Alarm Correlation in Traffic Monitoring and Control Systems: A Knowledge–Based Approach

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Abstract. The aim of the paper is to highlight the importance of alarm correlation in traffic monitoring and control systems, and to propose a knowledge–based solution for developing a module of a traffic monitoring and control system. The Alarm Correlation Module (MCA) integrated with the System for Automatic MOnitoring of Traffic (SAMOT) will be described. The aims of the MCA are to analyze, filter and correlate traffic flow anomalies detected by Video Image Processing (VIP) boards, to create adequate image sequences to be shown on operators Close–Circuit TVs and to display adequate messages in Variable Message Panels to keep motorists informed. Thus, the MCA provides SAMOT with an automatic processing tool that, based on traffic operators' experience and knowledge, supports operators in the interpretation of traffic situations and in the event–driven control of traffic anomalies. The MCA knowledge base implements a model of traffic flow concerning the most relevant traffic patterns and taking into account time and space dependence of detected traffic anomalies. The MCA integrated in SAMOT is a successful example of the knowledge–based approach applied to traffic monitoring and control. The MCA has been developed in collaboration with the SAMOT provider (Project Automation S.p.A.) and the Italian highway company (Societa' Autostrade S.p.A.). After a 6 months trial period, the system is now installed and functioning on two of the most crowded Italian highways (i.e. A7 and A10).

1 INTRODUCTION

Traffic safety, congestion prevention and effective actions in case of emergencies can be supported today by the use of sophisticated technology that supports and, sometimes, provides traffic monitoring and control. The aim of a traffic monitoring and control system is to detect traffic flow anomalies, to alert traffic operators and to support them in the management and control of emergencies [5, 3]

Different devices and technologies can be used for traffic anomaly detection (e.g. magnetic loop sensors, video–cameras, infrared, microwave radars, video image processors). In the last few years, the increase in demand for more diversified traffic information and more complex traffic control has lead to video–based detection systems and automatic incident detection systems. Image processing is a relatively new technology. It provides direct incident detection, automatic storage of pre–incident images, as well as simultaneous monitoring of different lanes of traffic data [4]. The image processing technique is also characterized by flexibility to modifications and is suitable for different traffic monitoring applications. A lot of information can be derived from the analysis of traffic video images performed by Video Image Processors (VIP) [2].

When traffic flows are monitored automatically with video processing techniques, each peripheral VIP generates a set of data referring to its own point of observation. Each individual sensor records and transmits any monitored variation with respect to a set of sensitivity thresholds. VIP devices derive information about the traffic flow of the monitored lane (e.g. average speed, volume, occupancy, slowdowns, queues, wrong–way driving vehicles, stopped vehicles, vehicle gap and so on) according to algorithms for vehicle detection that, for instance, process differences of grey tone between background and car images. Artificial intelligence techniques like genetic algorithms and neural networks have often been employed to automatically derive from VIP elaborations atomic anomalous traffic conditions [1]. Figure 1 shows a real–life video detection example in which a stopped vehicle (marked by the small white box) has been detected.

Figure 1. Real–time video detection of a stopped vehicle

Traffic monitoring systems alert traffic operators every time an atomic anomaly is detected by VIPs, and automatically store several frames of the pre–anomaly images that can be extracted for analysis at a later stage. Different video detection algorithms have been proposed, and their comparison is usually based on Detection Rate (DR), False Alarm Rate (FAR) and Detection Time (DT). These evaluation parameters strongly influence one another: the shorter is the

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DT, the higher is the DR but, unfortunately, the higher is also the FAR [7]. One of the main problems in traffic anomaly detection is that generally only atomic anomalies are considered.

This paper presents the Alarm Correlation Module (MCA) of SAMOT (System for Automatic MOnitoring of Traffic), a monitoring and control system. In SAMOT, atomic traffic anomalies that are detected by standard VIP boards supplied by Traficon NV [6], are analyzed, correlated and filtered by the MCA before taking appropriate actions and alerting traffic operators. The knowledge–based analysis, correlation and filtering of atomic traffic anomalies performed by the MCA allow to both reduce the FAR and increase the DR of the SAMOT system without significantly affecting its DT.

