FIRE LOCATION FROM A SINGLE OSBORNE FIREFINDER AND A DEM

Peter L. Guth, Professor
Department of Oceanography
U.S. Naval Academy
589 McNair Road
Annapolis, MD 21402
pguth@usna.edu

Tom Craven, Vice President
GeodesyBase
220 SW Ash Street
PO Box 1132
Sisters, Oregon 97759
tcraven@aol.com

Tom Chester
1802 Acacia Lane
Fallbrook, CA 92028
tom@tchester.org

Zeyn O'Leary
Fire Lookout
Prineville, OR
zeynoleary@yahoo.com

Jim Shotwell
Fire Lookout
Crescent, OR
jcshot@earthlink.net

ABSTRACT

The Osborne firefinder, a staple in many western fire towers, has calibrated compass and vertical angle dials, and can provide the horizontal azimuth and vertical pitch to a fire. Pitch angles have rarely been used, and most fire locations have required an estimate from one tower based on observer experience and visible landmarks or intersection from sightings by two towers. Using a digital elevation model (DEM) to compute the line of sight from the tower, we can now accurately compute a fire's location with a single sighting from one tower. USGS DEMs available for the US with 10-30 m (1/3-1") spacing provide adequate resolution for this application. Errors can be resolved into along- and across-sighting components, and depend on the accuracy to which the angles can be read. For the Osborne firefinder, across-sighting accuracy depends primarily on accurate alignment of the compass to true north. Longer sighting ranges magnify across-sighting errors. Along-sighting accuracy depends on the pitch reading and the slope of the ground. With typical tower sighting geometries, accuracy increases substantially as ground slope increases on slopes facing the tower. Our software determines fire location, estimates an error ellipse, provides a perspective view to compare with the observer's vantage point, and displays the location on digital maps. We have verified the results with tests at Vetter Mountain in southern California and from a number of towers in central Oregon, and have designed an improved telescope with inclinometer to use with the firefinder. This application can be extended to other cases with a pitch and azimuth sighting from a known location.

INTRODUCTION

The twentieth century saw the development of a warrior culture within the United States Forest Services and other government agencies as they battled fires in the American West. Fighting fires grew to resemble a vast military operation, with armies of firefighters (and even soldiers and the National Guard) deployed on the fire lines. Early detection and warning provided one tool in the arsenal, and almost four thousand observation towers once stood atop peaks and ridges in the West. With increased reliance on aerial surveillance and satellite imagery, only about 400 towers remain manned (Thoele, 1995). Figure 1 shows one of these towers.

In the 1920's William B. Osborne developed an instrument to help lookouts in towers accurately locate fires. His device, named the Osborne firefinder, combined a large compass ring for measuring an azimuth (horizontal angle) to the fire, and a vertical clinometer to measure the pitch (vertical angle). The large face of the instrument accepts maps, centered on the tower. Over time, the Forest Service sought tools to help lookouts use their Osborne Firefinders. These included panoramic photography, 360º views that replicated what the lookout could see (IamWho Panoramic Imaging, 1997), and many towers featured meticulous artistic hand-drawn sketches locating features in the landscape below. The Osborne firefinder became a prime tool for fire location, primarily using intersections from two towers. Vertical angles received much less attention.

Figure 1. Lava Butte fire tower in central Oregon. Exterior view on the left, and interior view on the right showing a labeled sketch of the surrounding terrain.

This paper reports success in using the vertical angles to accurately locate fires using sightings from a single tower. The method uses a geographical information system (GIS) with an accurate digital elevation model (DEM), so that the sighting for the Osborne firefinder can be intersected with the terrain surface in the DEM. We also report an enhancement to the firefinder, incorporating a digital pitch meter. We validated our approach using careful observations in southern California, and then tested during the summer of 2004 at four fire towers in Central Oregon. Our DragonPlot software uses a custom GIS application, but the concept could be incorporated into any GIS software.

DRAGONPLOT ALGORITHM

Input Information.

- Tower location requires the latitude and longitude of the tower, and the elevation of the Osborne firefinder above the ground. This can be found with a portable GPS, or derived from GIS data like DOQQs.
- Sighting: compass azimuth (degrees true) and pitch to the base of the fire observed with the Osborne firefinder.

