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Understanding how well current detection technology uses imagery from existing cameras on towers to detect smoke

PROJECT NUMBER: 301014839

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Seven vendors participated in a smoke detection exercise conducted in Alberta, Canada from August 23 to 29, 2021. This exercise aimed to understand how well current detection technology uses imagery from existing cameras mounted on towers to detect smoke. All vendors in this exercise use artificial intelligence / machine learning algorithms in their systems. Alberta Wildfire expects to gain a better understanding of these detection systems and how they differ from each other.

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BACKGROUND

Wildfire detection technologies and applications have been constantly evolving over the last 20 years. Currently, Alberta uses two categories of detection agents: planned and unplanned (Government of Alberta, 2021). Planned detection agents are aerial patrols, fire lookouts, and ground patrols. Unplanned detection agents are 310-FIRE (public reporting), cooperation of other industries, and government staff. An opportunity for improvement as stated in Alberta's Spring 2019 Wildfire Review (MNP LLP, 2020) is to "continue to evaluate the application and use of emerging wildfire detection technology on Alberta's landscapes" (p. 75).

FPInnovations has been involved in exploring detection technologies in the past with support from Alberta Wildfire. These projects included "Operational Trial of the ForestWatch Wildfire Smoke Detection System" (Schroeder, 2005), "A Video Camera System for Blind-area Smoke Detection" (Thomasson, 2008), and "Effectiveness of Distributed Decision (Crowdsourcing) Wildfire Detection" (Hsieh & Roy, 2017).

Alberta Wildfire has installed over one hundred cameras on lookout and telecom towers. These cameras are maintained and supported by Alberta Wildfire Telecommunications. Alberta Wildfire Management Areas have access to these cameras for environmental monitoring and safety, but most are not for wildfire detection. Only the Calgary Wildfire Management Area manually utilizes two cameras as detection tools to confirm public reporting in high traffic recreation areas. Multiple vendors have been developing detection technologies and showcased them at International Wildland Fire Detection Workshops held in 2003 (Schroeder), 2006 (Karmacharya), 2010 (de Bruijn), and 2015 (Ault, 2015). It is logical, therefore, to explore opportunities to utilize imagery from existing cameras with these technologies for wildfire detection.

In July 2021, Alberta Wildfire and FPInnovations came together to collaborate on a project to explore the capabilities of new and developing wildfire detection systems that can use imagery from existing cameras. From this project, Alberta Wildfire hoped to gain a better understanding of these detection systems and how they differ from each other. Alberta Wildfire will use this information to inform wildfire detection strategies moving forward.

OBJECTIVES

The objectives of this project were:

1. Identify wildfire detection systems that utilize imagery from existing cameras on towers.
2. Understand the capabilities of these detection systems.
3. Compare pan-tilt-zoom (PTZ) cameras and fixed cameras to understand the value of each option for wildfire detection.

METHODS

Due to the limited time available to prepare and complete this project (the project's inception was July 2021), all vendors agreed to remain anonymous to avoid nondisclosure agreements and reduce other paperwork; vendors were therefore identified for this project by an identification number. The vendors also agreed to volunteer their time and resources in return for access to imagery from Alberta Wildfire cameras and the opportunity to test their systems in a Canadian forest environment.

Vendors

Alberta Wildfire provided FPInnovations with a list of vendors they have had communications with over the last five years. The researcher sent invitations to 18 vendors on the list. Seven vendors agreed to participate in the exercise. All seven vendors use artificial intelligence (AI) / machine learning technologies to detect wildfire signatures (i.e., smoke) on imagery. The characteristics and readiness of each system as determined by the researcher are provided in Table 1.

Table 1. System readiness and characteristics.

Vendor ID	System Readiness	Provided Georeferenced Wildfire Location	Canadian Company
1	Commercial	Yes	No
2	Commercial	Yes	No
3	Commercial	Yes	No
4	Prototype	No	No
5	Commercial	No	No
6	Prototype	No	Yes
7	Prototype	No	Yes

Four of the seven detection systems are commercially available. Each of these four systems has a web-based user interface that provides detailed detection information. The other three systems were prototypes, and those vendors used this exercise as an opportunity to test their systems.