The MCA correlates sequences of atomic traffic anomalies and derives *anomalous traffic patterns*. Anomalous traffic patterns are derived analyzing sequences of anomalous and regular traffic images and interpreting them as typical and experienced patterns of anomalous traffic flow. Moreover, the MCA, according to traffic operators experience and knowledge, filters atomic traffic anomalies provided by VIPs evaluating their level of emergency taking into account the spatial (i.e. road section) and temporal location (i.e. time of the day) they refer to. The MCA provides automatic event–driven traffic control showing appropriate messages on VMPs, and it supports operators in the same task managing acoustic and visual warnings and showing appropriate camera image sequences on CCTVs.

A brief description of the general SAMOT system will be given in the following section in order to better explain the role and functionality of the MCA. The architecture of the MCA knowledge base and some examples of the rules in it contained will be described in Section 3. Section 4 summarizes the main features of the highway section where the MCA has been tested and is currently in use.

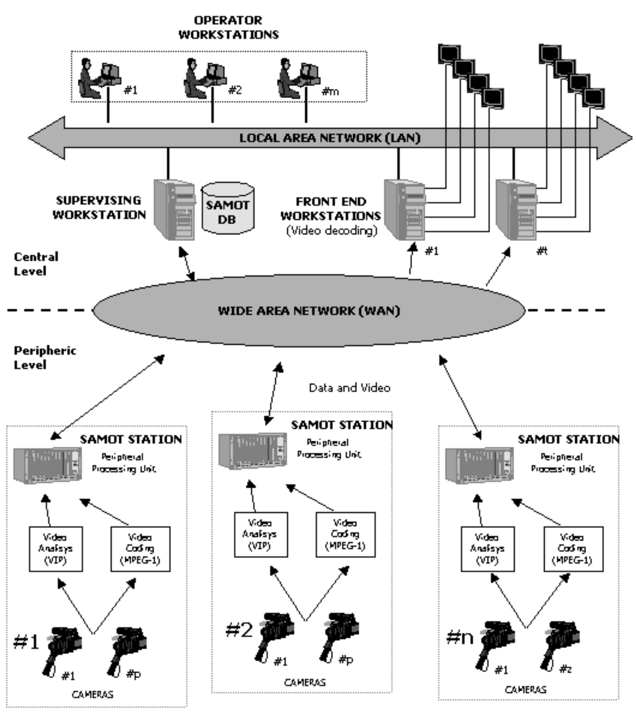

Figure 2. SAMOT System Architecture

2 THE SAMOT SYSTEM

Traffic operators devoted to traffic monitoring and control are provided by the SAMOT system with a set of data about traffic situation of the monitored highway section and, when traffic anomalies are detected, they can undertake all the needed operations on SAMOT devices through the SAMOT user interface. For instance they can select, create and activate an adequate sequence of camera images to be shown on the Close Circuit TV to verify the detected anomaly, or they can activate a message on Variable Message Panels to inform motorists about traffic anomalies.

The SAMOT system supports traffic operators in traffic control providing them with acoustic and visual warnings when anomalous traffic conditions are detected. Anomaly detection is performed by a set of Video Images Processing (VIP) boards that analyze images collected by video–cameras and identify according to vehicle velocity and road occupancy rate, anomalous traffic situations like *slow traffic*, *queue*, *stopped vehicle*, and *wrong–way driving vehicle*.

Moreover, the system provides its users with some applications to configure, supervise and maintain the system. These applications allows to modify and verify the working status of system components and to modify system parameters. For instance, it is possible to modify the number of cameras and VIPs or the default video sequences that, when traffic anomalies are detected, are shown on operator CCTV in order to observe its dynamic. Finally, a dedicated knowledge–based module (Alarm Correlation Module - MCA) provides SAMOT users with an automatic alarm elaboration tool that correlates sequences of traffic situations, filters traffic anomalies and supports and provides traffic control.

