The Visual Features of Smoke

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Problem Statement

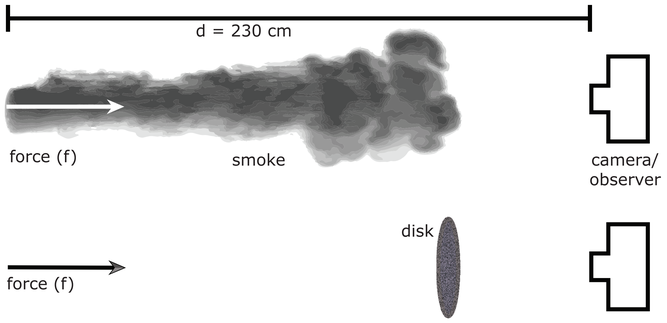
- Fast, appropriate reactions to smoke can be life-saving in fire emergencies
- Accurate visual assessment of how smoke is moving can provide vital information
- Unlike rigid objects, smoke and fluids change shape constantly; these dynamics can be informative [1] but can also create uncertainty as to the overall speed and direction of motion
- Prior work suggests that perception of global smoke motion may be unreliable and subject to systematic biases:
  - Speed tends to be underestimated when sensory uncertainty is increased [2,3]
  - Speed of threatening objects is overestimated [4]

GOALS

1. Identify potential motion cues in approaching smoke
2. Determine factors affecting perceived speed of approaching smoke

Simulating Smoke

- High resolution physics based plumes of smoke moving towards an observer (Mantaflow), rendered with a path-tracing renderer (Mitsuba)
- Smoke simulation based on fluid dynamics: Navier-Stokes solver with second-order semi-Lagrangian advection
- Wavelet noise applied to inflow velocities and smoke densities created turbulence



Smoke density

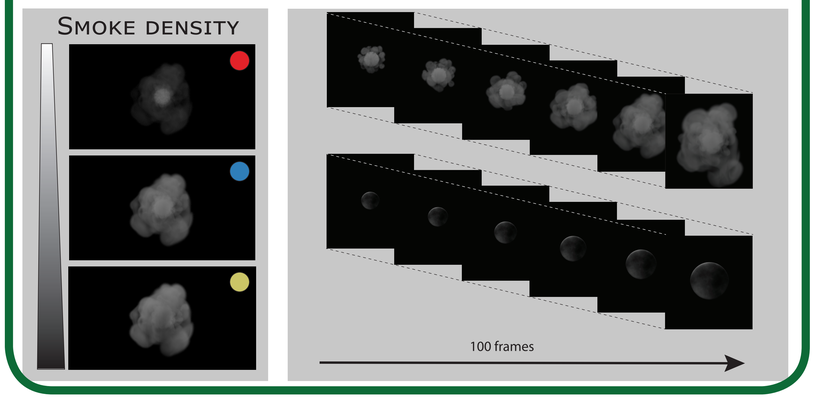
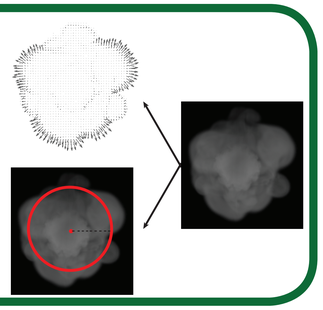


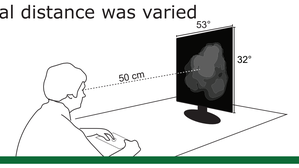
Image Analysis

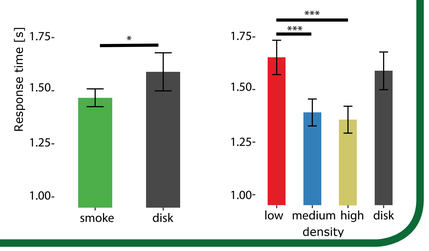
- **Optic flow:** Local differential motion estimation [5]
- **Encircled Energy:** Radius defined by the number of pixels that encircle 50% of a frame's intensity values



