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Contents

Evaluation of three wildfire smoke detection systems

Abstract

Three video-based wildfire smoke detection systems were evaluated in Alberta and Saskatchewan during the summer of 2003. Two of the systems utilized computer vision to help an operator identify smoke, and the third system relied on an operator to monitor remotely generated images. The Forest Engineering Research Institute of Canada (FERIC) evaluated the systems in terms of smoke detection capability and suitability to Alberta's and Saskatchewan's fire management programs.

Keywords

Fire management, Smoke detection, Wildfires, Towers, Video cameras.

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Introduction

Current wildfire detection techniques in Canada are primarily manned towers, aerial patrols, ground patrols, and public reporting. Among these, manned towers have declined across much of Canada but are still favoured in Alberta and Saskatchewan. However, the existing tower infrastructure is near or at the end of its life. Replacement of manned towers is costly and, as a result, FERIC was asked to investigate new detection technologies as alternatives to using manned towers.

Fire detection technologies that have been implemented abroad were showcased at a workshop in Alberta in March 2003.[1] Among these, two semi-automated systems that use fixed-position video cameras and computer vision demonstrated their potential for use in Canada. Following the demonstrations, Alberta Sustainable Resource Development (SRD), Saskatchewan Environment, and FERIC evaluated two semi-automated detection systems and a manually operated camera system from June to September 2003. The manual system was provided by Norsat Communications and was installed at Calling Lake, Alta. The semi-automated systems were ForestWatch by Envirovision Solutions of South Africa, and Fire Watch™ by IQ-Wireless GmbH of Germany. They were installed at Edson, Alta. and Prince Albert, Sask. This report presents the results of the evaluations and identifies benefits of adopting video detection technology.

Objectives

The objectives of the study were to:

- Evaluate the capability of three video-based smoke detection systems for use in Alberta and Saskatchewan.
- Determine the suitability of these systems to function within existing smoke detection programs in Alberta and Saskatchewan, in terms of ease of use by operators and infrastructure requirements.

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[1] Wildfire Detection Workshop. March 25–27, 2003, Hinton, Alta. Workshop presentations can be viewed on the FERIC Wildland Fire Operations Research Group (WFORG) website at www.fire.feric.ca/36152002/WorkshopPresentation.htm.

System function

All three systems use tower-mounted video cameras linked to remote monitors and camera control. Data transmission, i.e., camera control and image broadcast, can be done by satellite, microwave, or land line (Figure 1).

The manual system relied on an operator to monitor a television screen for smoke. It was set up to be operated by a fire lookout person within the cupola (Rock Island Lake lookout) or from the Lac La Biche dispatch office. The camera was mounted on a communications tower approximately 35 m higher than the adjacent Rock Island Lake lookout tower. This additional height allowed the lookout person to see into an area that was blind from the cupola. The monitor and control panel were mounted in the cupola with a second monitor located in the lookout cabin at the base of the tower. The camera could be programmed to automatically follow a pre-set path set by the tower operator.

The semi-automated systems use motion and scene-change detection algorithms to detect smoke and then alert an operator. The cameras view the landscape by scanning a series of pre-set subsections of the landscape. A sequence of images captured at each subsection is compared for changes that may be a result of smoke. False alarms occur even though the software can filter non-smoke motion, and an operator is needed to confirm alarms. Some alarm sources are not obvious and the operator may zoom in on the source or view a sequence of images showing the change that caused the alarm.

The operator can identify the smoke location using digital maps that are integrated with the detection software. Both systems use triangulation (Figure 2) or a single camera to display smoke location on a digital map. The maps also show any desirable features such as rivers, and display the smoke coordinates. A comparison of hardware and software features for the two systems is given in Table 1.

Methodology

The Edson installation used a 25-m fire lookout located 5 km from the Edson fire centre. Cameras were mounted on the side of the tower, below the cupola. As a result, the tower structure blocked part of the camera's view. Data were transmitted via microwave to the dispatch office and a direct line of sight was required for this technique. The operator computers were located in the dispatch room of the fire centre.