The two layers characterizing the architecture of the SAMOT system (*peripheral layer* and *central layer* in Figure 2) are connected by a Wide Area Network (WAN) and a Local Area Network (LAN). At the peripheral layer, close to the monitored road section, are located technological devices for image and traffic flow data acquisition (cameras and VIPs), video signal coding and transmission (codec MPEG-1 and multiplexers), and motorist information (Variable Message Panels - VMP). All the devices at the peripheral layer are linked to and managed by a set of Peripheral Processing Units (PPU) that are connected to the central layer through the WAN. At the central layer are located all the devices for video signal decoding into analogic format and for video display of images (decoder MPEG-1 and Front End), the Supervising Workstation and the Operator Workstations (Windows NT personal computer).

The quite modular, scalable and configurable SAMOT software provides device integration through the following modules:

- SAMOT Remote: installed at the peripheral layer on Peripheral Processing Units, provides an interface among peripheral devices for traffic data acquisition, image acquisition, coding and transmission, working status diagnosis and to execute action commands like messages on Variable Message Panels;
- SAMOT FrontEnd: installed at the central layer on Front End Workstations, it decodes in the analogical format the MPEG–1 video flow received from the network in order to show it on operator Close–Circuit TVs;
- SAMOT Supervisor: installed at the central layer on the Supervising Workstation, it manages the entire system by coordinating operator requests and their execution both at the peripheral layer (e.g. device configuration and messages on VMP) and at the central layer (e.g. video flow selection). Moreover, it manages and connects to other workstations the SAMOT archive (SAMOT DB). SAMOT DB contains an image of the real system (i.e. number

and type of PPUs, number and location of cameras, number of detecting devices, and so on) and allows each SAMOT module (i.e. user interface, maintenance module, MCA module, and so on) to work independently from technological aspects of the system;

- SAMOT GUI: installed at central layer on each Operator Workstation, provides the Graphical User Interface (GUI) for data visualization, remote device control and diagnosis (e.g. cameras, multiplexers and VMPs), user profile management (security settings) and system configuration both from the physical viewpoint (e.g. type and number of devices) and the logical one (e.g. relation between alarms and adequate actions). In particular, it handles video flows adequately, organizing them according to automatically programmed scanning sequences. Many previously programmed sequences can be retrieved and updated by adding new elements through the SAMOT GUI.
- SAMOT MCA: installed at central layer, it correlates atomic traffic situation (i.e. detection of anomalous traffic patterns), filters traffic anomalies taking into account their spatial and temporal location, and supports traffic operators in event–driven control actions.

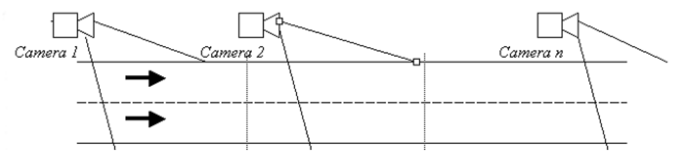

Figure 3. A schematic representation of the discrete rhythm of camera views located on a road section.

3 THE ALARM CORRELATION MODULE

The Alarm Correlation Module (MCA) supports traffic operators in the interpretation of traffic situations, correlating atomic traffic anomalies and filtering traffic anomalies taking into account their spatial and temporal location. Moreover, the MCA manages acoustic and visual warnings and camera image sequences on operator CCTVs and automatically displays adequate messages in VMPs to inform motorists.

Both traffic monitoring and traffic control supports are performed following a knowledge–based approach. Knowledge about traffic anomaly correlation, anomaly filtering and traffic control have been acquired with a knowledge acquisition campaign conducted with expert operators of the Italian highway company (Societa' Autostrade S.p.A.). Operator knowledge that has been experienced for several years in highway monitoring and control has been represented and implemented into the knowledge base of the MCA rule–based production system.

The MCA knowledge base implements a model of traffic flow concerning the most relevant anomalous traffic patterns, a representation of the monitored road section and a set of relationship among anomalies and appropriate actions derived from human experience and knowledge. The MCA knowledge base can thus be partitioned into three main components, according to the specific knowledge represented and the task it is involved in. The following subsections describe the three partitions of the MCA knowledge base.

