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AUTONOMOUS FOREST FIRE DETECTION

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1. SUMMARY

Forest fire detection is a very important issue in the pre-suppression process. Timely detection allows the suppression units to reach the fire in its initial stages and this will reduce the suppression costs considerably.

The autonomous forest fire detection principle is based on temporal contrast differences with the natural background and spatial characteristics of the smoke plume. The images are obtained from multiple staring black and white video cameras installed on a small platform in a tower. To reduce the bandwidth of the needed communication link with the operational centre, all processing is performed locally at the tower. The detection algorithm sends alarm messages with the co-ordinates of the location of the fire automatically and on request images or system status are sent.

2. INTRODUCTION

The need for early detection of starting fires in regions with dense population or of high value makes a high temporal resolution mandatory.

The methods used for forest fire detection can be split in three different groups. The ground based, aerial and space borne detection platform based techniques. All groups can be subdivided based on temporal resolution, spatial resolution, spectral resolution and the cost of the system. There is also a difference in the wavelength band(s) in which the fire is detected. Infrared and ultra violet are used to detected the energy produced by the fire, and the visible light is used to detect the smoke plume. All camera systems can be either staring or scanning.

The energy produced by a starting forest fire is mainly concentrated in the burning zone on the ground. Due to the transparency of the flame there is hardly any energy in the flame. Based on this information infrared and ultraviolet detectors need a direct line of sight on the burning zone of the fire. For space borne and aerial systems this is no limitation, where ground based systems might be obstructed by vegetation or topography. The NOAA satellite provides 4 images per day and the proposed FUEGO satellite constellation has 19-35 minutes revisit time, see [FUEGO 98].

The autonomous forest fire detection system under development at TNO is a ground based system, with multiple staring black and white video cameras to detect the starting forest fire based on the temporal difference of the smoke plume with the natural background.

The advantages of the system are the high temporal resolution due to the high number of staring cameras combined with computing power, also providing a relative high spatial resolution. The use of multiple small and light industrial B&W video cameras allows a light construction of the tower or the combined use of a tower with other services like telecommunications.

Scanning systems have the advantage of an almost unlimited spatial resolution, but on the other hand the temporal resolution gets lower as the system scans the horizon slower. The use of 3CCD colour cameras is due to price currently not an option in a staring system. A scanning head with sufficient precision is relative heavy and has moving parts that need additional maintenance which is difficult in remote areas.

The final configuration of the system can be adapted to the local situation where the tower will be installed. For a relative flat terrain we propose to use 18 cameras providing a good spatial resolution for the full 360 degrees. Each camera can be equipped with a different lens, providing more or less spatial resolution in that direction. With higher spatial resolution, less terrain is covered by a single camera, so more cameras are needed.

The system is currently under test in the AFFIRM project [AFFIRM 98] the configuration for the tests is based on four cameras (as the smoke will come from known directions) and a 10 bits frame grabber producing the digital images needed for processing.

The processing is done on a dual Pentium Pro 200MHz, with 128Mb RAM memory. In a 18 camera configuration all processing for each camera can be done every four seconds, based on this hardware.

3. SMOKE PLUME DETECTION

A B&W spatio temporal algorithm, developed by TNO in the framework of the AFFIRM project, is used to detect smoke plumes. In figure 1.B. there is smoke plume, but it is very hard to see this, because smoke plume is just indistinguishable from natural background elements. However, people see smoke plumes because of the changes in time. If you would put figure 1.A. and 1.B. in a sequence, the smoke is very easy to see. This is visualised by figure 1.C., the difference of the image reveals the smoke plume without any doubt. The processing is based upon this principle, but it is a little more complex. The complexity is needed to account for changes in light due to moving clouds or different temporal behaviour between parts of the image.

The processing steps are visualised in figure 2. The first step of the processing is to acquire an image from one of the cameras. This image is digitised by the frame grabber and stored into memory. The image is then divided into squares of equal height and width, using a binning table. The next step is to update the moving average and moving standard deviation of each bin. If the average intensity of a bin is outside the normal bandwidth of that bin, there is will be a detection. Bins with a detection in the last 16 times will clustered. If a bin has too many detections an alarm will be send to the operator.

A. B. C.

Figure 1: A. Background image. B. Same image (15s later) later with a smoke plume. C. The difference of the two images.