GIS Data.

- DEM. We have used USGS DEMs in 10 m and 30 m spacing (SDTS format), and 1/3" and 1" spacing (NED format, arc second spacing). Because of the size of the operational area in central Oregon, which spans two UTM zones, we prefer the NED data. Some GIS software reformats lat/long DEMs, but all the algorithms used in DragonPlot can use either type of DEM in native format.
- Auxiliary data. While the DEM provides all the GIS information to locate the fire, additional data put the fire in context and helps the lookout or the dispatch center respond to the report. The additional data also gives the lookout confidence in the computations. We have used TIGER data from the Census bureau for road and stream locations, PLSS data from the Bureau of Land Management to get the township and section location of fires, and gazetteer data from USGS to locate peaks and lakes. The Forest Service has traditionally used PLSS locations, although with the rise of accurate and inexpensive GPS units that is starting to change, particularly because GPS can pinpoint locations much more accurately than the traditional quarter-quarter section. The capability of GIS software to easily change among UTM, lat/long, and PLSS coordinates helps integrate new technology into existing operations. Additional GIS data that can be combined with the fire location system include digital raster graphics (DRGs), digital ortho quarter quads (DOQQs), and satellite imagery. These are much larger data sets than the DEM data, but easily within the capacity of common computers.

Computer.

- We designed the algorithm to run either on a local personal computer, or over the internet from a remote server. While most towers do not have internet connectivity or even electrical power, most have solar panels, batteries, and the ability to run a laptop computer. Where this is not feasible, the dispatch center can run the computations with the data reported by radio.

GIS Algorithm.

- From the tower location, compute the coordinates of points on the sighting line to the fire. This computation involves geodetic coordinates (Vincenty, 1975) to correctly account for horizontal earth curvature over the long sight lines common for fire towers. UTM coordinates could be used, but we found problems with UTM DEMs when the region spanned UTM zone boundaries. We compute points at half the DEM data spacing, suggested by the Nyquist sampling limit.
- Starting from the tower, at each point along the profile:
    - Compute the elevation from the DEM
    - Adjust for vertical earth curvature (Department of the Army, 1970; Yoeli, 1985), dropping the elevation.
    - Find the difference in elevation from the tower to the adjusted point on the profile.
    - Compute the pitch angle to that point (arc tangent(difference elevation / distance)).
    - Compare the pitch angle to the sighting pitch. The fire location will be the spot where the pitch angle first exceeds the sighting angle.
    - If the sighting angle never exceeds the pitch angle, flag the point as an air shot, and tentatively assign it to the horizon, the point on the sighting line with the largest vertical angle.

ALGORITHM ACCURACY

Our analysis suggests that the accuracy of the algorithm will be a function of range, and can be divided into an across-sighting component, dependent on the accuracy of the azimuth reading, and an along-sighting component related to the azimuth resolution and the slope of the ground. Figures 2 and 3 show the results of our computations.

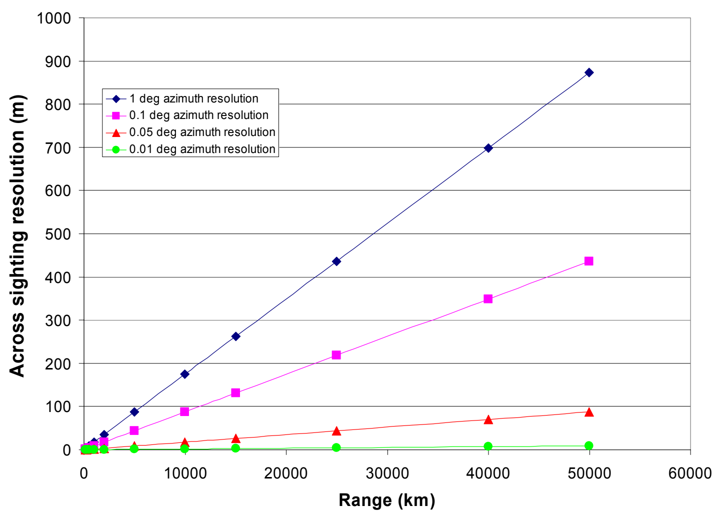

Figure 2. Theoretical across sighting accuracy with the Osborne firefinder as a function of range and the resolution to which the azimuth can be read.