The Prince Albert installation was located at the provincial fire centre. Cameras were mounted on a communications tower that was approximately 30 m tall and located at the centre, and were hardwired to the operator computer that was located in a vacant office at the centre.

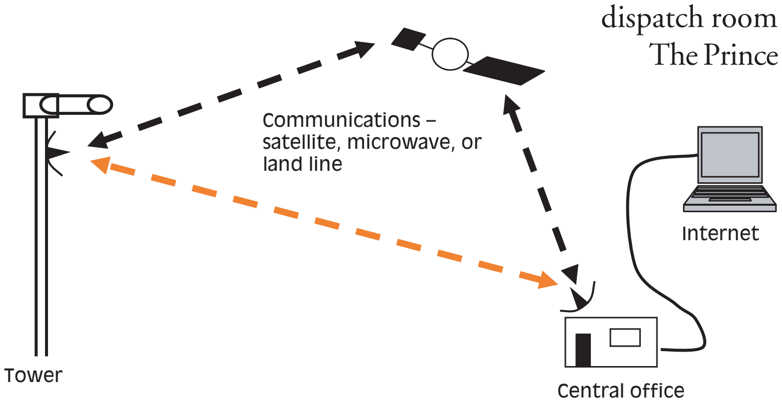

Figure 1. Schematic showing video hardware.

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Detection capability was determined by observing if the systems could detect smokes that fall within Alberta's and Saskatchewan's detection criteria. Because Alberta's smoke detection goal is to detect all fires before they reach 0.1 ha, SRD has set an area of responsibility around each manned tower based on a 40-km radius. However, minimum detection size may be expected to be as high as 2 ha on some days when visibility is poor (Niederleitner 1984). The Saskatchewan target is to detect fires before they reach 0.01 ha. Unfortunately, lighting 0.01- to 0.1-ha fires to test the systems was not possible due to the potential of escape fires.