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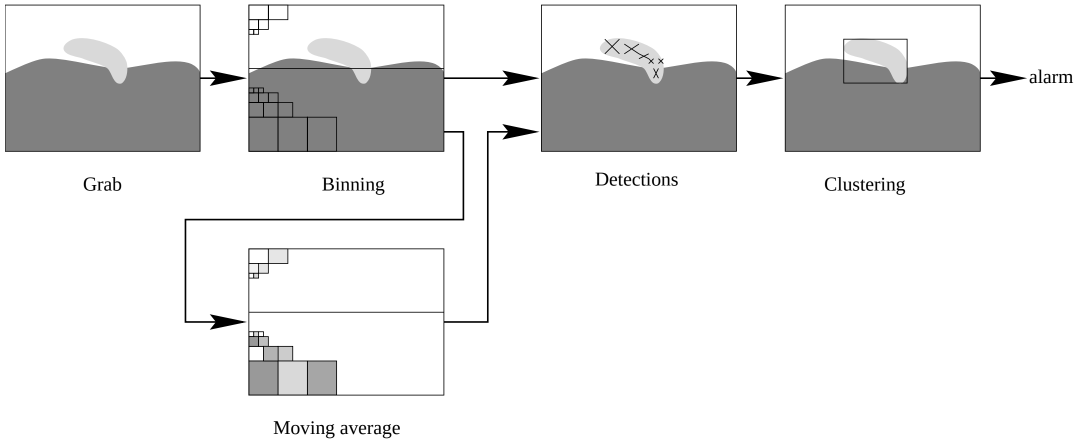

Figure 2: Flowchart of the forest fire detection algorithm.

3.1. Image acquisition

First it is necessary to select the correct camera. The four analogue cameras can be directly connected to the frame grabber. Within the frame grabber there is a video multiplexer, i.e. a switch, which selects the camera. If all of the 20 cameras are to be connected, either an external video multiplexer is needed or more frame grabbers need to be installed. To allow fast switching between cameras, it is necessary to synchronise these cameras. Otherwise, the frame grabber will have to wait for the beginning of a frame, before it can start digitising. If the correct camera is selected, the analogue signal of the camera is sampled and digitised. This results into an image of 768 times 576 pixels of either 8 or 10 bits stored in memory.

3.2. Binning

A pixel near the horizon comes from a much larger area than a pixel at the bottom of the image. Dividing the image into sections with equal physical terrain dimension, will solve this problem. These section are called bins. For each camera a separate bin table can be used, which divide the image into bins. A generic binning table is given in figure 3. The bin table can be adjusted to the different environments, such as a flat country in the Netherlands, as well as for mountainous areas.

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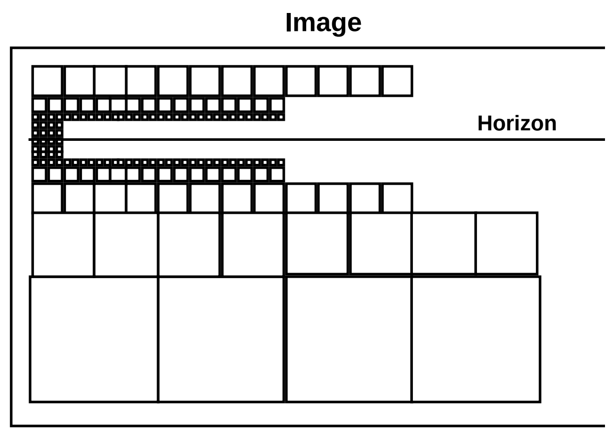

Figure 3: Binning an acquired image

For each bin, the average bin intensity and the square of the average bin intensity is calculated. The necessary processing power decreases very much by performing calculations on bins instead of individual pixels.

3.3. Moving average

The bin intensity will have normal variations, due to sun and clouds. Therefore a fixed reference intensity can not be used. A moving average will be used to follow these normal variations. To estimate the moving average of each bin, a decay filter is used.

For this filter, the new moving average is the sum of a fraction (α) of the old average and another fraction ($1-\alpha$) of the current average. By changing these fractions, the period of averaging can be increased or decreased. In figure 3, the current bin intensity and the moving average is plotted. One of the implications of this filter is that it has a delay time.

The variance in the bin intensity will be different from bin to bin, because the optical properties are different. These variations may also vary with time. It is therefore necessary to estimate these variations: moving standard deviation.

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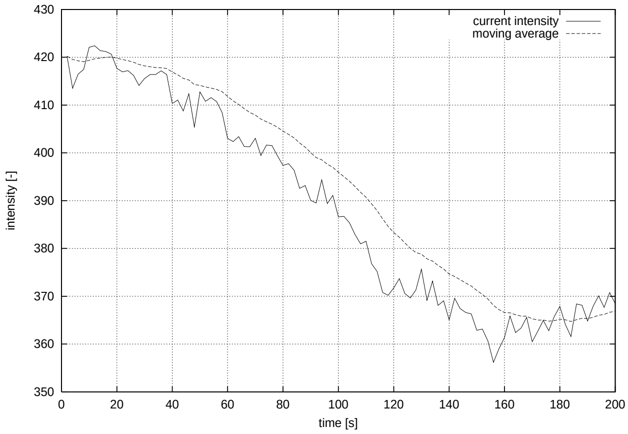

Figure 3: The moving average estimated with a decay filter with a coefficient of α=0.9.

To estimate the moving standard deviation of a bin, another decay filter is used. The input of this filter is the square of the bin intensity. The same coefficient as for the moving average is used for this filter. The bin standard deviation is now given by the square root of the difference between the moving square average and the square moving average. The bin standard deviation will be used as a threshold for detection.

