On the use of Video Content Analysis in ITS : a review from academic to commercial applications

Caroline Machy, Cyril Carincotte and Xavier Desurmont
Multitel asbl - Image department
Mons, 7000 Belgium
Email: {machy, carincotte, desurmont}@multitel.be

***Abstract*—Stand-alone cameras or CCTV networks are nowadays commonly present in public areas such as city centers, stores and more recently in transportation infrastructures. In the meantime, automatic processing of video data is a field of activity stirring up the utmost attention in the pattern recognition community; state-of-the-art advances in this area enable the reliable extraction of features and the investigation of numerous applications dedicated to ITS.**

A first obvious field of application of Video Content Analysis (VCA) consists in improving safety and security in transport's context. Embedded VCA in vehicles can track pedestrians to avoid collisions, improving safety. Used in railway station, VCA are able to detect left luggage allowing to enhance security. Video streams available from such installations may also represent a useful source of information for statistical transportation applications, e.g. monitoring of road traffic conditions or providing accurate counting statistics in railway/subway stations.

This paper proposes an overview of the VCA applications in terms of safety, security and efficiency for ITS, with a specific focus on the usability of such VCA systems (emerging research topics, state-of-the-art studies, already commercialized applications, etc).

I. INTRODUCTION

Nowadays, it is increasingly difficult for an operator to spot an incident on a wall of monitors as typically in use in CCTV control room. Research shows that the efficiency level of an operator dramatically drops over a period of time; after 20 minutes, an operator takes into account 5% of the information. When dealing with safety/security concerns, these numbers are not acceptable. Development of VCA systems allow to assist operators to focus on abnormal events.

Another interesting capability of VCA systems is the access of huge amount of information for transportation applications; e.g. statistical information about transportation context/usage can be computed and used to optimize the efficiency of existing infrastructures (reducing exploitation and maintenance costs, offering new services to customers, etc).

In this context, this paper proposes an overview, from academic to commercial usage, of the usefulness of VCA in transportation system, to improve safety, security and efficiency. Sec. II presents VCA systems to improve safety, essentially in road and railway context. Sec. III provides an analysis of VCA systems dedicated to security. And last, Sec. IV focuses on systems combining video analysis and statistical measurements to improve efficiency of transportation installations and traffic management.

II. VCA FOR SAFETY APPLICATIONS

A. Safety applications in road transport

The enhancement of computer vision technologies combined with the exponential growth in processor speeds now allows real time video-processing on embedded machines. In this context, on-board vision-based systems for road applications aim at avoiding collision by detecting obstacles, assisting the driver or by interpreting road traffic signs.

1) On-board pedestrians detection: In road area, target obstacles can be of various types but those receiving most attention are of course pedestrians. Xu [48] uses a thermic camera to detect and track pedestrians. The presented approach based on hotspots extraction, Support Vector Machine (SVM) classificator and Kalman filter tracking gives promising results. Schauland [40] performs a two-steps algorithm to detect pedestrians. A first feature extraction based on wavelet, symmetry and edge features, provides a feature vector, which is then classified as pedestrian or not using a SVM. The cascade combination of symmetry (computationally cheap pre-classification) and wavelet features (very good classification performance) leads to very satisfying results for non-occluded pedestrians. Evaluations have been performed on 4 different dataset (5616 images), separately on symmetry and wavelet features. Results are shown on Fig. 1.

Feature	Wavelet	Symmetry
Dataset 1	99.57%	73.00%
Dataset 2	94.25%	63.50%
Dataset 3	95.20%	88.73%
Dataset 4	98.24%	93.13%

Fig. 1. Illustration and test results of Pedestrian Detection [40].

On-board pedestrians detection technology becomes mature and some car manufacturers [26] already propose this safety system in option in their high-quality products.

2) On-board vehicles detection: On board road vehicles detection is one of the most important components of any driver assistance system. A survey of vision-based on road vehicles detection systems is presented in [43]. In brief, vehicle detection is a very challenging task due to huge variability in class of vehicle appearance. Vehicle detection system can be divided into two steps; first, hypothesis generation gives locations of possible vehicles in an image (knowledge based method using prior knowledge, stereovision based method using disparity map or motion based method using optical flow). Secondly, hypothesis verification performs tests to verify the presence of vehicles in an image (template based method or appearance method). The paper concludes that fusing data from multiple cues and sensors should be explored more actively in order to improve robustness and reliability of such systems.