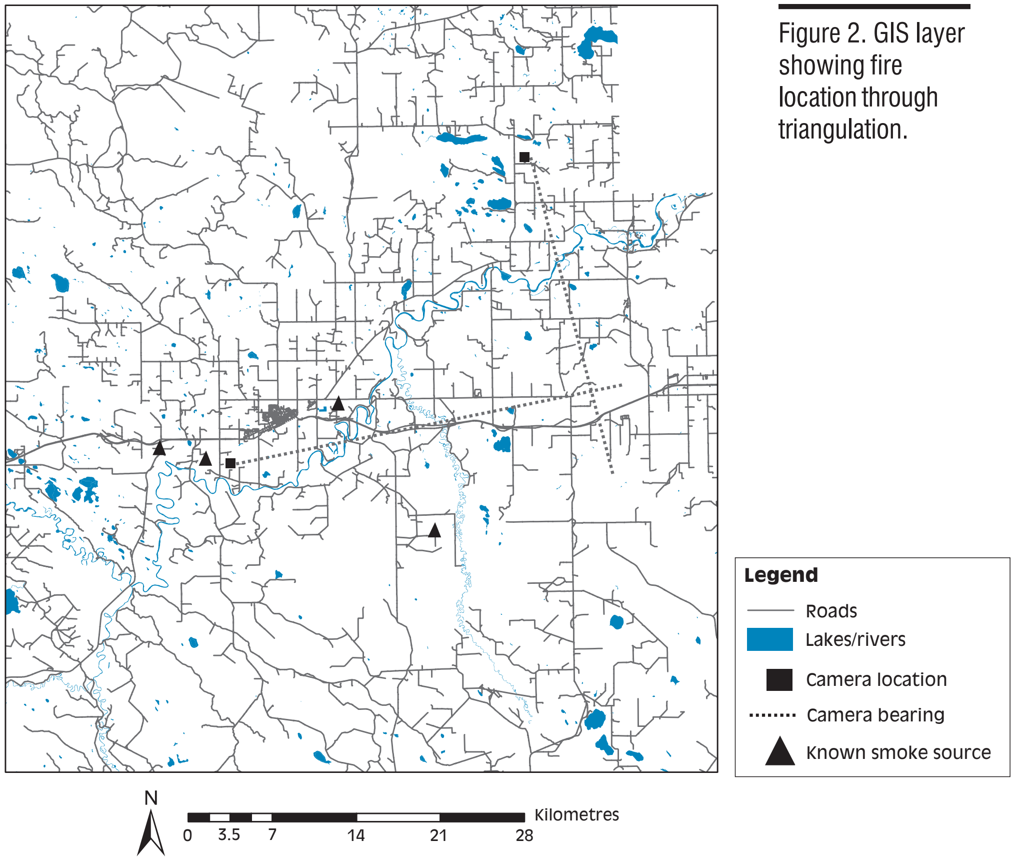

Figure 2. GIS layer showing fire location through triangulation.

Instead of test fires, brush piles, smoke bombs, and a burn pan (gas/diesel/oil mixtures in Prince Albert only) were used as evaluation test smokes (Figure 3). These smokes produced different colours and were done at different ranges. A 0.01-ha (10 m × 10 m) test fire in dried slash done by FERIC at the Community Forest Protection trials, Fort Providence, N.W.T., in June 2003 allowed some comparison between evaluation smokes and a small fire. The 0.01-ha fire produced a similar amount of smoke as the evaluation smokes that used small brush piles, and produced more smoke than a smoke bomb. The fire produced less smoke than a burn pan and the evaluation smokes that used large brush piles. The author estimated that the smoke generated by a large brush pile or burn pan would fall within the range of a 0.01-ha to 0.05-ha fire burning in light fuels. As well, several man-made smoke sources (e.g., industrial stacks) were present within the camera's views and were used to test and demonstrate the systems.

The second component of the evaluation was to determine the suitability of the systems for Alberta's and Saskatchewan's fire management programs. The criteria used to determine suitability were:

- Day-to-day fire detection capability.
- Effort needed to install and set up the system.
- Ease of use. Radio and tower operators and FERIC used the system.
- Compatibility with existing detection programs. Systems were installed at operating fire centres.

As well, several hands-on demonstrations provided the opportunity for personnel from each agency to see and try the systems.

Figure 3. Test smoke using a smoke grenade. Note the smoke does not form a convective column and is affected by slow winds.

Table 1. Comparison of semi-automated smoke detection systems

System function	Comments	ForestWatch	Fire Watch
Camera	Zoom capability is valuable for confirming smoke. Atmospheric haze limits both systems.	Any commercial product. A Honeywell™ Diamond Dome was used for the evaluation.	Proprietary: 14 bit, grayscale, digital scanner with specialized filter.
Camera control	Cameras are controlled by pan, tilt, and zoom motors.	Landscape subsections are user-defined. 360° scan time is 6–12 minutes depending on how the subsections are defined. Full manual camera override.	Landscape is divided into 10° subsections. 360° scan time is 7 minutes. No manual override.
Computer hardware	Both systems are designed to run on Microsoft® Windows® operating systems.	Any high performance personal computer, including video capture card.	High performance personal computer and includes surge and lightning protection.
Data processing and broadcast	Both systems require a high quality image for analysis. Image analysis can be done remotely or at a central office. Remote analysis (i.e., at the camera site) requires less data transmission capacity resulting in lower cost. However, this technique requires computers to be located at remote tower sites and may lead to potential service costs. Images are stored in a database for post-mortem analysis.	System designed for central image processing and can be adapted to remote image processing.	Image analysis is done at the camera site.
Smoke confirmation	A false alarm or smoke is not always obvious so both systems have functions to help operators confirm smokes. Operators can zoom, view a sequence of images that show smoke movement, and adjust image contrast to enhance the area of interest. Both systems allow known smoke sources to be blocked to reduce false alarms.	Manual camera control allows the operator to watch a suspicious smoke, with the tradeoff that the camera is no longer scanning the rest of the landscape.	Image sequence. Prioritize: an operator with a suspicious smoke can request the camera to scan the area more frequently than the normal 360° travel time.
Smoke location	Smoke direction from the camera is indicated by a line overlayed on a digital map by using the camera's bearing. Intersecting bearings allow rapid triangulation of the smoke location. Distance to smokes can also be calculated from single cameras but the techniques differ (see adjacent columns). Any desirable spatial data (e.g., roads, burn permits) can be viewed.	Each landscape subsection that the camera looks at is integrated with spatial data algorithms that calculate the range to any spot on the operator's monitor. Range is determined by pointing the cursor at the smoke base on the monitor. The operator can also query the map to obtain land use or other information.	Smoke range from a single camera is determined by clicking a cursor on the horizon and then the smoke. Distance is calculated by triangulation from the horizon and the system assumes a fixed horizon distance.

