A New Way to Look at Fire: Computer Vision Applied to Fire Dynamics

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Abstract

Computer vision principles enable the analysis of fire, wind, and plume behavior from **visual and infrared (IR) video** instead of sparse measurements obtained with expensive instrumentation. Data that quantifies the transport of heat and **fire spread**, **turbulent statistical information**, and **plume structure** can be obtained from either visual or IR images and contribute to our evolving understanding of fire behavior. Unfortunately, black-box computer vision programs are not suitable due to the visually unique environment of fires and complex turbulent nature of their dynamics. I describe **modifications of classical computer vision algorithms** with **adapted graph theory techniques** that can be applied to diverse instances of this environment, and use them to extract data from prescribed fire videos. These data extraction experiments improve our understanding of the dynamics in complex environments and can validate fire spread models.

Background

Most existing applications of computer vision to fire science **detect and identify** hazardous fires and smoke.

Fire Detection Using Computer Vision – Zaman, et al. (2018)

A Real-time Video Fire Flame and Smoke Detection Algorithm – Yu, et al. (2013)

A New Approach To Vision-Based Fire Detection Using Statistical Features and Bayes Classifier – Duong & Tinh (2012)

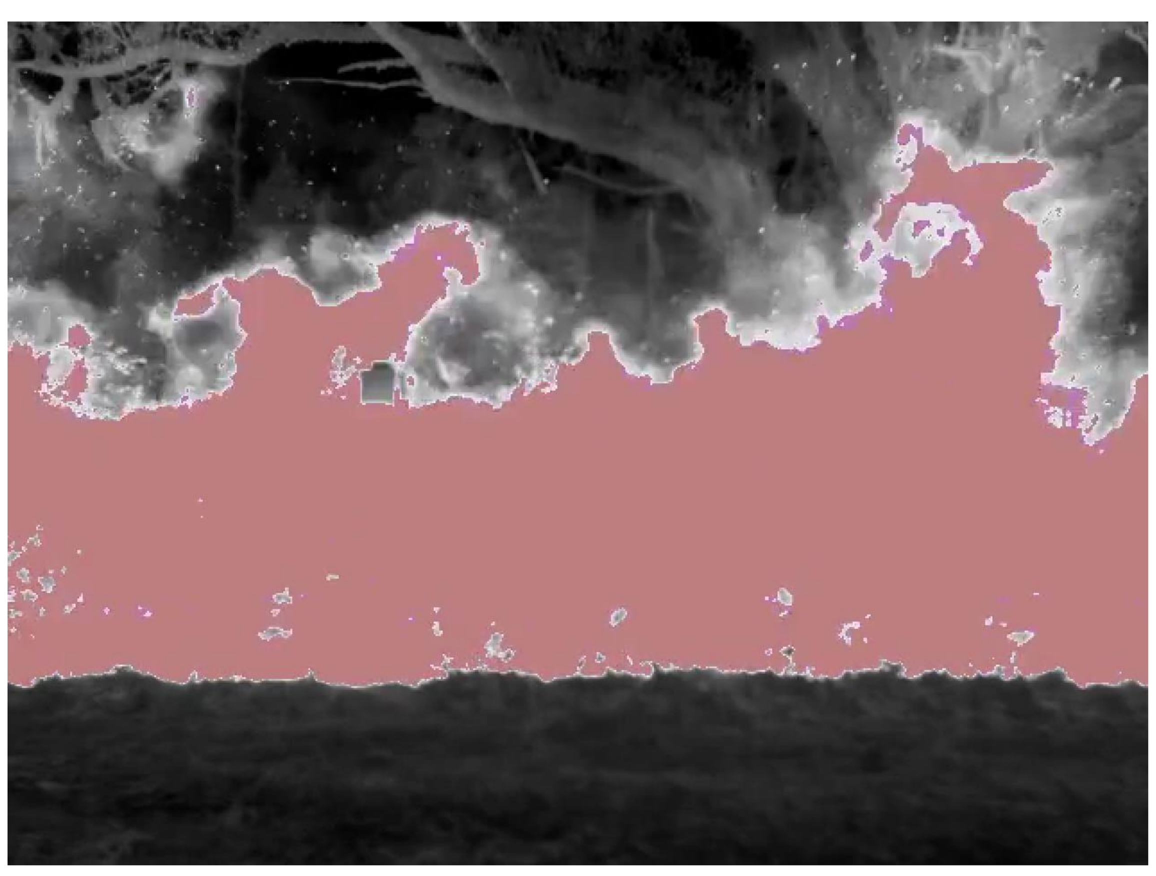
Also explored, albeit less commonly, are **fire spread and dynamics** from IR images and image registration techniques applied to cloud and fire movement.