The vendors who responded to the invitation, but chose not to join the exercise provided the following reasons:

- lack of resources to participate in the exercise due to contract commitments with other wildfire agencies
- their system works only with their proprietary sensors
- their system requires full control of the cameras

The vendors were asked to set up their own secure file transfer protocol (SFTP) sites. Alberta Wildfire Telecommunications used a program to capture imagery from the cameras and then transferred image files to these SFTP sites every minute during the exercise.

Other information provided to the vendors included:

- location of the cameras
- specifications for each camera

camera heights (see Camera information

Camera specifications are provided in Table 2. Camera information..

- Table 2)
- estimated bearings of camera views
- estimated fields of view[1] for each camera
- visibility maps
- known smoke locations (see description in the *Exercise Execution* section below)

Study locations

Three lookout towers were selected for this project. All towers had both fixed and PTZ cameras. These towers were:

- Stony Mountain Tower – south of the city of Fort McMurray
- Marten Mountain Tower – north of the town of Slave Lake
- Athabasca Tower – north of the town of Hinton

Camera information

Camera specifications are provided in Table 2. Camera information..

Table 2. Camera information.

Camera ID	Model	Resolution	Aspect Ratio	Height on the Tower (m / ft)
Athabasca Fixed	Axis P1357-E	2592 x 1944	4:3	61 / 200
Athabasca PTZ	Axis Q6045-E mk II	1920 x 1080	16:9	61 / 200
Marten Mountain Fixed	Ubiquiti UVC G4 Pro	3840 x 2160	16:9	30 / 100
Marten Mountain PTZ	Axis Q8665-E	1920 x 1080	16:9	61 / 200
Stony Mountain Fixed	Axis P1357-E	2592 x 1944	4:3	30 / 100
Stony Mountain PTZ	Axis Q6045-E mk II	1920 x 1080	16:9	30 / 100

Normally, the pan-tilt-zoom (PTZ) cameras are controlled manually (with a joystick controller) by staff of Alberta Wildfire Management Areas to monitor the surrounding environment; no specific preset views are set for wildfire detection purposes. For this project, Alberta Wildfire Telecommunications set the PTZ cameras to rotate automatically through six preset views to cover 360°. One preset view on each PTZ camera was set to the same field of view as the fixed

[1] The field of view is a part of the world that is visible through a camera lens at a particular spatial position and orientation. For the exercise, the field of view was identified by using the azimuths of an image's right and left edges.

camera on the same tower to allow the researcher to compare detection success between fixed and PTZ cameras.

Exercise execution

The exercise took place between August 23 and 29, 2021. The daily detection period was 09:00 to 19:00 Mountain Daylight Savings Time.

A Curtis Dyna-Fog 1200 smoke generator (Gibos, 2005) was used to generate artificial smokes during the exercise. Each artificial smoke was similar in size to the smoke generated from a small wildfire (simulates a 0.1 Ha in size) that would be suitable for an initial attack crew to action (Figure 1). All artificial smokes were generated within the field of view of the fixed cameras and at ranges of 5 to 23 kms from the tower. The smoke generator ran for 20 minutes at each location for each test. The vendors were not notified of the location or the time of the artificial smokes. Experienced lookout observers would confirm whether the smoke was visible or not from the towers.

Figure 1. A smoke generator producing artificial smoke (left). An image of the same smoke captured by the lookout observer through a fire finder at a range of 23 kms (right).

The vendors were asked to detect real wildfire smoke and artificial smoke, and to demonstrate the ability of their system to avoid false alarms and reporting known smokes. A false alarm is a detection notification triggered by a detection system for an environmental condition that is not fire related but misinterpreted as a smoke, such as cloud, dust, haze, and water reflections. Known smoke is a real smoke but is related to permitted industrial activity and flares up at the same location repeatedly (e.g., smoke from pulp mills and gas well flares). Unidentified known smokes are known smokes but the vendors were not informed of these ahead of the exercise.

Alberta Wildfire agreed to share with the researcher their records of any wildfire events that occurred within the coverage areas during the time period of the exercise.