Results and discussion

Detection capability

The area within the manual camera's view did not experience any wildfires, and a test fire was readily detected at 10 km range. FERIC also tested this system in 2002 and found that test smokes could be detected up to 20 km. The 2002 tests, where a lookout person was located beside the camera, indicated that smoke visibility was the same through the camera system as for a lookout person. However, the operator had to concentrate on small scene changes that might be due to smoke, which resulted in fatigue. The number of cameras an operator could manage was not determined. The lookout person at the Rock Island Lake tower found that the camera was helpful for looking into an area that was not visible from the cupola, and as a means to watch the landscape from the cabin monitor at the base of the tower. Staff at the Lac La Biche dispatch office were also able to use the camera to monitor the landscape. However, images sent to Lac La Biche were of poorer quality than in the cupola because of image compression. It was not determined how the compressed images would affect an operator's ability to detect smokes.

Both semi-automated systems were designed to detect wildfire smoke within a 10-km radius of the camera (the German criterion is a 10 m^2 smoke column), and were able to detect test smokes within a 10-km radius at Edson and Prince Albert. A long distance test with a large brush pile was successfully detected at 37 km with the ForestWatch system in Edson in good visibility. As well, a burning brush pile was successfully detected and located accurately at 48 km. Several long distance tests (47 km) were undetected, but a lookout person positioned beside the camera also did not see the smoke. Unfortunately, long distance tests were not done on the Fire Watch system in Edson because of high fire hazard. False alarms resulted for both systems from objects at all ranges from the tower, including road dust, cloud shadows, and clouds moving along the horizon.

Simultaneous system comparisons were done in Prince Albert. Smoke tests were conducted up to 40 km but were unsuccessful beyond 20 km. Fifteen tests were done with the burn pan. Three were beyond 20 km, and of those under 20 km range, all were detected if the column was not affected by wind (7 of 13). A lookout person was not used to validate test smokes.

The Sturgeon Lake fire (29 km range) was detected by the Fire Watch system and an alarm was recorded. Unfortunately, the wildfire occurred in the evening while the systems were not being monitored. It was assumed that the ForestWatch system also alarmed, but with no operator present, the smoke image was overridden during subsequent camera passes.

The number of false alarms in Prince Albert (greater than 300 per day) was greater compared to Edson (less than 70 per day). The lack of long distance detection and large number of false alarms at the Prince Albert tests were partially due to a sub-optimal camera location. The tower used for mounting the cameras was not very high, and trees in the north view were almost the same height as the camera, thus limiting the visible area. The resulting camera angle to the trees meant that trees swaying in the wind caused false alarms with both systems, which would not have occurred if the cameras were higher. As well, long distance tests were hampered by frequent wind gusts that kept the smoke near the ground.

The tests showed that both systems detected small smokes (equivalent to a 0.01-ha fire or less) up to 20 km in good visibility. It was assumed that none of the test smokes conducted at long range, or the long range brush pile detections (at 37 and 48 km range with ForestWatch) in Edson, produced more smoke than a 0.1-ha fire. It was concluded that the Fire Watch system would also detect test smokes at ranges greater than 20 km because it alarmed on the same smokes as ForestWatch when shorter range tests were done. As well, both systems alarmed on non-smoke features (e.g., moving clouds) at ranges over 40 km, indicating the ability of the systems to detect motion/scene changes at long distances. Therefore, it was concluded the ability of the semi-automated systems to detect smoke falls within the detection standards for Alberta and Saskatchewan.