3.1 Anomalous Traffic Patterns

Figure 3 shows a schematic representation of a road section as a sequence of cameras installed in order to monitor adjacent portions of a road section. Atomic traffic anomalies are detected by VIP devices according to algorithms for traffic flow analysis and vehicle detection. Often, multiple traffic anomalies detected by VIPs and referring to adjacent cameras can be correlated and interpreted as an *anomalous traffic pattern*. An anomalous traffic pattern represents a traffic anomaly referring to multiple cameras and, thus, a sequence of atomic traffic situations detected by VIPs referring to adjacently located cameras.

A partition of the MCA knowledge base regards knowledge for anomalous traffic pattern management (i.e. creation, modification and deletion) according to spatial and temporal adjacency between traffic anomalies (both atomic anomalies and anomalous patterns). A dedicated set of rules implements knowledge about sequences of *temporally adjacent* anomalous traffic patterns and the *spatially adjacent* atomic traffic anomalies that constitute them. This set of rules manages anomalous traffic patterns being involved in their identification and modification.

T0	-	-	-	-	-	-	-	Creation
T1	-	-	X	-	-	X	o	
T0	-	X	X	-	-	-	-	Extension
T1	-	X	X	o	o	-	-	
T0	-	X	X	o	X	X	o	Decomposition
T1	-	X	X	-	X	X	-	
T0	X	o	o	X	X	-	-	Reduction
T1	-	-	o	X	-	-	-	
T0	-	X	X	X	-	-	-	Shifting
T1	-	-	X	X	X	-	-	
T0	-	X	X	-	o	X	o	Composition
T1	-	X	X	o	o	X	o	
T0	-	x	x	o	x	o	-	Deletion
T1	-	-	-	-	-	-	-	

Figure 4. Anomalous traffic patterns and their representation as sequences of atomic traffic anomalies detected by a sequence of VIPs in two temporally adjacent time stamps (i.e. T0 and T1). Each column refers to a portion of the road section monitored by cameras referring to the same VIP. Circles and crosses respectively indicate 'slow traffic' and 'queue' atomic traffic anomalies, while empty cells represent 'normal' traffic situation.

Each pair of rows of Figure 4 schematically represents two traffic patterns that is, two sequences of atomic traffic anomalies, referring to two consecutive time stamps (i.e. T0 and T1). As shown in the figure, according to spatial and temporal relations among atomic traffic anomalies and anomalous traffic patterns, anomalous traffic patterns can be:

- *Created*: when two or more spatially adjacent road section portions change their states from 'normal traffic' (i.e. empty cells at T0) to 'anomalous traffic' (i.e. circles and crosses in T1);
- *Extended*: when at least a road section portion that is adjacent to an already detected anomalous traffic pattern changes its state from 'normal' to 'anomalous' traffic;
- *Decomposed* into two patterns: when at least a road section portion belonging to an anomalous traffic pattern, changes its state from 'anomalous' to 'normal' traffic;
- *Reduced*: when at least a road section portion that is one of the endpoints of an anomalous traffic pattern changes its state from 'anomalous' to 'normal' traffic;
- *Shifted*: when an anomalous traffic patterns is reduced at an endpoint and extended at the other endpoint;
- *Composed* with another pattern: when at least a road section portion that is located between two different anomalous traffic patterns changes its state from 'normal' to 'anomalous' traffic;
- *Deleted*: when all the road section portions of an anomalous traffic pattern change their states from 'anomalous' to 'normal' traffic.

