Automatic CCTV Surveillance – Towards the VIRTUAL GUARD

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INTRODUCTION

The VIRTUAL GUARD is a general-purpose computer-based CCTV surveillance system for detecting potential criminal activity in public areas. The system monitors all activity in the surveillance area, the vast majority of which is people innocently going about their normal business. It will alarm when the observed activities of particular pedestrians and vehicles match any of the pre-defined "suspicious behaviour criteria" programmed into the system. At the same time as analysing movement behaviour, the system uses computer-controlled Pan Tilt Zoom (PTZ) cameras to obtain close-up video recordings of any pedestrians and vehicles at the scene.

The system can provide automatic surveillance in many different situations, from parking areas and commercial districts, to housing, recreational and transport facilities. It is particularly suited to the protection of government or commercial buildings located on city streets or other public areas where it is not possible to install perimeter fences.

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CURRENT SITUATION

The usefulness of CCTV as a surveillance tool is usually severely limited by the need for human participation in the detection chain. Humans are very poor at remaining alert for long periods of time and it is generally accepted that guards will frequently miss incidents clearly visible on CCTV monitors. Contrary to popular belief, impressive control rooms with large banks of monitors generally do not provide an effective "real time" surveillance service. The vast majority of installed CCTV cameras remain unwatched and incidents are not likely to be detected while they are occurring. CCTV is therefore reduced to a "post-mortem" tool or alternatively, a verification and support tool, provided that incidents are detected by some other means.

There are exceptions to the "most monitors are not watched" maxim. In some instances where there is no alternative to security guards viewing TV monitors as a means of providing security, the high revenue costs required to maintain manning levels just have to be met. The most common example is X-Ray baggage inspection at airports. In this case, security personnel view a single TV monitor and the team members are rotated at regular intervals, limiting any one session in front of the screen to 40 minutes or less. This represents a manning level of more than one guard per "watched" monitor!

In some installations, where no activity in the surveillance area is expected, automatic Video Motion Detectors (VMDs) can be used as guard prompts. VMDs have existed for over 20 years and some of the better ones can be used to good effect on external cameras. However,

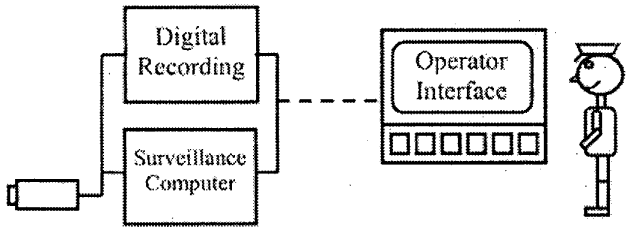

Fig. 1. VIRTUAL GUARD and digital recorder with operator interface

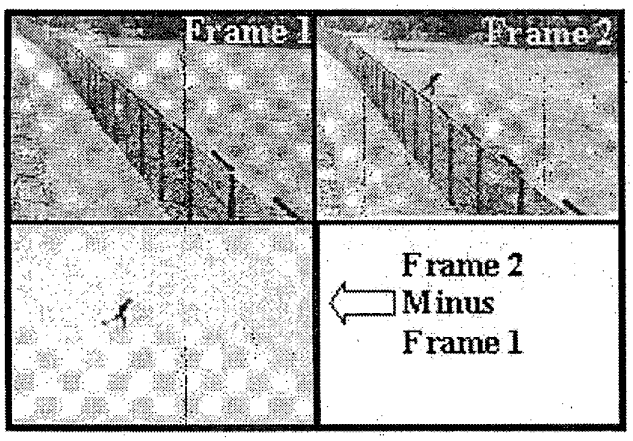

Fig. 2. The frame differencing method used by low cost VMDs

even good VMDs are prone to false alarm in bad weather and may cease to function correctly if their set-up is invalidated by a change in camera position or adjustment. Lower cost VMDs, such as may be built in "for free" inside multiplexes and cameras, cannot be used outdoors at all because of the high false alarm rate. Even used indoors under more controlled lighting conditions, some low-cost VMDs are so poorly designed that they are of little practical use.