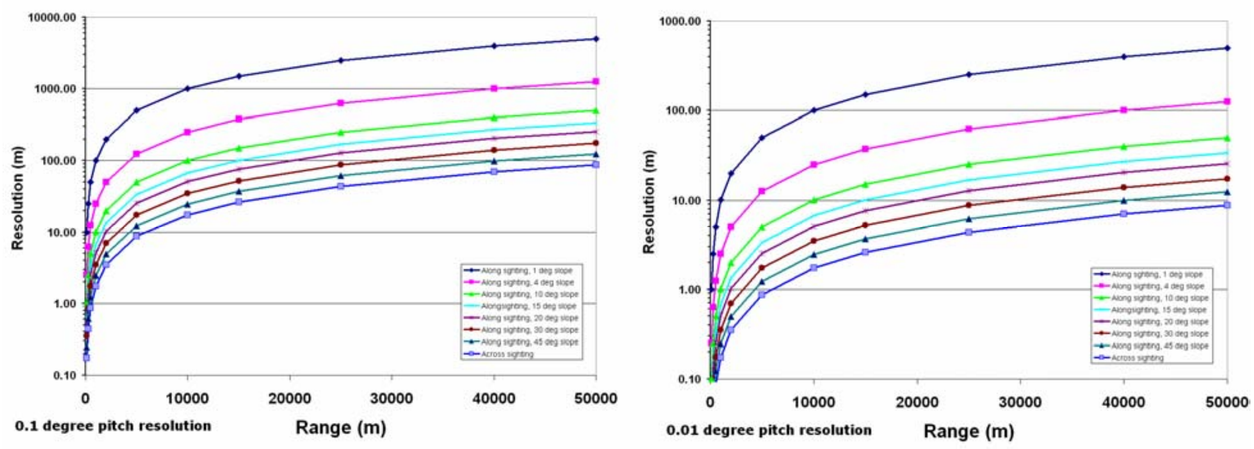

Figure 3. Along sighting resolution for the Osborne firefinder as a function of range and the ground slope toward the fire tower. On the left, pitch can be resolved to 0.1º, while on the right pitch can be resolved to 0.01º.

IMPROVED FIREFINDER

Based on initial experience with the difficulty in reading pitches with the Osborne firefinder, we added a telescope and digital pitch meter. An initial meter provided readings to 0.1º, but we found that the accuracy was less than desired. Further experience suggests that the 0.01º instrument provides much higher resolution (Figure 3), except in very high towers where wind sway makes reading the meter difficult.

Figure 4. Improved Osborne firefinder with attached telescope and digital pitch readout. The photo shows the map disk inside the compass ring.

VALIDATION AT VETTER MOUNTAIN

The first test of our algorithm came at Vetter Mountain, in southern California. Chester and Strong (2000) reported sightings to 26 surrounding peaks. Using USGS 10 m DEMs, we created perspective views for each of the azimuth and pitch readings (Figure 5). Our methodology included the following steps:

1. Create a perspective view with the pitch and azimuth recorded by Chester and Strong (2000).
2. On the peak nearest the computed intersection, determine from the perspective view the pitch and azimuth.
3. Create a blow up of the region around the target, contouring from the 10 m USGS DEM. Mark the peaks from the USGS GLIS system on this map. These positions are not precise, but will indicate if the correct

peak has been identified. (Figure 5)

4. If no peak appears in the USGS data base, or the location of the peak is not obvious on the contours (e.g. a long ridge), open the USGS 1:24,000 DRG from Terraserver. MICRODEM can automatically request the tiles at the desired scale from Terraserver (www.terraserver.com).
5. Measure the geodetic bearing from the fire finder to the peak, using the geodetic bearing tool in MICRODEM.
6. Measure the distance from the estimated location to the peak, using the measure distance tool in MICRODEM.
7. Record the distance to the target recorded by the intersection algorithm.

