Extraction of Active Fire Fronts from Airborne Time-Sequence Imaging of the Arch Rock Fire in Southeast Ohio

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BACKGROUND

Prescribed fire has been suggested as a site preparation method in order to sustain oak regeneration in eastern mixed-oak forests. One of the most important fire parameters is rate of spread, which can be estimated once direction of fire propagation is known. The active fire fronts, then, become central features because they can be used to estimate how fast the fire moves and predict where the fire is likely to be in the future. See examples of prescribed fire in Figure 1.

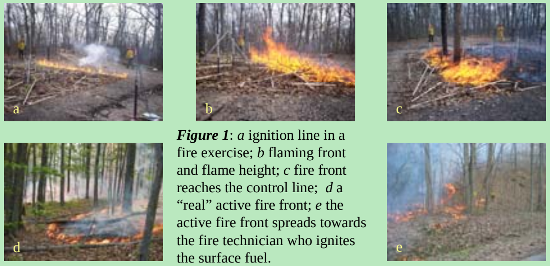

Figure 1: *a* ignition line in a fire exercise; *b* flaming front and flame height; *c* fire front reaches the control line; *d* a "real" active fire front; *e* the active fire front spreads towards the fire technician who ignites the surface fuel.

AIRBORNE FIRE MONITORING

Airborne fire monitoring has become a resourceful remote sensing method in examining fire behavior at a very high spatial resolution. This project investigates a prescribed fire in southeastern Ohio through remote sensing measurements of emitted radiance. Time-sequence airborne imaging consisted of multiple over-flights with a repeat interval of 3-6 minutes performed by an aircraft equipped with an infrared camera. Four subsequent images were processed and analyzed in order to extract the active fire fronts and estimate the direction of fire propagation.

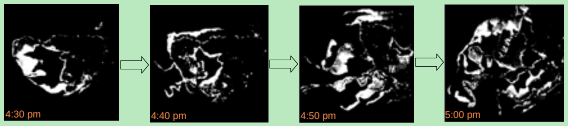

Figure 2: Time-sequence imaging of the Arch Rock fire as taken on April 17, 2004 (Courtesy of Robert Kremens, R.I.T.)

STUDY AREA

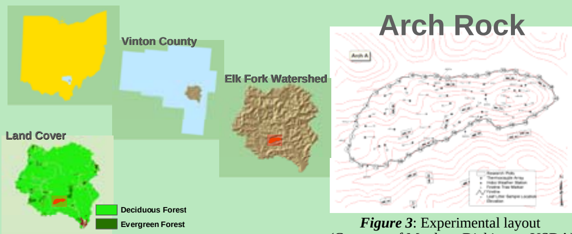

Figure 3: Experimental layout (Courtesy of Matthew Dickinson, USDA)

METHODOLOGY

Step 1: Image Enhancement

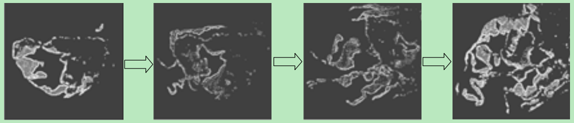

Figure 4: Gradient magnitude images: rapid radiance changes (contrast)

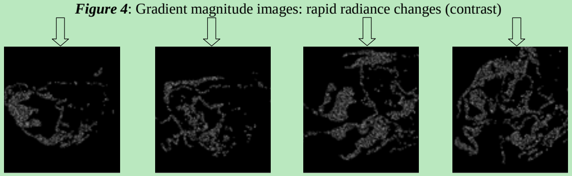

Figure 5: High gradient magnitude pixels: digital number 255 (in white)

Step 2: Bi-Spectral Edge Detection

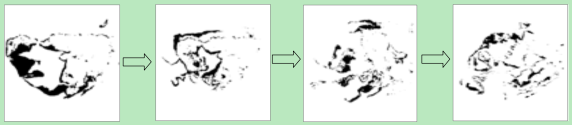

Figure 6: Normalized Difference Burn Ratio [-1, 1]; negative values in black (burned areas)

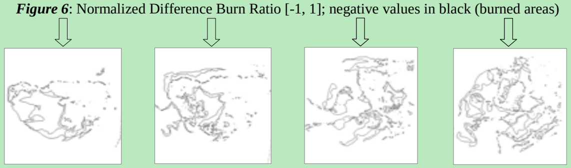

Figure 7: Edge detection on NDBR; pixels DN = 255 define the fire perimeters (in black).