When smoke was detected, the vendors were expected to email a detection message to the researcher in timely manner. The detection message was to include:

- a georeferenced location of the reported smoke
- time of detection
- an image of the detected smoke
- a completed FP40 form

An FP40 form is used to record a detection message with a consistent format within Alberta Wildfire. The information fields on the form include detection agent, location, smoke description, discovery date, and time. An FP40 form has a "Protected A" information security classification level and cannot be shared in this report.

Analysis

The researcher compiled the detection messages received from the vendors. The detection messages were compared against all wildfire, artificial, and known smoke events. The detection messages were categorized as either a wildfire smoke, an artificial smoke, a false alarm, a known smoke, or an unidentified known smoke. Detections categorized as a wildfire, an artificial smoke, and an unidentified known smoke were classified as successful detections. Detections categorized as a false alarm and a known smoke were classified as unsuccessful detections.

The artificial smokes were generated at various distances from the towers so the researcher could determine the effective detection range of these systems.

The researcher calculated the difference between the reported location and the actual location of the detected smoke to understand the georeferencing capability of each system.

The researcher calculated the discovery time and the reporting time for each detection. Discovery time was the time between smoke initiation and detection time. This difference represents how long it takes for a system to detect a smoke. The reporting time was the time between detection and when the detection message arrived at the researcher's inbox (a proxy for a wildfire duty room). Reporting time represents the latency caused by data-transfer limitations from the detection system to the duty room. Only successful detections of artificial smokes were used for this analysis because smoke initiation times were available for only these events.

To allow the researcher to calculate discovery times and reporting times, the following time stamps were collected during the exercise:

- when the smoke was initiated
- when the first smoke signature could be visually identified in the captured imagery by the researcher
- when the smoke was detected by a vendor's system
- when the detection message arrived by email to the researcher's inbox

To compare PTZ and fixed cameras, the researcher compiled the number of successful detections by each camera type. Unfortunately, the program that captured images did not correspond to the movement of PTZ cameras. Therefore, the order of the captured images from PTZ cameras was random. The detection systems could not identify nor differentiate image files between preset views by file name or properties. The ability to sort files based on the preset views is important for any detection and georeferenced system. Due to the limited time available to prepare this exercise, updating the image capture program was not possible. To overcome this, a text box was embedded on each image that noted which preset view generated it (Figure 2). This allowed the vendors to develop an additional system component to sort the imagery from PTZ cameras. Not all vendors had the resources to develop this additional component for their system on such short notice; therefore, vendors were given the option to utilize imagery from both types of cameras or just the imagery from fixed cameras. Two vendors chose to develop additional system components to utilize the imagery from both types of cameras; all others chose to use imagery from only the fixed cameras.