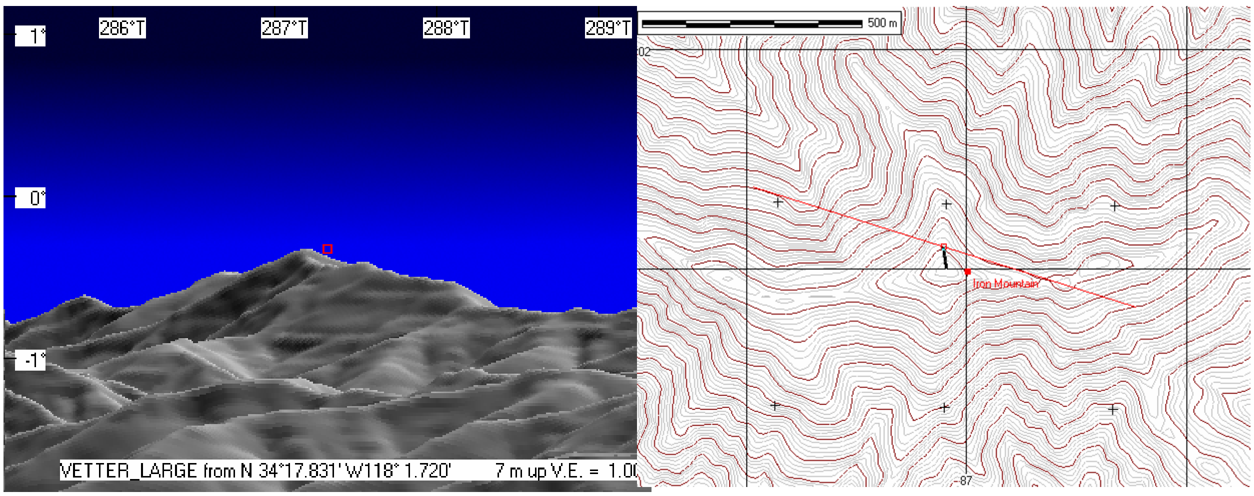

Figure 5. On the left, computed perspective view of Iron Mountain from the Vetter Mountain lookout tower. The red box shows the location of the Osborne firefinder sighting, which is off by about 0.13º in azimuth. On the right, Iron Mountain, with 5 m contours computed from the USGS 10 m DEM. The open box shows the calculated position of the peak, with the red line showing the sighting azimuth from Vetter Mountain. The solid box with the peak label is from the USGS GLIS database, which is not precise but confirms that the peak is indeed Iron Mountain. The true location of the peak is taken as the center of the highest closed contour line, and the solid black line shows the positional error in the location, in this case about 50 m.

Based on the perspective views, we think that Chester and Strong (2000) misidentified two peaks with near neighbors: their Cucamonga Peak is actually Ontario Peak, and Baldy is actually West Baldy. Additionally, a ridge about 7 km away from Vetter Mountain blocks Pallett Mountain, about 14 km away, and the actual sighting must have been to unnamed peak with benchmark Pallett about 2 km NW of Pallett Mountain.

For all of the readings, the average error in azimuth is 0.15º (maximum absolute value is 0.64º), and the average error in pitch is 0.03º (maximum absolute value is 0.43º). We note no significant trend in the azimuth errors, especially considering that a number of the peaks have a broad summit, but find a significant sinusoidal trend in the pitch errors (Figure 6). The simplest explanation for this pattern is that the firefinder is tilted about an axis running 110º-290º, with a maximum tilt of about 0.45º toward 20º-200º.