The correlation of atomic traffic anomalies allows an interpretation of traffic situations similar to the one usually performed by traffic operators. As an example of anomalous pattern interpretation, let us consider the detection of a 'stopped vehicle' after a regular traffic situation and the same anomaly detected when a traffic congestion is already present. A dedicated set of MCA rules represents the knowledge for traffic anomaly interpretation taking into account spatial and temporal dependence among different traffic patterns. For instance, in the two rules reported below, temporal dependence is taken into account in the interpretation of the traffic anomaly 'Stopped Vehicle'. Different interpretations are given to this traffic anomaly depending on the traffic situation referring to the time stamp immediately preceding its detection. For instance, if the anomaly is detected after a 'Regular Traffic' situation, operators are alerted that an incident may have caused the 'Stopped Vehicle' traffic anomaly; otherwise if 'Heavy Traffic' pattern precedes this anomaly, the latter is filtered, adequate video sequences are created and shown on operators CCTVs but they are not alerted with acoustic signals.

```
if
   (Initial state = RegularTraffic(k))
   % portion k is characterized by 'Regular Traffic'
   (Anomaly = VStopped(k), ts)
   %'Stopped Vehicle' detected on k at time ts
then
   (ActionsGUI = VStopped(k))
   % 'Stopped Vehicle' anomaly shown on operator GUI
   (Beep = 'yes')
   % acoustic warning to operators
   (Video = 'k')
   % images on CCTV are fixed on the portion k
   (Panels(k) = 'Incident')
   % adequate message for VMPs are created
   (Time = ts)
   % immediate operator alerting
   (Duration = 'Event')
   % control actions end when the anomaly ends
```

```
if
   (Initial state = Heavy-Traffic(k-i, k+j))
   % portion k belongs to the 'Heavy Traffic' pattern (i,j)
   (Anomaly = VStopped(k), ts)
   % 'Stopped Vehicle' detected on k at time ts
then
   (ActionsGUI = SlowTraffic(k))
   % 'Slow Traffic' anomaly shown on operator GUI
   (Beep = 'no')
   % no acoustic warning to operators
   (Video = 'sequence(k-i, k, k+j)')
   % adequate video sequence is created for operator CCTVs
   (Panels(k-j, k+i) = 'Queue')
   % adequate message for VMPs are created
   (Time = ts)
   % immediate operator alerting
   (Duration ='Event')
   % control actions end when the anomaly ends
```

3.2 Anomaly Filtering

In order to reduce the False Alarm Rate, the MCA filters atomic traffic anomalies provided by VIPs. To better understand the importance of this MCA functionality we must take into account that in an hour traffic operators can be notified about hundreds of traffic anomalies referring to road sections often interested by traffic congestions. Alarm filtering is performed according to traffic operator experience and knowledge, and consists in the evaluation of the alarm emergency level taking into account their spatial (i.e. road section) and temporal location (i.e. time of the day). The monitored road section is described by the sequence of cameras installed along it and their working status. Moreover, MCA users can specify if a road section is frequently interested by each of the possible traffic anomalies. Thus, the representation of the monitored road section is given in terms of *normal* or *critical* sections that is, monitored sections interested by traffic anomaly at a given time of the day. This type of representation allows the MCA to filter detected anomalous traffic flows and then to reduce the set of control actions to be suggested to traffic operators and to motorists. For instance, different detection frequencies have been associated to VIPs depending on their spatial location. In this way, operators are always and real–time alerted about a congestion detected on a normal road section, while operator alerting is delayed if it regards a critical one.

For instance, let us consider that at a given time of the day an atomic alarm 'queue' is detected by VIPs. The MCA, knowing that the monitored road section is often interested by traffic congestion at that given time, evaluates and manages it as a normal traffic situation (i.e. without alerting traffic operators with sound signals, it only shows on their screen the situation). In the case the monitored section is critical for queues, the system does not alert immediately the operators but waits for a fixed (and modifiable) time.

3.3 Traffic Control

Finally, MCA performs traffic control automatically managing VMPs. In order to provide automatic en–route information for traffic anomaly response, the MCA selects the set of Variable Message Panels, checks their working status (i.e. operating, degraded or out–of–order), chooses the appropriate messages and operating mode (i.e. duration time of the message on the VMPs) and activates them.