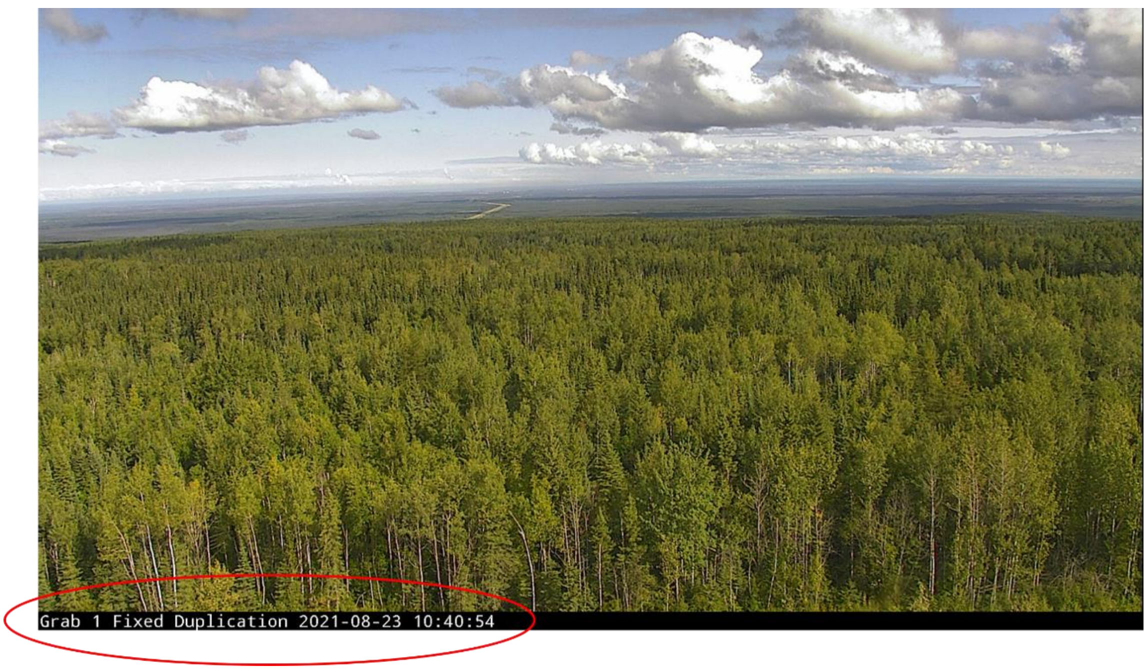

Figure 2. A text box was embedded in each PTZ camera image. *Grab 1* indicates that this image was captured using the Preset 1 view.

RESULTS

Smoke events

During the exercise time period, no wildfires occurred within 30 kms of the lookout towers. The researcher generated 13 artificial smokes (Table 3); eleven were deemed valid. The Stony Mountain 1 smoke was not visible by the lookout observer and was therefore deemed invalid. The Martin Mountain 1 smoke was visible and verified by a lookout observer, but it was deemed invalid because the software that was responsible for transferring the imagery had malfunctioned and the images were not delivered to vendors' SFTP site.

Table 3. Artificial smokes generated during the exercise.

Artificial Smoke ID	Start Time	Distance from Camera (km)	Visible to Lookout Observer	Detected by Vendors (vendor ID)
Stony Mountain 1	8/23/2021 15:47	4.6	No	n/a; invalid
Stony Mountain 2	8/24/2021 11:33	23	Yes	not detected
Stony Mountain 3	8/24/2021 13:03	11.1	Yes	not detected
Stony Mountain 4	8/24/2021 14:26	8.7	Yes	2, 3
Martin Mountain 1	8/26/2021 09:51	20.5	Yes	n/a; invalid
Martin Mountain 2	8/26/2021 12:30	20.5	Yes	not detected
Martin Mountain 3	8/26/2021 13:50	15.4	Yes	not detected
Martin Mountain 4	8/26/2021 14:28	10.1	Yes	3, 7
Martin Mountain 5	8/26/2021 15:55	5.7	Yes	1, 3
Athabasca 1	8/28/2021 09:58	17.7	Yes	3, 5
Athabasca 2	8/28/2021 11:06	17.8	Yes	3
Athabasca 3	8/28/2021 12:14	15.2	Yes	3, 5
Athabasca 4	8/28/2021 13:59	6.5	Yes	3

Categories of detection messages

A total of 171 detection messages were received. These detection messages were categorized into four categories (Table 4).

Table 4. Categorized results of detection messages.

Vendor ID	Successful Detections		Unsuccessful Detections	
	Artificial Smoke	Unidentified Known Smoke	False Alarm	Known Smoke
1	1	0	0	1
2	1	0	0	0
3	7	4	11	2
4	0	0	0	0
5	2	2	84	3
6	0	0	0	0
7	1	0	52	0
Totals	12	6	147	6

Vendor 3 had the best performance. Its system detected 7 out of the 11 valid artificial smokes. It had the highest detection success, generated 11 false alarms, and reported two known smokes. Based on the data, the four commercially available systems had fewer false alarms and reports of known smokes but did not eliminate them entirely.

Components of detection messages

As described in the Methods section, the vendors were asked to include four pieces of information in their detection messages. Table 5 summarizes the ability of each vendor to deliver these pieces of information.

Table 5. Delivery of requested information in detection messages.