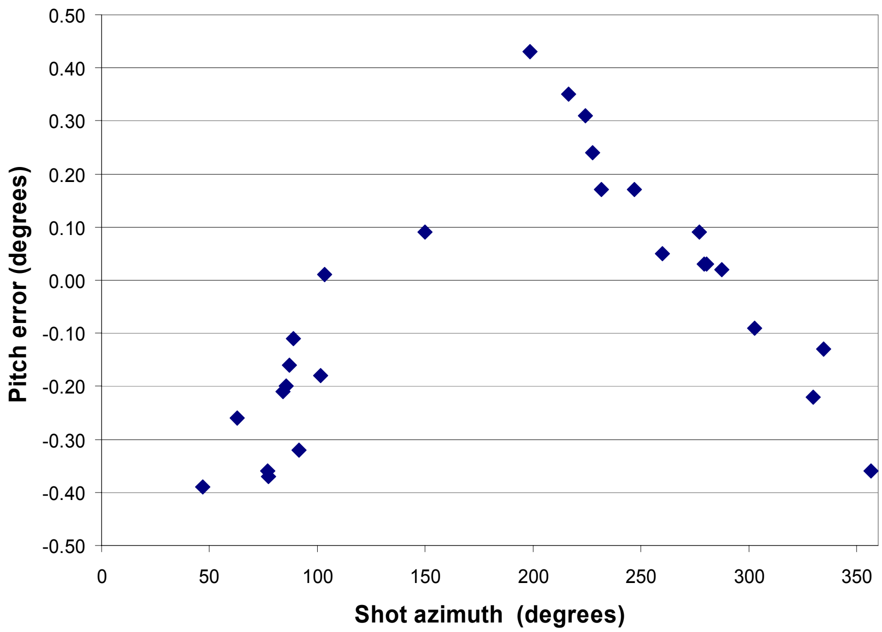

Figure 6. Pitch error from the Vetter Mountain firefinder as a function of azimuth. The regular pattern suggests a tilt to the instrument.

The average error in location, using the corrected pitches, is 108 m. The largest error is 245 m, for a peak 37.8 km away. We used three different DEMs to investigate the sensitivity of the technique to DEM accuracy. With spacings of 10 m, 30 m, and 3” (about 90 m) we achieved very similar results (Figure 7). The results at Vetter Mountain suggest that a single Osborne firefinder can produced very accurate results when paired with a DEM and GIS software.

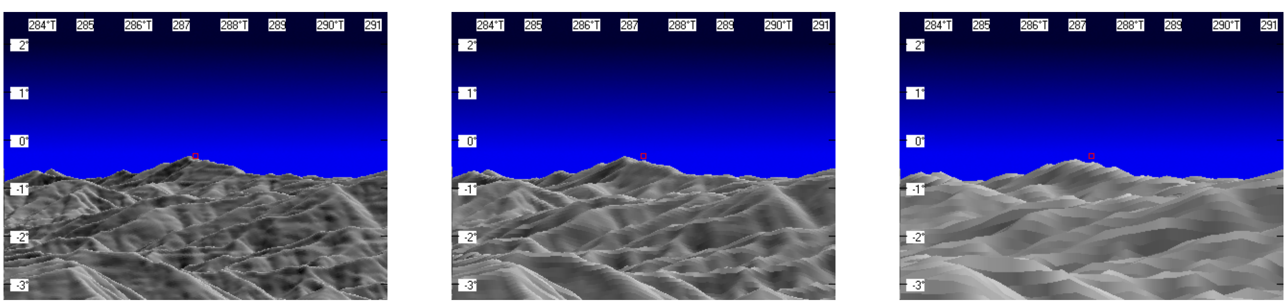

Figure 7. Views of Iron Mountain from Vetter Mountain with three different DEMs, showing that at least for this range of scales, DEM resolution does not significantly affect the algorithm.

OPERATIONAL TESTING IN CENTRAL OREGON

During the summer of 2004, we deployed computers with DragonPlot software in four fire towers in Central Oregon. These tests allowed us to refine our algorithm, primarily in simplifying the user interface to work in an operational setting, and to validate the approach to using GIS data to support fire detection efforts.

At Pisgah Mountain, we collected 19 tests comparing results from DragonPlot with ground truth (Table 1). Five were fire locations, and 14 mirror flashes from another person on the ground with a mirror and radio. About half of the tests located the flash within 100 m, and 84% were within 250 m. Anomalies in the last three tests resulted in extreme mislocations and suggest that blunders were made in reading or transcribing the data.