Infrared Imagery of Crown-Fire Dynamics during FROSTFIRE – Coen, et al. (2004)

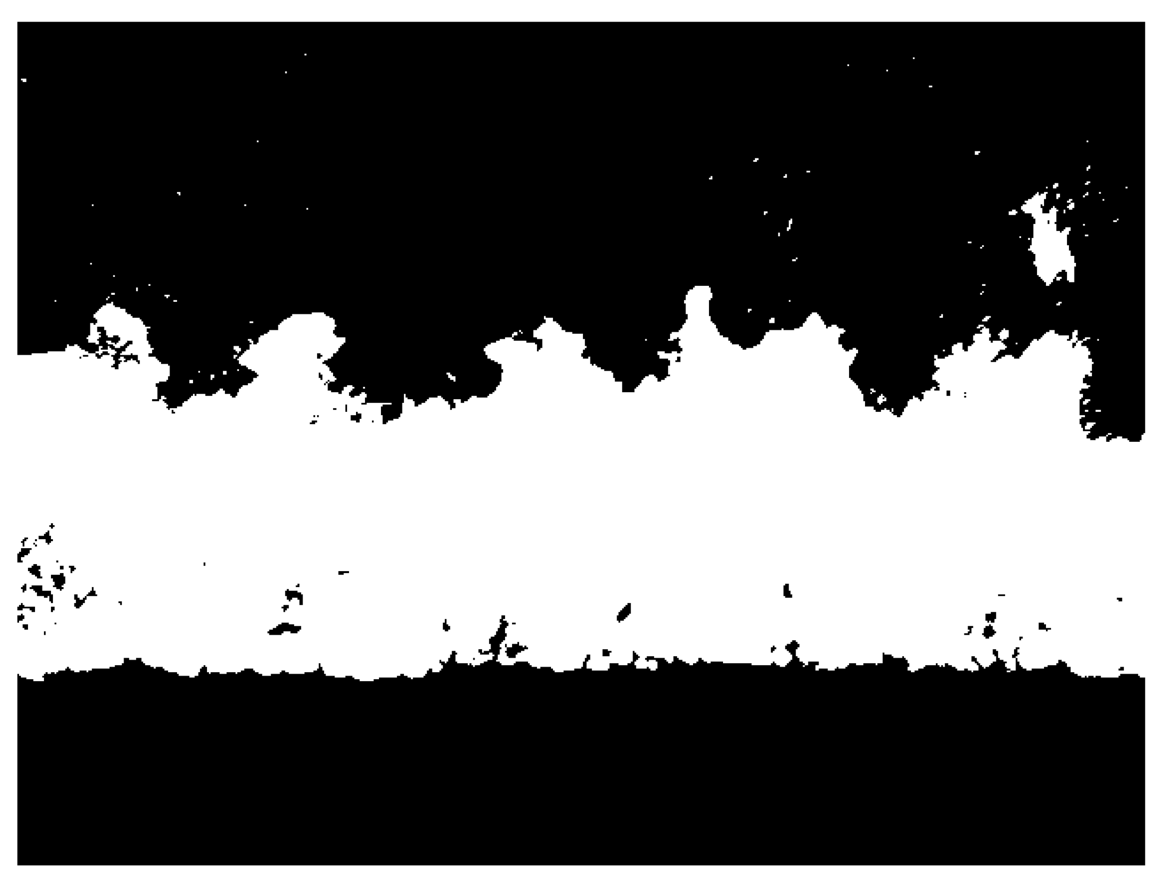
Optimal Mass Transport for Registration and Warping – Haker, et al. (2004)