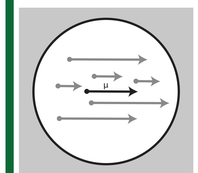
Behavioral Study

- Prediction-motion time-to-contact paradigm [6]
- N = 12; 240 trials
- Initial distance was varied

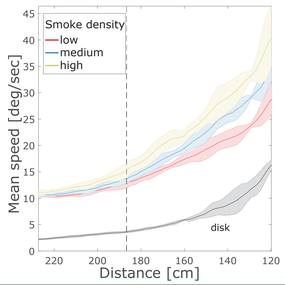




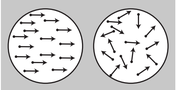
Speed



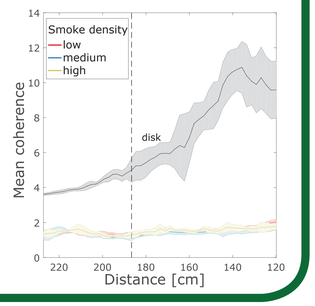
Average speed of motion



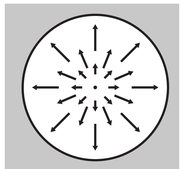
Coherence



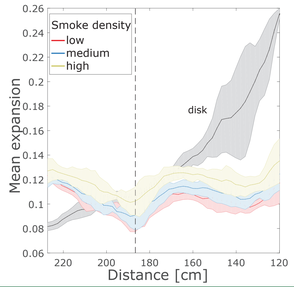
Average angular variance of motion vectors over 1°



Expansion

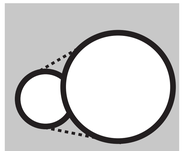


Radial increase in speed from focus of expansion

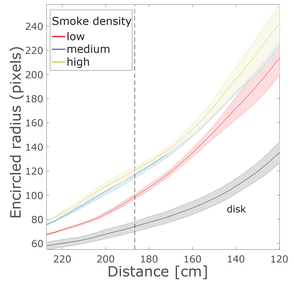


Unlike for solid objects, the optic flow rate of expansion does not reliably indicate approaching smoke.

Size Change



Increase in encircled energy over time



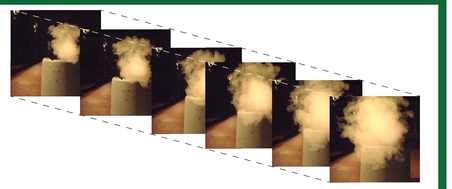
Nonetheless, the size of approaching smoke increases consistently over time, providing a cue to approaching motion.

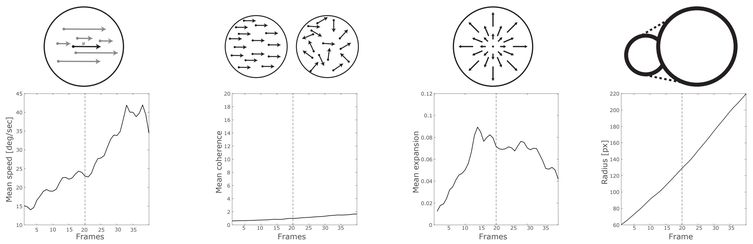
This cue differs depending on smoke density.

Real Smoke

Is virtual smoke visually comparable to real smoke?

- High resolution video recording of artificial smoke ("disko fog")
- Distance from smoke machine: 117 cm
- Matched image analysis
- Recorded at 100 fps





Discussion

- Optical flow expansion and size change are not necessarily correlated motion cues in smoke [7]
- A systematic bias in perceived time-to-contact is consistent with size change information
- Fire evacuation models may be improved by considering perceptual features of smoke [8]

References

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8. Ronchi, E., et al., Representation of the Impact of Smoke on Agent Walking Speeds in Evacuation Models. Fire Technology, 2013. 49(2): p. 411-431.

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