DEPLOYMENT OF AUTOMATIC SURVEILLANCE SYSTEMS

Figure 1 illustrates a typical installation. The key elements are as follows:

- The Surveillance Computer analyses the camera scene continuously in "real time" and raises an alarm when it detects activity. In current systems this may be a simple VMD but, in the future, surveillance will be provided by a sophisticated VIRTUAL GUARD system.
- A Digital Video Recording system records pre- and post-event video when triggered by the Surveillance Computer.
- The simple operator interface automatically presents the video clips and report information on the system monitor and the guard has a single button to acknowledge the alarm.

LOW COST VIDEO MOTION DETECTORS

Most inexpensive VMDs use the differences between video frames to detect motion. In controlled conditions this works well but it is prone to false alarms in real life situations, especially outdoors. See Figure 2.

The false alarms occur because target movement is not the only source of image differences. The other sources are:

- Daylight changes
- Camera auto-iris changes
- Camera movement
- Trees – foliage movement
- Video artifacts – noise, banding and jitter

VIDEOTRACKER

This was our first system developed specifically for CCTV applications. We noticed that even though VMDs had been around for a long time the products on offer either did not work properly outdoors because of high false alarm rate, or were difficult to set up for the average installation engineer. The net effect is that many VMD installations never work properly and are eventually abandoned. In an attempt to correct this situation, we designed VideoTracker:

- The system "learns" a new scene within a few seconds and allocates the trigger thresholds automatically. It is therefore compatible with Pan Tilt Zoom cameras and resumes detection as soon as the camera motion ceases.
- The learning process operates continuously, adjusting automatically to lighting changes, time of day, and seasonal changes.
- Set-up of detection zones is not normally required because, by default, the system analyses the entire video image. (Potential areas of nuisance alarms can, optionally, be masked out.)
- Special filters discriminate between "unwanted scene differences" such as camera shake and foliage movement and "wanted scene differences" such as pedestrian and vehicle movement.

Fig. 3. VideoTracker – Detects pedestrial movement but not tree foliage movement

Fig. 4. AMETHYST – Intruder in shadow near the fence

- The system performance degrades gracefully as video quality or weather conditions become more adverse.

In Figure 3, the tree foliage and the reflections of the tree foliage in the car windows and roofs, are swaying in the wind. The VideoTracker is managing to track the pedestrian but ignore this other motion.

Generally, the verdict on the system is very favourable. Its main advantage is that it is "plug and play" and never needs maintenance because of its self-adjusting characteristics.

Some problems do remain however, although the majority can be minimised with appropriate installation:

- Avoid placing floodlights next to the camera. At night, insects are attracted to the lights and can cause false alarms.
- Avoid camera mountings that give excessive camera movement in high winds. This does not cause false alarms but does reduce detection performance.
- Use a shrouded camera housing that minimises the risk of rain running down the lens. This can cause false alarms if sufficiently severe.