It is a reasonable assumption that the smoke detection systems will detect some smokes beyond the detection criteria and miss some within the area of responsibility, as is the case with lookout persons. The Alberta detection criteria is based on U.S. Forest Service research done in the 1930s (Jemison 1940; Byram and Jemison 1948). They found that a lookout person could reliably spot wildfire smokes without aid, resulting from surface fires in light fuels at the following ranges:

- 0.05 ha, or 22 m^2 fire at 13 km
- 0.1 ha fire at 25 km

This research also found that visible distance, i.e., the range that an average lookout person could reliably spot a small smoke, was affected by time of day, time of year, and geographic location. These same factors will affect a video-based detection system, but such a system can be tuned to "see" differently than humans. For example, ForestWatch has night vision capability by scanning near infrared wavelengths, and the Fire Watch system is tuned to see slight changes in colour and brightness that are beyond human optics. As well, camera capability will be the same at every tower, whereas human capability is variable (Byram and Jemison 1948).

The number of test fires was not exhaustive. Haze, sun position, fire location relative to topography, and background colour all affect smoke visibility (McArdle 1936), and were not investigated.

Installation effort

Installation involved mounting cameras and data transmission hardware on the tower and data reception sites. For most towers, this requires a qualified rigging team (Figure 4). After the experience of the initial installation, a team of five people was able to install the system in two days. However, cameras mounted at remote sites require more time.

The setup required establishing the settings and correct internal bearing for the cameras. In the case of Fire Watch, the scanner is levelled with the horizon and then follows 10-degree pre-set locations automatically. Geographic information systems (GIS) data have to be converted to a bitmap image format and copied to a dedicated folder where they are read automatically. ForestWatch requires more set-up time as each subsection is set manually (several hours per camera). This system uses ESRI™ shapefiles, or GeoTIFF images, for GIS layers that are copied into a dedicated folder and read automatically by the software. Both systems allowed GIS data to be easily and frequently upgraded which would be useful if layers such as fire hazard maps were to be integrated.

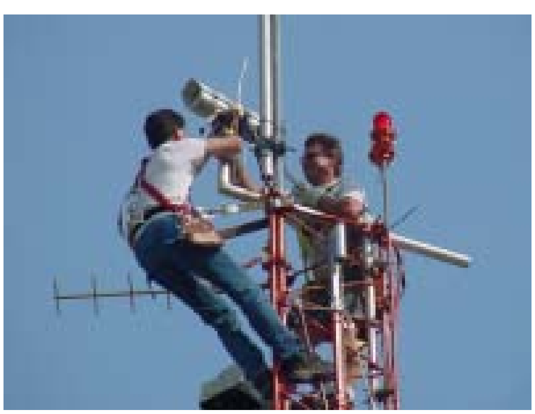

Figure 4. Camera installation on communications tower.

Ease of use

Both of the semi-automated systems are designed so that an operator, with minimal computer knowledge, can learn the system quickly (1 to 3 days) and manage multiple cameras. A dedicated operator is needed even with only one camera. As with a lookout observer, knowledge of the camera's landscapes is valuable.

The alarm processing features of both systems worked well in identifying small or distant alarms. As well, the operators were faced with numerous false alarms from, for example, road dust, cloud and cloud shadow movement, and permanent smoke sources. False alarms cannot be prevented and, to some degree, help the operator concentrate on the system.

The GIS component of the systems is necessary for smoke location and was easy to use. In the case of Fire Watch, spatial data are shown as an image, and the camera bearing to a smoke is overlaid on the map. When a smoke position is identified through triangulation, the operator moves the mouse pointer over the bearing intersection and records the coordinates. ForestWatch has the same features and also allows the operator to query the spatial data by clicking the mouse pointer on the map. Spatial information can include known smoke sources and burn permits. ForestWatch displays the bearing and range to the smoke from each camera. Therefore, if only one camera can see the smoke, the operator can still query the smoke position on the map. The operator could easily zoom and pan on map features for both systems.