Table 1. 2004 Pisgah Mountain DragonPlot Test

Error	Percentage of Tests
< 100 m	47.4 (9/19)
< 250 m	84.2 (16/19)

At Odell Butte, we made tests with both single firefinder shots, and crossing shots from two towers to provide an intersection (Table 2). The computer software can provide the intersection faster and more reliably than plotting on a topographic map, especially at longer ranges when the towers and targets occur over multiple map sheets. We took the standard of accuracy to be a quarter mile (the quarter section used in PLSS land descriptions), and the algorithm performed very well.

Table 2. 2004 Odell Butte DragonPlot Test

Category	Accurate (with ¼ mile)	
Single shots, < 20 miles from tower	31/32	1 within 1/3 mile
Single shots, > 20 miles from tower	4/6	1 within 1/3 mile 1 a little more than a mile off
Cross shots, < 20 miles from both towers	26/26	
Cross shots, > 20 miles from both towers	9/10	1 off by 1/3 mile

Table 3 summarizes the results from both towers for 15 fires. Figure 8 plots the location error as a function of range. As suggest earlier in Figures 2 and 3, the error increases with increasing range. Figure 8 also includes 6 mirror flashes, which show generally smaller location errors than with the fire locations. This makes sense, as the bright flash of a mirror and the lack of pressure in a testing situation, allowed the operator to get a better sighting. This operational testing confirmed the validity of the GIS algorithm.

Table 3. Summary of 2004 testing with fire locations

			Plotted with Dragon Plot		Actual (GPS at fire)		
Tower	Fire #	Range (km)	Lat	Long	Lat	Long	Error (m)
Odell	463	9.32	43.45184	-121.97711	43.45167	-121.97611	83.24
Odell	569	52.15	43.68180	-121.29478	43.68472	-121.28944	538.85
Odell	827	24.01	43.54918	-121.58838	43.54944	-121.58750	76.79
Odell	951	11.03	43.54657	-121.95415	43.54556	-121.95361	120.77
Odell	956	40.76	43.62935	-121.40518	43.63000	-121.40961	365.16
Odell	1056	24.06	43.41984	-121.57165	43.42028	-121.57500	275.36
Odell	1156	9.39	43.53125	-121.94534	43.53125	-121.94506	23.31
Odell	1165	12.91	43.35636	-121.89243	43.35639	-121.89306	50.56
Odell	1218	28.73	43.58099	-121.54396	43.58139	-121.54278	105.14
Odell	1256	20.87	43.28412	-121.88614	43.28353	-121.88631	67.32
Pisgah	671	1.70	44.44167	-120.23172	44.44214	-120.23165	52.45
Pisgah	677	47.19	44.04432	-120.12985	44.03903	-120.13207	613.94
Pisgah	682	18.42	44.29752	-120.30559	44.29909	-120.30599	177.32
Pisgah	1066	20.30	44.58182	-120.42193	44.58178	-120.42247	43.56