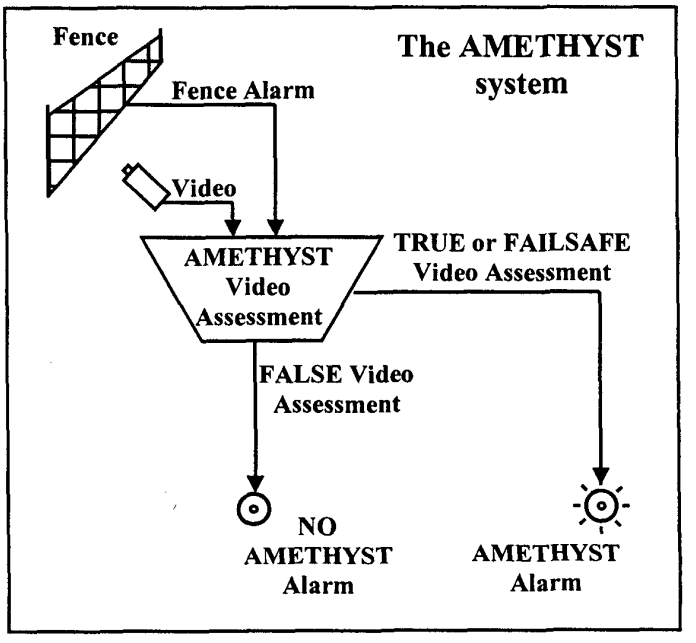

Fig. 5. AMETHYST – Automatic assessment of perimeter intruder detection system alarms

DEVELOPMENTS IN COMPUTER TRACKING

The advent of powerful personal computers enables complex video analysis to be performed in software, with the result that more advanced VMDs can now be made to operate much more reliably.

As background material, two application-specific PC-based systems are described below with particular emphasis on the key characteristics needed for operation in field conditions. These systems have provided important information on the challenges of automatic surveillance and some insights into the solutions now possible using the latest PC hardware.

AMETHYST

The Police Scientific Development Branch in the UK devised AMETHYST, as shown in Figure 4, as a means of reducing the impact of false alarms from Perimeter Intruder Detection Systems (PIDS). See Figure

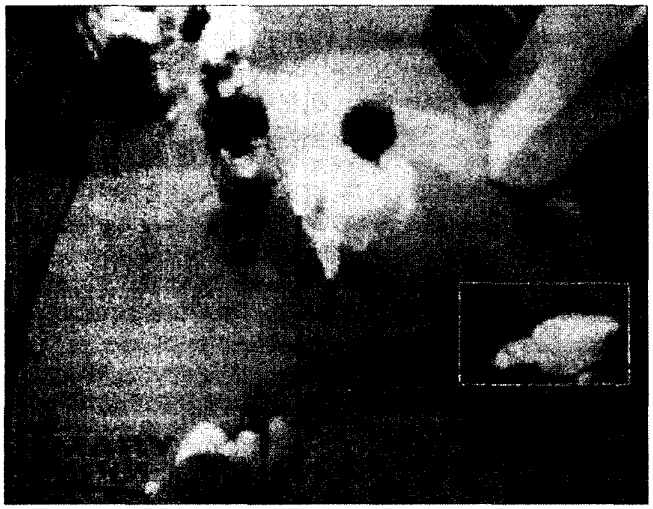

Fig. 6. Exit Lane Monitoring System – Detects pedestrians moving in the wrong direction

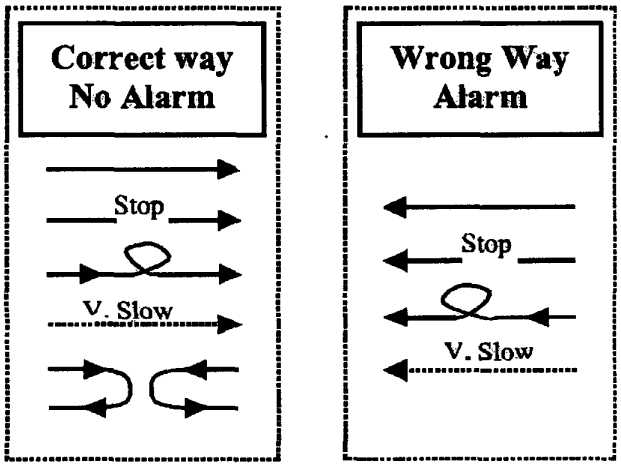

Fig. 7. Exit Lane Monitoring System – Legal and illegal motions

5, on previous page. There are various sources of such false alarms and if they occur frequently they can compromise site security by "desensitising" the guards and reducing their reaction to alarms.

AMETHYST shares common characteristics with the VIRTUAL GUARD by combining pre- and post-alarm storage with computer-based video assessment. However, in this case, the automatic assessment is triggered by a standard Perimeter Intruder Detection System (PIDS) and the decision of whether to pass the alarm through to the AMETHYST output is determined by the computer video analysis.

