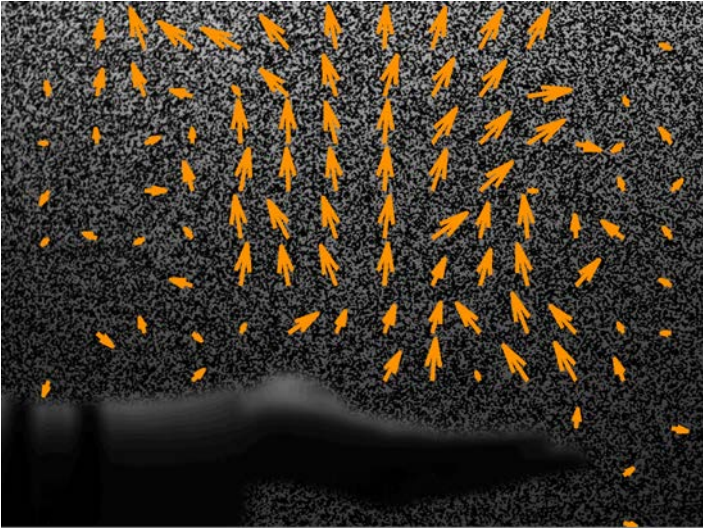Wiggle feature (Right view)

3D view of air flow

Real Sequence: Hand

Input Video


Wiggle feature

Flow field of air

Wiggle features

- We introduce *wiggles* as a video image feature. These are small motions, here caused by the motion of turbulent air.

- These wiggles can be <u>stereo-fused</u>, revealing the depth of the turbulent flow.

- The wiggles can be <u>tracked</u>, revealing the motion of the turbulent flow.

- We introduce a <u>probabilistic algorithm</u>, using both mean and variance estimates, to reliably track the wiggle features, which can be small and noisy.
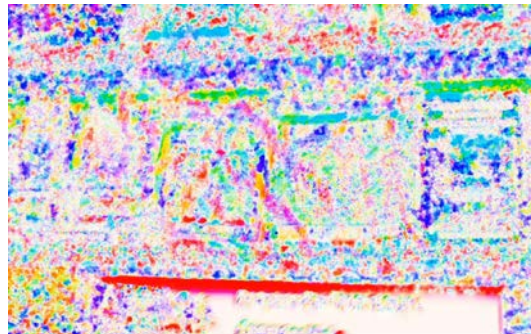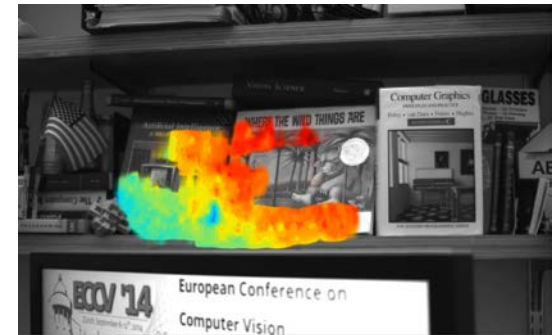
Thank you!

Or search for: "wiggle flow MIT"
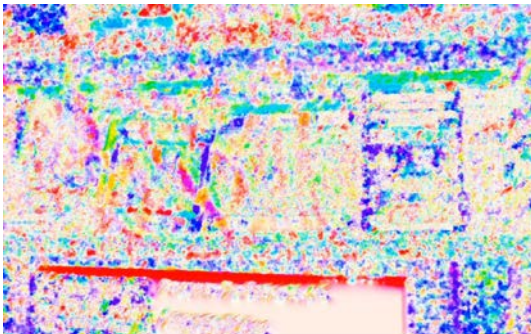
Left view

Right view

Disparity of air