Vendor ID	Georeferenced Location	Time of Discovery	Image	Completed FP40 Form
1	Yes	Yes	Yes	Yes
2	Yes	Yes	Yes	Yes
3	Yes	Yes	Yes	Yes
4	No	No	No	No
5	No	Yes	Yes	Yes
6	No	No	No	No
7	No	No	Yes	No

All vendors chose to separate their detection message into two emails. The first email was triggered automatically by their detection system as soon as a smoke was detected. The email contained the georeferenced location of the smoke, the time of discovery, and the image of discovery. Vendor 1, 2, and 3 also included links to their web-based user interface that provided graphics. The second email contained a completed FP40 form and was generally sent out few hours after the first email. The FP40 forms were completed by hand, scanned, and attached to the emails as photos.

Detection ranges

Effective detection range is an important attribute to calculate a coverage area and cost of a detection system. The distances of the 11 valid artificial smokes from the lookout towers ranged from 5.7 to 23 kms. All successful detections were within 17.8 kms of a tower (Figure 3).

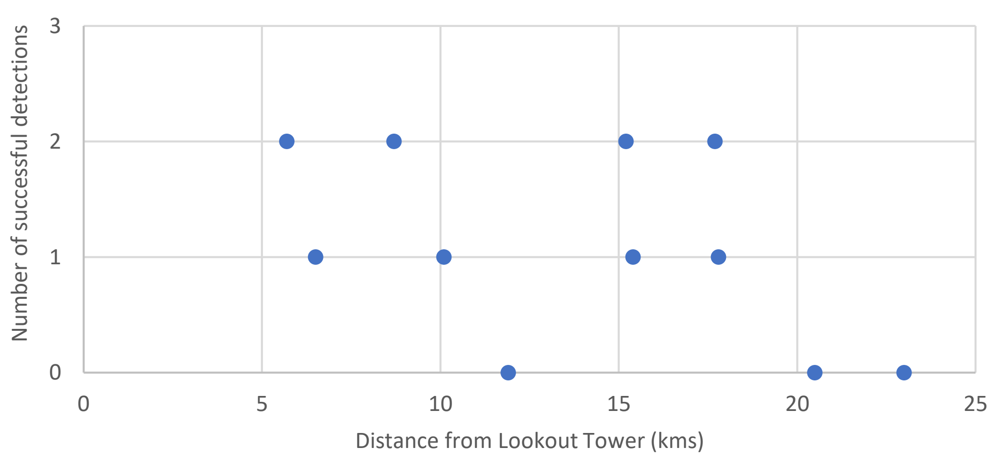

Figure 3. Distances from the lookout tower for the successful detections of the 11 valid artificial smokes.

Accuracy of reporting fire locations

Accurate reporting of smoke locations helps initial attack resources to locate and arrive at a fire faster. Vendors 1, 2, and 3 demonstrated the ability to provide a georeferenced location for the smoke in their detection message. Their detection messages also contained links to access their online digital maps. Vendors 1, 2, 3, and 5 marked the fire signature within the images to provide a visual reference.

Nine detection messages from Vendors 1, 2, and 3 were used to assess the accuracy of their georeferenced locations (Table 6). The researcher also calculated and assessed the camera bearings of these reported locations.

Table 6. Results of reporting accuracy.

Vendor ID	Artificial Smoke ID	Distance from Camera (kms)	Distance Between Reported and Actual Location (kms)	Bearing
1	Martin Mountain 5	5.7	0.5	Right on target
2	Stony Mountain 4	8.7	9.3	Right on target
3	Stony Mountain 4	8.7	2.1	Right on target
3	Martin Mountain 4	10.1	3.2	Right on target
3	Martin Mountain 5	5.7	5.5	Right on target
3	Athabasca 1	17.7	7.4	4 degrees off
3	Athabasca 2	17.8	16.6	Right on target
3	Athabasca 3	15.2	19.5	Right on target
3	Athabasca 4	6.5	11.2	Right on target

All the detection messages contained latitude and longitude to pinpoint the smoke locations. The distances between reporting and actual locations of smokes varied but the bearing accuracy among the successful detections was high.

Timeline and latency

Table 7 shows the mean discovery and reporting times of the five vendors who had successful detections.

Table 7. Mean discovery time and reporting time for successful detections.