The following scene is of "medium" difficulty for automatic video analysis, showing an intruder in an area of shadow by the fence. The floodlights are causing a number of problems: loss of contrast in the main image, lens reflections and flare around the lights.

AMETHYST classifies the video assessment results in one of three ways:

- **TRUE:**
  A moving or stationary target has been identified.
- **FAILSAFE:**
  A condition exists that has prevented definitive analysis. Usually caused by low video quality or some problem with the weather such as fog or heavy rain.
- **FALSE:**
  No target has been identified and the video image was measured to be of acceptable quality.

In case of **TRUE** or **FAILSAFE** video assessment, the PIDS alarm is passed through and results in an AMETHYST alarm. In case of a **FALSE** video assessment, the AMETHYST alarm is suppressed.

The computer video assessment does not have to run all the time and is only called on when there is a PIDS alarm. This enables many cameras to share one assessment computer, which has the advantage that AMETHYST functions can be added quite inexpensively to existing manual video assessment systems. The other advantage is that all the power of the computer can be concentrated on the thorough analysis of a few short video sequences. Consequently, good performance in key areas is achieved, including:

- Good discrimination of low-contrast targets.
- Ability to detect stationary as well as moving targets.
- Immunity from lighting and camera iris changes.
- Immunity from camera sway caused by the wind.

The prototype AMETHYST systems have been on trial now for 6 months with very encouraging results.

AIRPORT EXIT LANE MONITOR

At first sight, this system would seem to bear little resemblance to the VIRTUAL GUARD application but it has been useful for the development of algorithms for tracking pedestrians in crowded conditions, as shown in Figure 6.

The principle of operation is very simple. An overhead camera is positioned to look straight down on passengers as they pass along an airport corridor. Departing passengers must pass through the metal detector arch and have their hand luggage X-rayed.

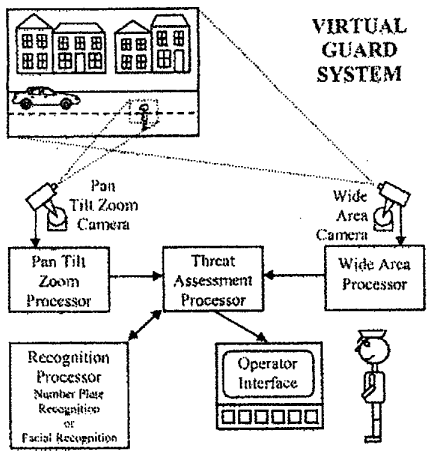

Fig. 8. The Virtual Guard System – Detection of "suspicious" behaviour with close-up video evidence of the participants

Arriving passengers can bypass these security checks and pass directly through the exit lane.

The purpose of the system is to detect passengers attempting to miss the security checks by going the wrong way through the exit lane. See Figure 7, on previuos page.

The design challenges arise from the variations in "normal" passenger behaviour and the system has been designed to cope with the following:

- Passengers who momentarily stop in the detection zone.
- Children "orbiting" their parents and other significant causes of backward movement.
- Very slow moving passengers.
- Passengers who change their minds and double-back.
- Maintaining detection in crowded conditions where a single person is going the wrong way through a flood of arriving passengers.

A number of problems occurred during development and testing that had to be solved:

- Spot-lights create awkward shadows which travel in the opposite direction to passenger movement.
- People with white hats or bald heads significantly change the overall light level experienced by the camera, resulting in frequent corrective adjustments by the auto-iris.
- There is a need to make the system immune to all forms of tampering. Security staff have a lot of time on their hands and will play about with anything they can!
- Security guards and police have a natural tendency to challenge the system and try to sneak past it.