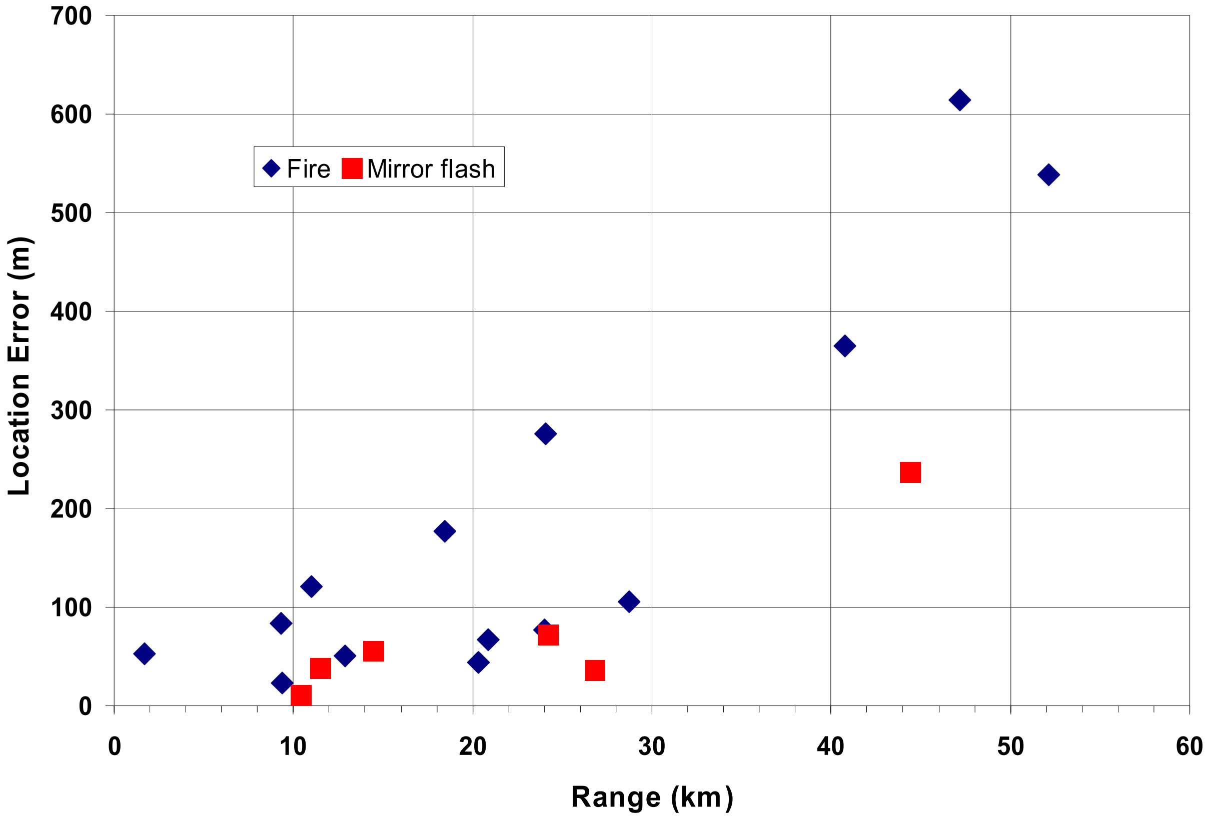

Figure 8. Plot showing the relationship between sighting range and location error for 14 sightings on fires. The r^2 value for a linear fit is 0.77. Six mirror flashes are also shown.

CONCLUSIONS

Our tests last summer primarily used 4 lookout observers with decades of combined experience, but also included the relatively inexperienced backups who covered during days off. Even the experienced lookouts found that the perspective views generated by the computer increased their understanding of terrain around the tower. This increased understanding led to confidence in the computer algorithm, and let them confidently locate fires without the visual landmarks that a lookout normally uses. The GIS solution performs well even when visibility is partially impaired due to thunderstorms, smoke, haze, dust, fog, or low light, and even works well after dark. As long as the base of a smoke is sighted, the computer can obtain accurate fire locations. This allows a lookout to work with less stress regarding a fire location, and to consider the big picture: fire behavior, fire weather, road access, and other fires. GIS levels the playing field for inexperienced and seasoned employees, and brings fixed detection into the digital age. As a result, this will expedite safer fire responses, reduce resource damage, and lower suppression expenses. The lookout observers believe that integrated computer systems will become critical to dispatchers, fire managers, fire fighters and fire lookouts alike to quickly share and coordinate information in the ever increasingly complex real-time fire environment. Figure 9 shows a screen capture of what such a fire detection system might look like in a fire tower.

GIS software using DEMs and an improved Osborne firefinder with a telescope and digital pitch meter can accurately locate fires. The algorithm could easily be extended to other applications when a sighting with a known orientation and observer's position can be combined with a DEM to compute target locations.