Moreover, the MCA supports traffic operators in the same task, performing the following operations:

- operator GUI management: adequate graphic symbols are displayed when traffic anomalies are identified. For instance, see Figure 5 where symbols referring to cameras 13 and 17 have been colored;
- acoustic alarm management: activated when traffic operators must be alerted about an emergency;
- CCTV management: adequate video flow sequences are created according to detected traffic anomalies and shown on operator CCTVs. For instance, if a traffic congestion regards several cameras a cyclic sequence of their images is shown to operators.
  Default video sequences for each traffic anomaly have been studied during the knowledge acquisition campaign with expert traffic operators. Since this type of functionality has been judged very interesting and important by SAMOT users, the system has been designed in order to provide default video sequences that can be modified and integrated with CCTV video sequences created by users. This additional functionality allows to better customize the system use.

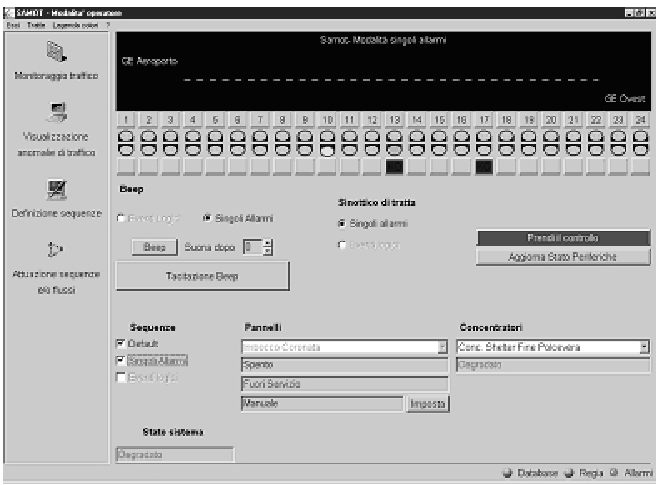

Figure 5. A snapshot of the traffic operator system interface.

4 FIELD TEST AND INSTALLATION

The SAMOT system and the MCA have been field proven for 6 months and is now functioning on a section of the A7 and A10 Italian highways. The highway section interested by the installation is really various and characterized by several critical sections (e.g. three tunnels of about one kilometers each, a bridge without emergency lane and some uphill sections where trucks usually keep slow speed). 24 cameras and 24 VIP boards have been installed along this highway section in order to guarantee its full monitoring. Cameras and VIP boards are connected to a Peripheral Processing Unit that is linked by optic fibers to one Front End, one Supervising Workstation and three Operator Workstations.

The system for the whole period of its functioning has demonstrated its robustness in managing the huge amount of traffic anomalies detected each hour by VIPs (i.e. about one thousand per hour). Moreover, system users have evaluated as very useful and interesting the MCA alarm correlation and filtering functionality.

5 CONCLUSION AND FUTURE WORK

The Alarm Correlation Module (MCA) of the SAMOT (System for Automatic MOnitoring of Traffic) has been presented. The MCA correlates atomic traffic anomalies and filters them according to their spatial and temporal location. Moreover, traffic control is achieved by the MCA that provides traffic operators with necessary information about the detected anomaly and directly shows adequate messages on variable message panels. For the MCA development a knowledge–based approach has been adopted. The knowledge acquisition campaign has been conducted on the team of traffic operators that are the current end–users of SAMOT. This knowledge has been acquired, modelled and then implemented into the MCA rule–based production system.

The MCA has been integrated into the SAMOT general architecture and is now successfully installed and functioning on two of the main and traffic congested Italian highways. One of the main features of the general architecture that integrates the MCA is its flexibility. In a not expensive way the MCA can be integrated in all the future SAMOT installation without any change to the core model embedded in its knowledge base.

Possible functionalities that have been planned to be integrated into the SAMOT system are:

- to correlate incident detection data and statistical traffic information in order to anticipate traffic congestion situations, and thus to improve traffic safety;
- to manage road sections not fully covered by cameras. For this aim additional knowledge–based modules for the analysis of VIP elaborations regarding not–adjacent road sections are needed. In this way, SAMOT and the MCA could be used for longer road sections;
- to create a web–based user interface for SAMOT users, once that multiple installations will be available.

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