LESSONS LEARNED

Reliable automatic surveillance is being made possible by the rapid increase in the power of personal computers. Today, the average desktop PC has more number-crunching power than sophisticated military systems of just five years ago. The VideoTracker, AMETHYST, and Exit Lane Monitor systems described above have provided invaluable experience. The majority of the lessons learned have less to do with advanced software algorithms and are more concerned with issues of resilient design, which enable the systems to work reliably in the real world.

Automatic systems will be judged harshly. Customers, and particularly their security staff, will pounce on any weak spots and these will be mercilessly exposed – humans love beating machines!

THE VIRTUAL GUARD

The VIRTUAL GUARD system combines pre- and post-alarm digital recording with computer-based automatic video assessment. The system has two important differences to those described previously. First, it is general purpose and can be "programmed" to identify behaviour specific to the user's needs. Second, it operates in public areas looking for "suspicious" incidents within the "clutter" of innocent activity. The system described below is only part-way through development and is not yet fully implemented.

Compared with existing security solutions the VIRTUAL GUARD will offer the following benefits:

- Protection of buildings in built-up areas that cannot be protected with conventional fences and alarms.
- Protection of large areas from a single vantage point.
- Automatic collection of close-up video evidence.
- Ability to provide an immediate alert while an incident is still in progress.
- Improvement in the effectiveness of existing security staff by acting as a guard prompt.

The system produces a simple report for each incident, consisting of video clips within which the suspicious target is highlighted, details of the behaviour that has been detected and, if available, further information on the target from the Recognition Processor. The system can either be used actively with manual alarm verification or passively to gather evidence for later review.

Fig. 9. Detection of illegal parking in a bus stop

The VIRTUAL GUARD system illustrated in Figure 8 consists of the following major components:

- A Wide Area Camera covering the whole of the surveillance area.
- A Wide Area Processor (WAP) responsible for tracking all targets in the surveillance area. Both moving and stationary targets are tracked and a classifier assigns each target to an appropriate group (such as pedestrian, car, bus, etc). Digital storage of the Wide Area Camera imagery is also provided within this unit.
- A Threat Assessment Processor (TAP), which compares target behaviour with the previously defined "suspicious" behaviour. The system can survey for multiple types of behaviour at the same time.
- A computer-controlled Pan Tilt Zoom (PTZ) camera. This is programmed to obtain close-up images of the various targets in the scene. If a "threat" is detected it will obtain close-up imagery of pedestrians and vehicles involved.
- A Pan Tilt Zoom Processor (PTZP) responsible for close-up tracking of targets and further classification of targets into subgroups. Digital storage of the PTZ Camera imagery is also provided within this unit.
- A Recognition Processor that uses the close-up images from the PTZ Camera to provide further target information for the Threat Assessment Processor. This can take one of two forms – an Automatic Number Plate Recognition system or a Facial Recognition system.
- An Operator Interface for reporting incidents to the guard.

The system is general purpose, in that users can define the threats that are of concern at their own sites.