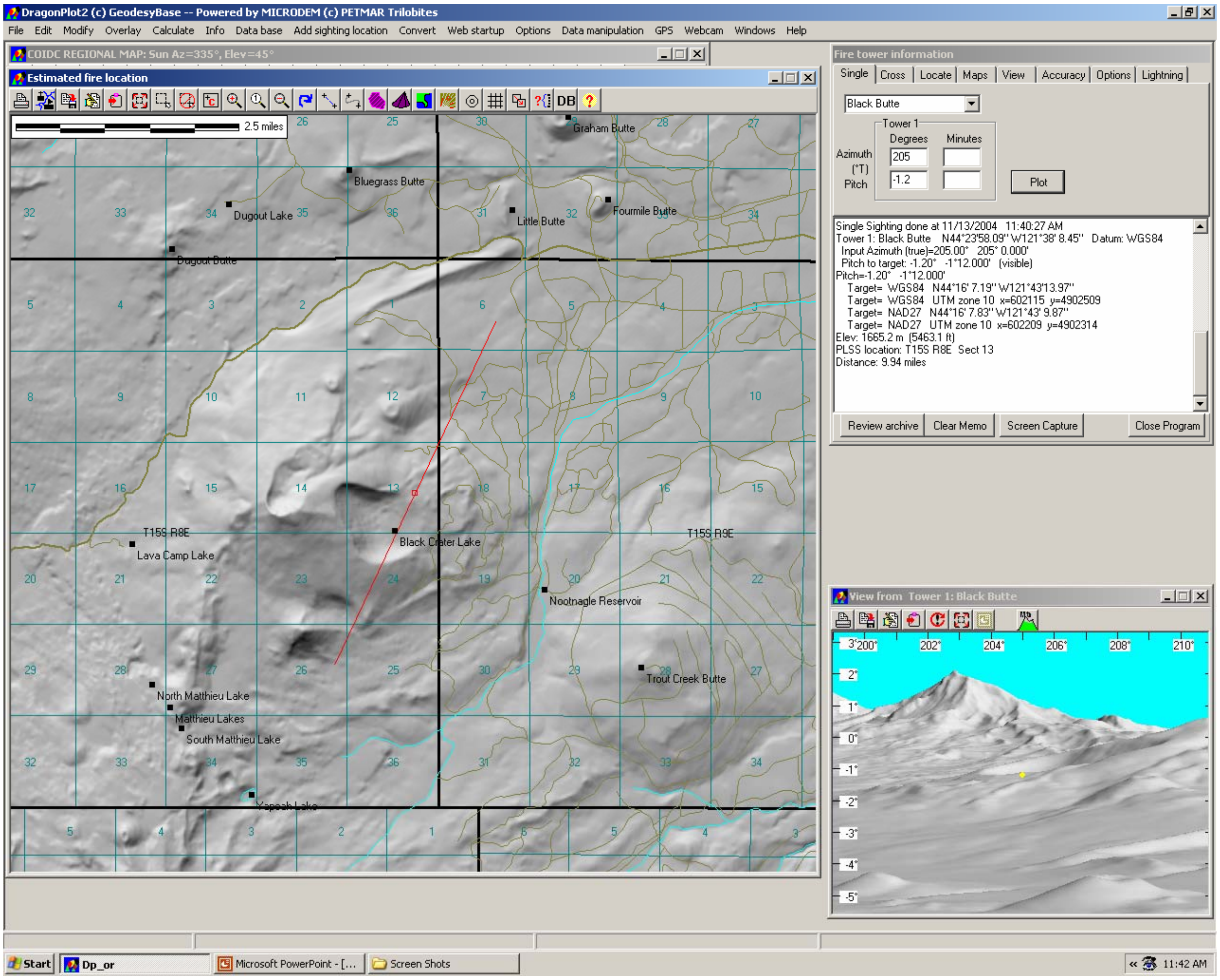

Figure 9. Screen of the DragonPlot application running on a personal computer to locate a fire. The large map on the left shows the sighting line and the location of the sighting, with TIGER roads and streams, PLSS townships and sections, and gazetteer features. The perspective view on the right shows the sighting in context, and the text memo on the upper right contains a record of the sighting.

ACKNOWLEDGMENTS

Author responsibilities for this work: Guth provided GIS expertise, developed the algorithms, and coded the application; Craven developed the initial concept, integrated the system, and coordinated the field tests in Oregon; Chester made the original measurements at Vetter Mountain that proved the concept worked; and O'Leary and Shotwell performed operational field tests in Oregon.

Glen Corbett, Black Butte Lookout, Sisters, OR, and Scot and Stephanie Hartung, Lava Butte Lookouts, Bend OR, also worked with the software during the summer of 2004 and supplied helpful feedback and comments. J. Strong assisted Chester with the original measurements at Vetter Mountain.

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