Methods and Results

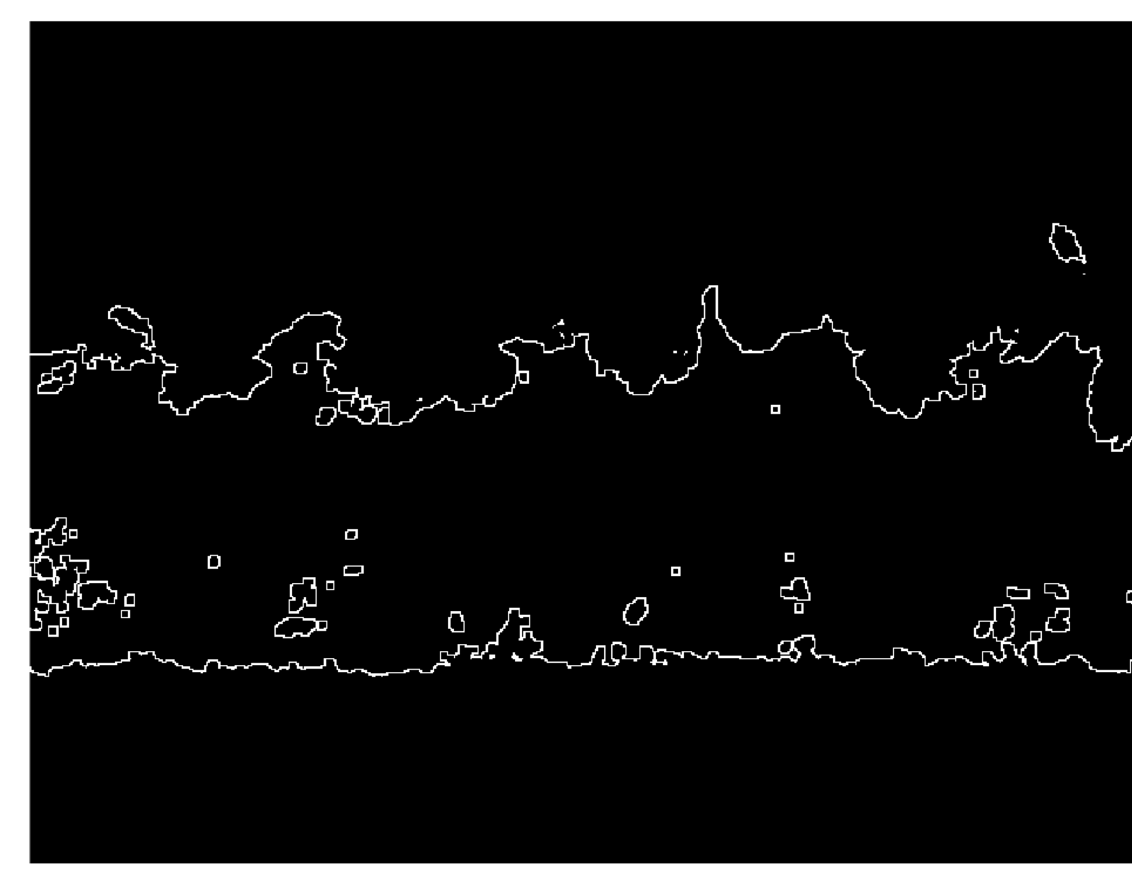
Images are **segmented** based on color (visual images) or temperature (IR images). After segmentation, a **Cleaner** is applied to the image. The Cleaner determines components of an image relevant for fire line calculations. It removes small embers but keeps large sections of fire that have broken off from the main body. An **edge detection** algorithm is applied to the cleaned image (edge detection operator: Prewitt 3x3, Sobel 3x3, or Sobel 5x5).