3) Road/Highway traffic monitoring for safety applications: Motorways authorities monitor the traffic in order to increase security of drivers. Many roads are already equipped with monitoring systems which are able to detect incidents, e.g. traffic in wrong directions, abrupt changes in traffic velocity or traffic congestions. A considerable amount of research and engineering has been done in this field. Karim [24] presents a new two-stage incident detection model based on advanced wavelet analysis and pattern recognition techniques. Wavelet analysis is used to denoise, cluster, and enhance the raw traffic data, which is then classified by a radial basis function neural network. Presented results show excellent detection and false alarms characteristics. Considering a video camera fixed on the front of a public bus, Parisot [37] proposes a cost-effective approach to estimate the speed of the vehicles on the adjacent lanes when the bus operates on its reserved lane. Using pre-defined speed thresholds, the traffic can be classified in realtime into different categories such as fluid or congestion. The Fig. 2 shows an example of track line positions (pink) and presents performance of the system.

Data	Detection Rate
Fluid: 191	186 (97%)
Busy: 33	13 (39%)
Slow Down: 26	23 (88%)
Congestion:6	6 (100%)

Fig. 2. Illustration and test results of Traffic Flow Classification [37].

Traffic management systems are now matured technologies, widely exploited by companies [44], [47].

4) Driver fatigue evaluation: Another way to reduce or avoid collisions, and thus to improve safety, is to detect the driver fatigue. To do so, classic methods are decomposed into three main steps: face detection, eye detection and tracking, and open/closed eye state. Using these ideas, Zhang [50] extracts face position using Haar cascades, detects the eye position with projection techniques, tracks eyes with unscented Kalman filter, gives state of each eye using a vertical projection. Five consecutive frames with eyes closed trigger an alarm in the car to alert the driver. Illustration and performance evaluation of eye tracking are presented in Fig. 3.

Many of the biggest car manufacturers [49] are involved in research projects dealing with driver fatigue detection,

	Results
Total Frames	7829
Tracking failure	39 (0.49%)
Real Dozing	15
Correct warning	15 (100%)

Fig. 3. Illustration and test results of driver fatigue detection [50].

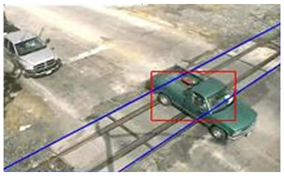
researches which will lead to commercial products in the next few years.

5) Road infrastructure detection for driving assistance: Detection and interpretation of, for example, road traffic signs or lane marking can assist drivers and help them understanding their environment. Concerning road sign detection, methods can be divided in two categories: those using tracking [13] after a road sign detection, and those using image interpretation; Shirvaikav [42] develops a method for automatic detection and interpretation of road signs. The real-time approach is based on an independent spectral (using color cues) and spatial (using attributes derived from object model) features analysis.

Other studies try to extract lane marking. Liu [27] reaches a detection rate between 92% and 100% using edge points cue to detect lane marking. Combining to filters (based on road orientation and confidence measures) to remove wrong lane, and to a finite state machine to finally classify the good lanes, he obtains an effective and robust system. Lane marking detection has been exploited by most of the car manufacturers in order to improve road user safety. In 2002, Toyota [41] introduced its Lane Monitoring System, warning the driver if the vehicle is beginning to drift out of its lane. In 2003, Honda [46] launched their Lane Keep Assist System on the Inspire model. In 2005, PSA became first in Europe to offer Lane Departure Warning Systems. In 2007, Volvo [38] introduced the Lane Departure Warning system along with the Driver Alert Control on its 2008 models. In 2009, Mercedes-Benz began offering a Lane Keeping Assist function on the new E-class, system which warns the driver with a vibrating steering wheel if the vehicle is beginning to leave its lane.