Compatibility with existing detection programs

Systems are designed to be stand-alone and operated in a dispatch office so that fire managers can be immediately notified of smokes. As well, fire managers can see the smoke column as it develops and the system could be linked to a projector in a dispatch office.

The GIS function could be integrated with spatial data related to fire such as lightning indicators and daily fire hazard level maps. Smokes identified from other sources could also be located on the GIS. These spatial data could be projected similarly to the smoke images. Information on known smokes and burn permits can be integrated as well. This information would help the operators confirm smoke alarms by allowing them to do a spatial query of potential known smokes on the alarm area.

Installation considerations

The same installation considerations apply for camera tower locations as for manned lookouts. However, existing communications towers may be used and offer better visibility (heights of 60 to 100 m compared to 30 m for manned lookouts). If existing towers are not available, new towers do not need to be built for human occupancy which could result in cost savings, and can be much taller than manned lookouts.

Ideally, cameras are mounted on tower tops. However, this space may not be available on an existing tower. The least expensive solution is to accept the obstruction provided by the existing structure and equipment. An alternative solution is to mount two cameras on one tower. This solution offers several additional benefits:

- Camera failure doesn't require immediate replacement.
- Triangulation would be available on more fires—cameras can be mounted at different heights to improve triangulation.
- The system can continue to scan if one camera is in manual override mode (ForestWatch system).
- Greater scanning intensity can be maintained when both cameras are in automatic mode.

Data transmission has not been a serious issue at other installation sites in other countries for either of the semi-automated systems because unlicensed microwave or land lines have been available. It is unlikely that these methods can be widely used in Alberta or Saskatchewan at present because many potential camera sites are in remote locations. An alternative transmission method is satellite communications. However, live video via satellite is costly, and only feasible using compressed images.

Conclusions and implementation

The three video-based smoke detection systems evaluated in this study were deemed capable of detecting wildfire smoke within the criteria set by Alberta SRD and Saskatchewan Environment. However, the two semi-automated systems are more reliable than the manually controlled system because the potential for oversight, likely to happen due to operator fatigue, is removed. The two semi-automated systems were similar in their capability to detect smoke, but differed in user features and hardware configuration. The semi-automated systems were integrated with GIS data, allowing the operator to quickly identify smoke location—another advantage over the manual system.

Benefits of a semi-automated smoke detection systems are:

- Continuous landscape monitoring can be done, as ForestWatch has night vision capability (Fire Watch night vision is in development).
- One operator can monitor multiple cameras.
- Permanent record of smoke events (date-stamped image) can be obtained.
- Better landscape coverage is possible compared to manned towers by locating cameras on tall towers.

- Little or no tower construction cost is necessary if existing communications towers can be used.
- New tower construction could be less expensive because towers do not have to be engineered to house people.
- Cameras can be mounted on mobile towers for temporary installations.
- Existing fire management information can be integrated with the detection system (e.g., recent lightning detection and wildfire threat rating systems).
- Potential for real time fire video broadcast to dispatch offices or fire command centres is available.
- Multiple uses for the imagery are possible, e.g., monitoring landslides in steep slopes.

Considerations for systems implementation include tower location, camera location on a tower, and data communications. Tower location must be chosen to maximize landscape coverage and considered within a network of towers. Camera location is optimal on the tops of existing towers. However, other antennae are likely already to be in place. Having two cameras per tower is more expensive but can offer additional benefits. Effective data communications is the key to link remote cameras to a central office. The best solution for Alberta and Saskatchewan appears to be satellite communications, because of the large areas to be covered and tower isolation.

Future work

FERIC and Alberta SRD will conduct an operational pilot study in 2004. This will confirm the feasibility of an operational system (i.e., using existing communications towers and satellite communications with a dedicated operator) and add confidence in the system capability. As well, a tower with two cameras will be tested. This configuration allows greater scanning intensity compared to one camera and provides a backup should a camera failure occur. Finally, the study will allow a detailed cost analysis based on operational use of the system.

FERIC will also work towards establishing a visual database that shows smoke columns resulting from known fire sizes and different boreal fuel types. This information will help to refine expectations for semi-automated systems, and could also serve as a training tool for lookout persons.

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