Original IR image

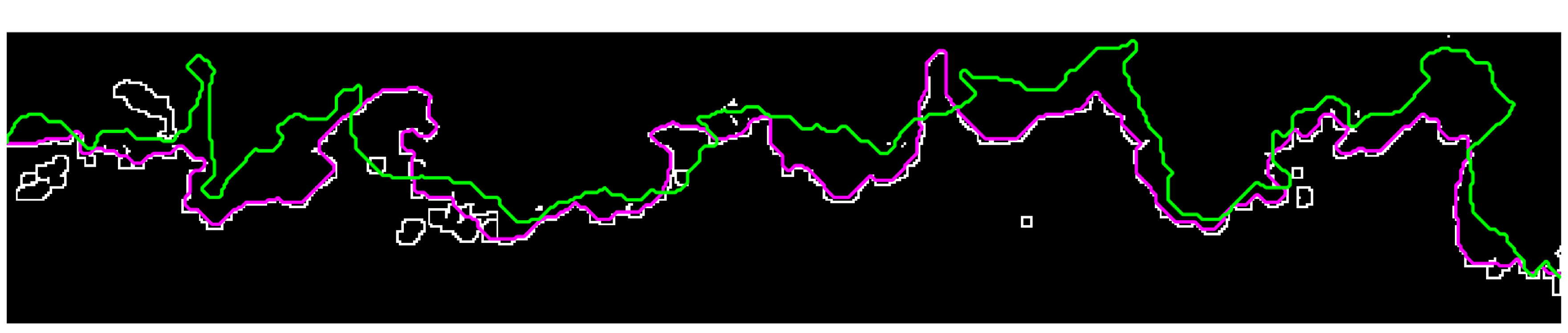


Segmented image

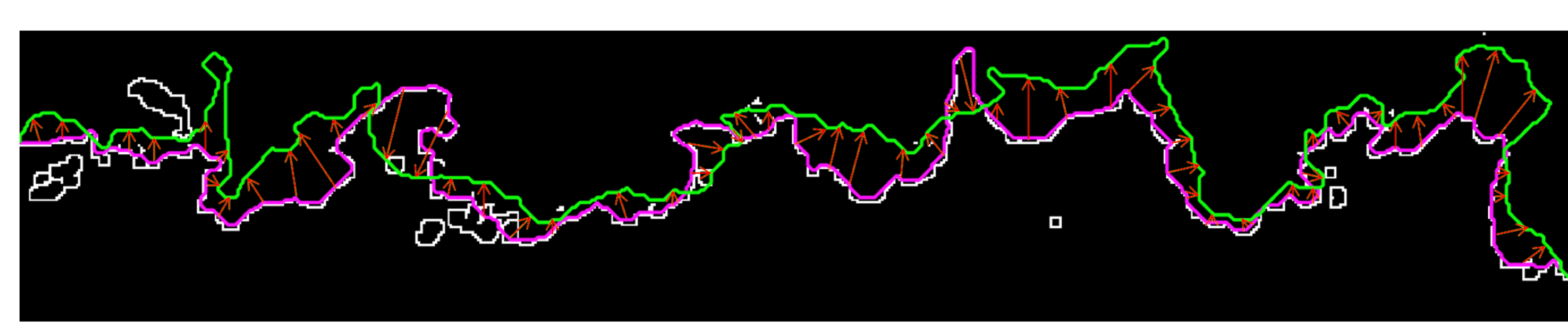


Edges of cleaned image

An adapted version of **eager Dijkstra's algorithm** traces the outflow line (top line) to determine a 1 pixel-thick line of best fit (named **Crawler**) of each frame. A comparison is done by solving an **assignment problem** of a weighted bipartite graph, where each frame's outflow line is treated as a set of points. The assignment problem links points between frames such that the **overall distance** and the **distance between individual points** are **minimized**.