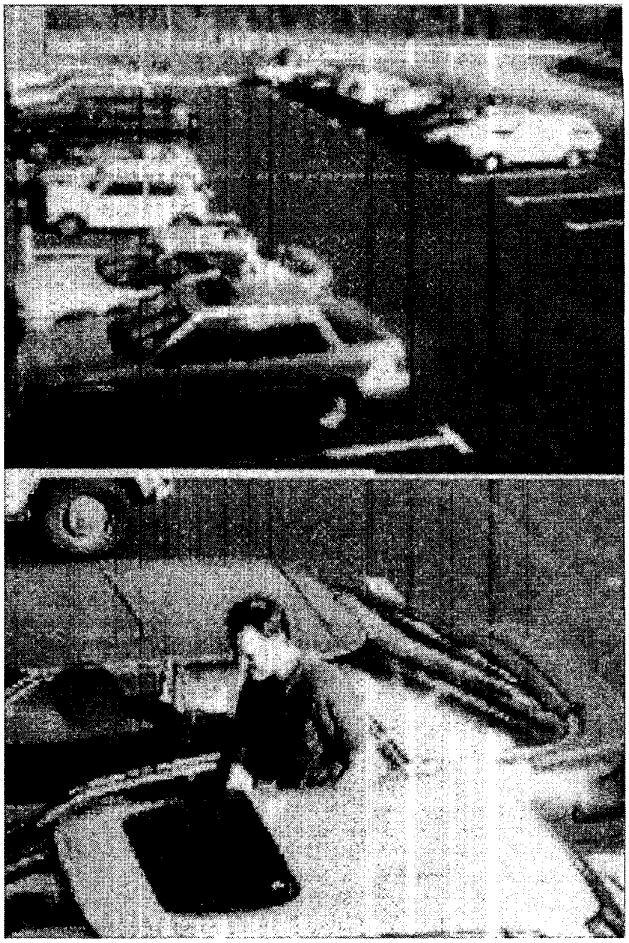

Fig. 10. Virtual Guard – Automatic close-up evidence collection

Usually this can be achieved through minor modification to the existing behaviour rules but, if necessary, completely new rules can be defined to meet new situations.

The threats and behaviour rules are not discussed in detail here but Figure 9 illustrates a representative scenario. The system could be used to detect vehicles that illegally park in the bus stop. The system has to be sufficiently intelligent not to false alarm when the vehicle is a bus, nor must it false alarm when there is a traffic jam and a queue of stationary traffic passes through the bus stop.

The evidence-gathering role of the system is illustrated in Figure 10, which were obtained from experiments with a computer-controlled PTZ camera. The upper image is from the Wide-Angle camera and the lower image is from a PTZ camera with a 4 X zoom setting.

There have been no formal trials of the VIRTUAL GUARD system as yet, but our preliminary experiments lead us to believe that the system will be effective in the buildings protection role. We are also hopeful that the system will be effective in detecting more complex

behaviour associated with drug dealing, vehicle theft, and vandalism.

CONCLUSION

The recent improvements in processor performance have enabled high-end image processing applications to migrate from military systems to the commercial environment. It will be a long time before these machines fully match the incredible visual skills that our eyes and brain give us. However, machines such as the VIRTUAL GUARD system, with the advantage of an infinite attention span, will transform CCTV from being largely a post-mortem tool into a front-line crime-fighting system. It will not be many more years before this level of intelligence finds its way into dome cameras available from your local CCTV stockist. ■

Book Review

Au Revoir, Sarnia Chérie

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Winnipeg, Manitoba, R3M 3J2, Canada ; 1-800-650-3269

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Reviewed by Dave Dobson

Sarnia is the Norman name for Guernsey – Ed.

This magazine has published many personal experiences and aspects of technology from the World War II years; we will continue to bring them to you as a glimpse of history and to make them available to future historians.

Lest you think you are being falsely led into another technical tale, ***Au Revoir, Sarnie Chérie*** (subtitle: ***Good-Bye, Dear Guernsey***), is not technical in any sense other than that the author is a long-time member of the IEEE. It is the personal reminiscences of a young lad, born and reared on Guernsey (an English Channel Isle), who was uprooted and evacuated to England as a young student, one week prior to the German occupation (the islands were indefensible) in World War II.

The first half of this book consists of boyhood tales which include the usually-never-admitted day-dreaming of what one wants to do, childhood fear of heights, family picnics at the beach, and similar gems. The second half is a detailed chronology of the evacuation of entire schools – including teachers – to locations in the British Isles. The author and his family were reunited in England; with relatives already living in Canada, they decided to restart their lives there. Standing out in my mind is the fact that his parent's home was lost for non-payment of the mortgage *during the five years of enemy occupation* (!!).

In the interests of full disclosure, I have known the author for many years which gave me the impetus to learn more. This book was read in less that two hours; it is well worthwhile reading as – in the author's own words – *"An aggression occurs against* **individuals***, each of whom suffers separately. We must always recognize that."*