Vendor ID	Number of Successful Detections	Mean Discovery Time (minutes)	Mean Reporting Time (minutes)
1	1	11	1
2	1	1	1
3	7	11	2
5	2	9	2
7	1	16	4

Although only Vendor 3 had a sizeable number of samples for analysis, the overall results still show the mean discovery time was under 16 minutes and the mean reporting time was below four minutes.

Detection success based on camera type

Multiple fixed cameras are required to cover 360^o because each camera has one fixed view that never changes. In contrast, only one PTZ camera is required to cover 360^o by configuring a series of presets and rotating through them during operations.

During this exercise, only Vendors 2 and 5 decided to use imagery from both fixed and PTZ cameras. Both vendors developed additional processes to recognize text within the digital images to identify and arrange them in a usable order. However, both vendors had only three successful detections combined, and the source of these three detections was a fixed camera. The dataset was insufficient to support a meaningful comparison of detection efficacy between PTZ cameras and fixed cameras. However, during the post-exercise debrief, the vendors provided useful information based on their preferences. Their feedback is summarized in the discussion session.

DISCUSSION

Difference between systems

All systems are similar in architecture because they were restricted to using imagery from existing cameras and delivering detection messages by email in this exercise. All vendors used AI / machine learning algorithms to detect smoke signatures within the imagery. The researcher did not investigate the different AI / machine learning algorithms among systems because these are the intellectual property of the vendors.

Vendor 1, 2, 3, and 5 are commercial systems. They showed their capabilities by including time of discovery, the images of the smoke, and completed the FP40 forms in detection messages. Except for the FP40 forms, all information were auto generated by the detection systems. Vendors 5 was the only commercial system that could not provide georeferenced location for their detection messages. All commercial systems observed integrate mechanisms intended to reduce false alarms and avoid reporting known smokes.

Vendor 4, 6, and 7 are prototype systems. These systems did not show the ability to generate detection message at the time of the exercise.

In overall performance, vendor 3 had highest number of detection successes. The other systems did not perform near this level.

Accuracy of reporting fire locations

Accurate reporting of smoke locations can help duty officers and initial attack crews to find and action wildfires more quickly. Only three vendors provided georeferenced information (latitude and longitude to pinpoint smoke location) in their detection messages, with accuracies varying between 0.5 and 19.5 kms. Based on the feedback, all three vendors used digital elevation model (DEM) overlays for their georeferencing systems. The resolution of the DEM, system calibrations, smoke signatures on imagery, and local knowledge could impact accuracy greatly.

Bearing accuracy was high. Although cross shots may not be possible in Albertan landscapes because of long distances between tower infrastructure and the short detection range of these systems, bearing is still an important piece of information to locate a fire. Future users of these systems should make all data available to initial attack resources, including the georeferenced location, bearing, smoke imagery, and local knowledge.

FP40 form

Vendors were asked to complete an FP40 form for each detection message. However, out of 171 detection messages only 18 FP40 forms were received during the exercise. That was because vendors could not complete FP40 forms automatically. All FP40 forms were handwritten, scanned, and attached as photos in follow-up emails. Vendors were also located in different time zones around the world and did not have the resources to respond during non-business hours. The majority of completed FP40 forms were delivered 12 hours after the initial detection message.

The FP40 from was developed by Alberta Wildfire before it was possible to transfer digital files and imagery between lookout towers and duty rooms. Half the items on an FP40 form are georeferenced data for a fire's location, and these items were redundant during this exercise because vendors provided that information within their detection message.

The rest of the items on an FP40 form are attributes that describe a smoke. During wildfire operations in Alberta, these descriptions are transferred verbally via radio between fire lookouts, dispatchers, and initial attack fire crews to help find and assess a wildfire. The data from these forms are stored in a database for historical record keeping and future possible investigation; plus, in the hopes of utilizing it in the future for automatic detection technology development.

All systems in this exercise require access to the Internet with a reasonable bandwidth. The ability to transfer real-time digital imagery between the detection systems and the duty room was demonstrated. After receiving smoke images in the duty room, they can then be shared with the duty officer and initial attack crews to find and assess a wildfire. Because these detection technologies were able to share these images, the FP40 form was redundant and unnecessary for this exercise.