Step 3: Fire-Pixel Extraction

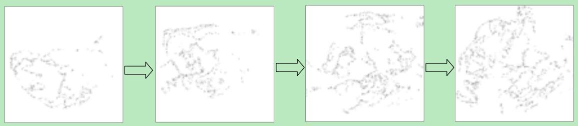

Figure 8: A Boolean And logical operator was applied to Fig. 5 and 7. Pixels having the same value 255 in both images were coded 1 and all other possible combinations 0.

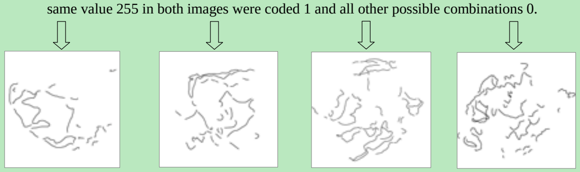

Figure 9: Linear active fire fronts were edited through the selected active fire pixels. Linear features were then smoothed using a cubic B-spline approximation.

SPATIAL ANALYSIS

Fire Propagation: Direction & Distance

Direction of fire propagation was estimated based on the assumption that a fire front is elliptical in shape; therefore, quadratic fitting was performed for some of the dominant fire pixels on the extracted fire fronts in order to estimate straight lines pointing towards unburned areas.

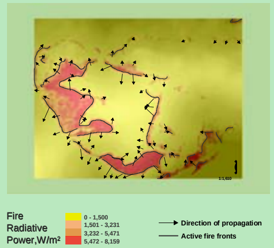

Figure 10: Thermal data resulting from the image composite corresponding to t = 4:30 pm was overlapped with elevation; lighter areas indicate high elevation (210-230 m).

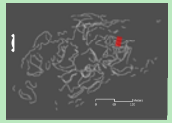

Figure 11: The active fire fronts extracted in Step 3, merged into a binary map.

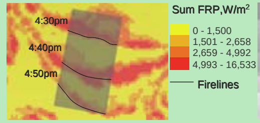

Figure 12: A 21 x 50m transect focuses on three subsequent fire fronts; total FRP is mapped behind.

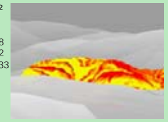

Figure 13: A 3D view of fire spread across the landscape (NE viewpoint)

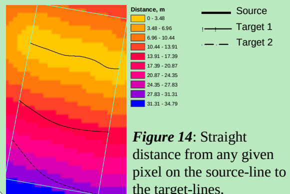

Figure 14: Straight distance from any given pixel on the source-line to the target-lines.

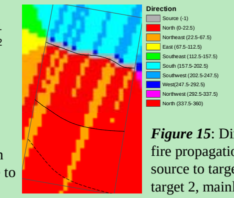

Figure 15: Direction of fire propagation from source to target 1 and target 2, mainly N & NE.

SIGNIFICANCE OF RESEARCH

Using airborne high resolution infrared imagery provides an unprecedented opportunity to accurately extract the active fire fronts and estimate direction of propagation, rate of spread, fuel consumption and fire intensity over large burn units. The resulting fire behavior information can then be used to determine the fire's ecological effects.

APPLICATIONS

- Forecasting future fire dynamics
- Fuel consumption assessments
- Model predictions for tree injury and mortality
- Smoke transport simulations
- Time series analysis to predict for unknown locations and time
- Trend surface analysis & Cost weighted surface analysis
- Fire Animation