1 pixel-thick outflow line at two frames



Arrows (sparse) showing calculated change in position between the two frames

Work has begun to remove the main body of the fire and perform **Farnebäck's dense optical flow** on the remaining **airborne particles**. This method employs a three-tier Gaussian pyramid to combat the large motions present between frames. The floating embers, debris positions, and temperature data help determine: pressure gradient, air density, potential temperature, turbulent Reynolds covariances and covariant fluxes, friction velocity, vorticity, helicity, Reynolds number, mean and turbulent kinetic energy, and air stability analysis.

Current and Future Work

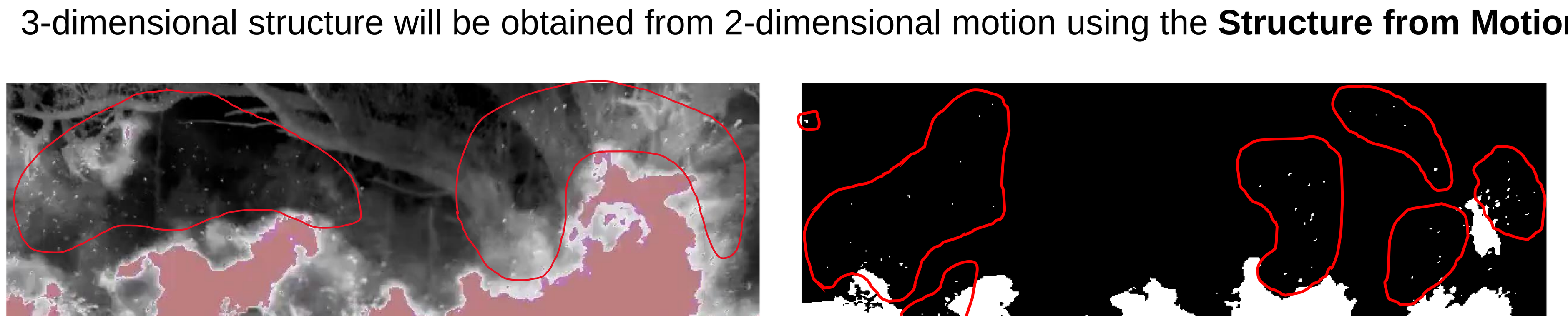
Crawler can be **run in parallel** to decrease the computational time. Furthermore, the Crawler must pass through points where the outflow line reduces to 1 pixel, and points where the line intersects itself; these points break one long problem into multiple smaller independent ones.

Work has also been done to adapt Dijkstra's algorithm for **circular paths**. With this, the following types of fire motion can be analyzed:

(i) outflow in (x,z), seen above (ii) linear fire spread in (x,y) (iii) radial fire spread in (x,y) where (x,y) denotes the Earth's surface and +z is height above the surface.

Farnebäck's dense optical flow is being implemented for airborne particles in fire environments, and will lead to the aforementioned **small-scale atmospheric dynamics calculations**. Further work will see this expanded to a **stereoscopic** camera setup so that full calculations can be done, rather than a projection. Potential applications include a fire-driven wind model and ember transport model.

An investigation into **plume behavior** as a coupling of spread rate and atmospheric dynamics is in its beginning stages. Plume motion will be analyzed using **Dynamic Mode Decomposition** (DMD) and 3-dimensional structure will be obtained from 2-dimensional motion using the **Structure from Motion** (SfM) technique.



Particles to be tracked using optical flow/particle image velocimetry

References

Farnebäck, Gunnar. *Two-Frame Motion Estimation Based on Polynomial Expansion,* vol. 2749; 363–370, 2003.

Lucas, Bruce D., and Takeo Kanade. *An Iterative Image Registration Technique with an Application to Stereo Vision,* International Joint Conference on Artificial Intelligence; 121–130, 1981.

Toussaint, Godfried T. *An Optimal Algorithm for Computing the Minimum Vertex Distance Between Two Crossing Convex Polygons,* vol. 32 (4); 357–362, 1984.