Based on feedback from the vendors, the description of a smoke on an FP40 form cannot be mathematically quantified in a consistent way. Vendors use AI / machine learning algorithms in their detection systems, and these algorithms automatically generate smoke qualification criteria through deep learning processes based on different datasets and scenarios. These smoke qualification criteria are numeric and constantly changing. Therefore, the smoke descriptors on the FP40 form are unusable by the technology.

Review of detection messages

A high number of false alarms and reports of known smokes are distracting to a duty officer and can potentially increase the cost of initial attack. During the seven days of this exercise, the researcher received 171 detection messages; 147 were false alarms and six were known smokes. This exercise showed that total elimination of false alarms and reports of known smokes may not be possible at this time. Additional human resources would be required to inspect all incoming detection messages from these systems before reaching the duty officer or initial attack crews. These additional resources could be posted at local dispatch centres to take advantage of their local knowledge, or at a centralized location that has access to known permanent smokes and fire permits.

Vendor preference on camera types

During the post-exercise debrief, Vendors 1, 2, 3, and 5 provided feedback regarding their preference for PTZ cameras or fixed cameras. Vendor 1 preferred PTZ cameras because their system can move the camera automatically to focus on the smoke after a detection is made. For its detection algorithms, Vendor 1 did not have a preference. Vendor 2, 3, and 5 preferred using imagery from fixed cameras for the following reasons (assuming there would be enough fixed cameras on a tower to cover 360^o):

- unlike PTZ cameras, fixed cameras have no turn-around time
- possible to have continuous detection in a view without turn-around
- easier to adjust detection frequency without the limitation of turn-around
- no motor vibration from rotating through preset views
- less image drift (i.e., an inconsistency between images with the same field of view due to PTZ camera motor movement and tower vibration in a strong wind
- less power consumption
- easier to configure and maintain

If a PTZ camera is the only option, vendors said they would prefer non-dome style over dome style cameras (Figure 4). According to the vendors, dome style cameras have curved glass or plastic covers that introduce more glare than the flat view covers on non-dome style cameras, especially when the sun angle is low. That makes the imagery from dome style PTZ cameras less useful during mornings and evenings. Most high-end non-dome style cameras have wipers to clean the view covers after rain and snow; most dome style cameras do not have wipers. Dust and dried water marks could also impact the detection capability of dome style cameras.

Figure 4. A non-dome style PTZ camera on the left and a dome style PTZ camera on the right. Source: axis.com

CONCLUSION

Seven vendors joined a seven-day detection exercise conducted between August 23 and 29, 2021. This excise aimed to understand the capabilities of automated detection systems in using imagery from existing cameras positioned on towers. All the systems in this exercise used AI / machine learning algorithms to detect smoke. Four vendors had established commercial systems and have existing customers, and three vendors had prototype systems that were under development.

Imagery from three different lookout towers, each with a PTZ camera and a fixed camera, was pushed to the vendors' SFTP servers in real time during the exercise. The detection systems scanned through imagery and returned detection messages if smokes were found.

No wildfires occurred within a 30 km radius of the towers during the exercise. The researcher generated 13 artificial smokes using a smoke generator; 11 were deemed valid for the purposes of this project.

The list below provides a summary of the findings from the seven-day exercise:

- One system detected seven of the 11 valid artificial smokes. Four systems detected one to two smokes. Two systems did not detect any smokes.
- All successful detections were within 18 km of a lookout tower.
- False alarms and reports of known smokes still occurred. Additional human resources are recommended to inspect incoming detection messages before reaching the duty officers for dispatching initial attack crews.
- Three systems were capable of providing latitude and longitude to pinpoint the location of the smoke. The distance from the tower accuracy varied but the bearings were highly accurate.

- All successful detections of artificial smokes were made within 16 minutes. After detection, emails containing detection messages were delivered within four minutes.

Although the data was insufficient to compare the effectiveness of PTZ cameras and fixed cameras, the vendors stated that imagery from fixed cameras was a better fit for their detection systems: fixed cameras have less image drift and have the capability to scale up detection frequency because they do not rotate through preset views.

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