B. Improving safety using video in railway environment

1) Obstacle/activity detection at level crossings: The purpose of obstacle or activity detection in railway context is to prevent vehicle and train collisions at Level Crossings (LC). Such systems mainly allow for the timely detection of objects caught within the LC area and provide automated alert notification. Ohta [36] develops a system of stereo cameras used to achieve a large coverage area. Stereo cameras enable the system to obtain the 3D shape information which significantly reduces the number of false detections due to shadows and headlights. Machy [28] presents another approach based on video monitoring detecting stopped vehicles on the level crossing when a train is approaching. Built on video analysis algorithms, it interprets the image context in order to isolate presences rather than movements. Fig. 4 presents such a system and performance evaluation done on 24h sequences.



	Results
Nb of real obstacles	40
Detection Rate	39 (97.5%)
Missed Detection Rate	1 (2.5%)
False Alarms Rate	3 for 24h

Fig. 4. Illustration and Performance evaluation of Obstacle detection at LC [28].

2) Video transmission in railway context: The capability to have access to live video is very useful to enhance safety in complex environments, e.g. between metros and control room, or between the back and front of a train. The problem is then not related to video analysis but to video transmission. Initiatives to develop bandwidth efficient communication system to transmit videos are in progress [14]. Wireless video transmission can then be envisaged to assist train backing maneuver (a tricky operation because the driver do not see the front of the train). In order to improve safety during this operation, systems can be envisaged [29] to acquire high quality video and audio from the back of the train and to transmit them to the front using a wireless robust link over several hundred meters, able to function in complex and noisy context. Fig. 5 shows the transmitter and receptor of such a system on a train.

(a)Transmission part. (b)Receptor located in the cab.

Fig. 5. System to assist train backing [29].

In complex environment like railway, bandwidth is actually too narrow to transmit megabits of data. Consequently, embedded VCA system can be used to detect events (e.g. alarm combined with a small sample of the video around the event) which are then transmitted instead of the whole video. The BOSS[1] project aims to evaluate and demonstrate efficient transmission from the train to a control center. The aim is to transmit extracted events, such as fight detection, to the control room in order to improve passengers' safety.

3) People on tracks detection: The detection of people falling on tracks is of high interest for the research community, with the intention of increasing user' safety. Through computer vision processing, Khoudour [25] system automatically detects people or objects falling on or crossing the tracks in public transport. It then determines and sends in due time alarms and the corresponding video image to the systems operators. Such technologies have also been developed by some companies. iOmniscient'system [22] detects not only people on the train tracks but also people who get too close to the edge of the platform.

[1]BOSS: On Board Wireless Secured Video Surveillance; research project launched by France, Spain, Hungary and Belgium under the framework of Celtic programme. See http://www.celtic-boss.org for more details.

III. VCA FOR SECURITY APPLICATIONS

A. *Harmful behavior detection in transportation context*

In terms of security, researchers have boundless imagination to detect abnormal situations in order to avoid small crimes.

1) Robbery detection: Chuang [9] develops a novel method for suspicious object detection and robbery event analysis in public areas. The method is based on a background subtraction using minimum filter followed by a moving object tracking. The trajectories are then analyzed and suspicious object transferring between two persons is extracted.

2) Loitering detection: Loitering behavior often leads to abnormal situations, like suspected drug-dealing activity, car robbery, pickpocket. Some researchers are leading studies to detect these situations. Bird [4] detects loitering in the context of inner-city bus stops, mainly to detect drug-dealers. After steps of segmentation (mixture of gaussians) and tracking (segmented blob matching) of pedestrians, people are stored in database using short-term biometric and clothing color features. Loitering is judged evaluating how long an individual is present around the bus station. Preliminary results shows an accuracy of 66% for loitering detection.

3) Graffiti detection: Nowadays, countless acts of graffiti are committed daily against public and private properties all around the world. The costs caused by such damage are huge, mainly for the uncleanness and perceived insecurity in railway/bus/underground stations. Graffiti detection is an emergent research subject, still in its infancy. In this context, Angiati [1] presents a method for graffiti detection based on change detection algorithm and motion vector. The aim of this system is to detect the graffiti painting act while people are going to draw, identify them and distinguish the drawer. The author also provides a performance evaluation of his system given in Fig. 6.