3.4. Detections

For detection, two threshold are used: a lower bound and an upper bound threshold. The upper bound threshold is set at the moving average plus a constant (*k*) times the moving standard deviation and the lower bound is set at the moving average minus *k* times the moving standard deviation, see figure 4. If the current bin intensity is above the upper or below the lower bound threshold, there will be a detection.

If there is smoke plume in a bin, the intensity will several times increase above and decrease below the detection thresholds. A car on a quiet road will give a single or at maximum two detections within a bin.

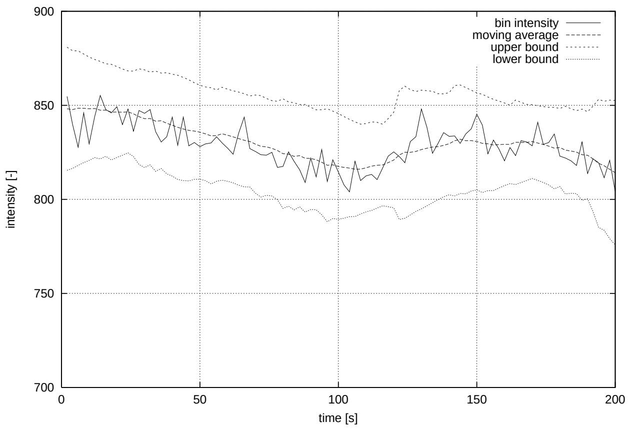

Figure 4: The relation between the bin intensity, its moving average and the upper and lower detection thresholds.

3.5. Clustering

To determine the size of the smoke plume and to reduce the number of alarms to be send, bins are clustered spatially. Each cluster will get it's own unique identification number (ID). The clusters are checked for any overlap with clusters in the previous frame. If there is some overlap between clusters, information like the ID is passed on from the previous frame to the next. The ID will be used at the user interface to check if an alarm is a new one or one which is already known and is repeated.

3.6. Alarms

Based on the spatio temporal characteristics of a cluster, alarms will be generated. Alarms will always be send to user interface. The following information is contained in an alarm message:

- camera number
- figure of merit: the confidence level of the algorithm in this alarm
- x-position and y-position: geometric mean
- x-width and y-height: size of the boundary box
- cluster ID and cluster size in bins

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4. COMMUNICATION WITH OPERATIONS CENTRE

The fire detection system will be mounted on towers in remote areas. These towers will have a lack of high bandwidth communication infrastructure. Therefore the fire detection system limits the necessary bandwidth by only sending alarm messages. Possible communication infrastructure includes telephone line, a radio connection or a low bandwidth satellite linkup, which is used depends on the cost and the availability.

The most critical messages that need to be communicated are the alarm messages. These messages are send autonomously and were already discussed in the previous section. Other communication is only send upon request, so these are only send when necessary. These messages will be discussed below.

4.1. Background images

Upon request the current view of each camera can be send to the operations centre. This allows the operator to verify that each camera is working and pointed in the right direction. These background images are relative big and may take a long time to transmit.

4.2. Alarm image sequences

To visually verify an alarm, a whole sequence of images can be send to the operations centre. The images in the sequence are usually a small section of the complete camera image. An image can send every 2 seconds, because of the short transmission time. An operator can now view the sequence in almost real time and he or she can decide whether there is a starting fire.

4.3. Application control and verification

Finally, an operator can control and verify parameters of the fire detection process. The parameters can be optimised for the specific circumstance of the terrain and the weather conditions.

5. PRELIMINARY TESTING AND RESULTS

Based on the data acquisition campaign planned for summer ’98, the algorithm will be further refined. Initial tests in the Netherlands show very good results. The reduction of false alarms is a continuous point of attention. The algorithm is currently configured so that there will be no missed alarms, but this increases the number of false alarm. However, as a operational application, it is essential that no detections are missed.

6. CONCLUSIONS

The autonomous forest fire detection system is capable of detecting quickly (high temporal resolution) a relative small smoke plume (high spatial resolution) with a low false alarm rate. These characteristics meet a demand from the fire community, and needs to be finalised and tested during operational conditions to obtain a commercial and operational product. Such systems provide fire managers with an all year detection system with fixed cost. Patrolling and manned watch towers have additional variable cost during to the period these detection methods are used.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

[AFFIRM98] AFFIRM: INDRA, UPC, ARMINES, TNO-FEL, “AFFIRM: a system for autonomous early and reliable forest fire detection” in “3rd International conference on Forest Fire Research”, Proceedings, Coimbra, Portugal, 1998

[de Vries94] J.S. de Vries, R.A.W. Kemp, “Results with a multi-spectral autonomous wildfire detection system” in “2nd International conference on Forest Fire Research”, Proceedings, Volume 2, Coimbra, Portugal, 1994

[FUEGO 98] http://www.ctv.es/insa/fuego/