	Day		Night		
	Data1	Data2	Data3	Data4	Data5
DR	97%	65%	95%	69%	91%
FAR	0.5%		0.6%		

Fig. 6. Illustration and test results of graffiti detection method (DR: Detection Rate - FAR: False Alarm Rate) [1].

B. *Video-based surveillance for critical transportation applications*

Unusual events happening in transportation context, e.g. intrusion detection, left luggage, may also be source of dangerous situations, like terrorism. A huge number of researches have been conducted during the last decades, covering these sensible subjects.

1) Intrusion detection: People entering a predefined forbidden area may lead to security problems. Many academic researches deal with intrusion detection [2], which consists in detecting people going into an unauthorized area. The researches become mature and companies now offer such systems. Perimeter Intrusion Detection Systems [16] is a fast emerging application deployed to prevent intrusion of unauthorized personnel into secure areas such as airports, railway/subway stations..

2) Left Luggage: Candidates of abandoned luggage items may pose potential security problems. A high number of systems have been developed by researchers to detect left objects: methods are mainly tracking-based [3]. As an alternative to tracking-based approaches that heavily depend on accurate detection of moving objects, Porikli [39] presents a pixelwise method that employs dual foregrounds to extract temporally static image regions. The method has been evaluated using different public dataset, results are presented in Fig. 7.

Nb Frames	60120
Nb Events	51
DR	50 (98%)
FAR	5

Fig. 7. Illustration and test results of left luggage benchmark (DR: Detection Rate - FAR: False Alarm Rate) [39].

Left luggage detection is becoming a mature and of interest technology for governments, e.g the i-LIDS initiative of UK government facilitates the development and evaluation of vision based detection systems. In France, SYSTEMATIC is a world class cluster dedicated to fund research project in the fields of Automotive, Transport, Security and Defence.

3) Weapon detection: The detection of weapons concealed underneath a person's clothing is an important topic to improve security in airports or train station. Manual screening procedures are common in control settings but it is sometimes desirable to detect weapons from a standoff distance. R&D premises in this domain are presented here. Chen [10] presents a tutorial overview of development in imaging sensors and processing. A number of sensors based on different phenomenology (infrared, passive millimeter wave (MMW) imaging sensors) as well as image processing support are being developed to observe objects underneath peoples clothing. A more recent imaging modality used to detect weapon is terahertz imaging (THz). Ramirez [6] presents the application of a basic unsupervised classification algorithm for the segmentation of indoor passive Terahertz images. Combined with image processing and pattern recognition techniques, the system is able to detect weapons under clothes.

4) People tracking and behavior analysis: Object tracking in video is a very active research topic in dynamic scene analysis, because it is usually the first step before applying higher level algorithms. In the context of multiple object tracking (MOT), establishing the correspondence between objects and observations is not a trivial task. Piater [17] makes an overview of existing MOT techniques. Particle filtering is often used in MOT because of its ability to carry multiple hypotheses. Humphreys [20] presents a new approach to MOT using a combination of simple neural cost functions based on Self-Organizing Maps. The algorithm matches 98.8% of objects to within 15 pixels.

Multiple cameras tracking (MCT) is also needed to cover large environments for monitoring activity. To track people successfully in multiple cameras, one needs to establish correspondence between objects captured in the different views. Colombo [12] presents work towards a system for tracking a pedestrian in multiple cameras using the color appearance of the observations. A novel method for estimating the appropriate transform between each cameras color space is proposed, using covariance of the foreground data collected.

IV. VCA FOR EFFICIENCY APPLICATIONS

A. Traffic Statistics in road applications

When looking at the roadside, advanced VCA can produce useful statistics on individual vehicle measurements (time, length, width, height, lane, speed and distance/time to previous vehicle), estimate lane occupancy and average flow speed, perform vehicle classification (e.g. car, truck, van...). An important number of researches have been conducted in vehicle detection and classification [32] to guide surveillance operators and reduce human resources for observing hundreds of cameras. Buch's system [5] performs per frame vehicle detection and classification using 3D models. Motion silhouettes are extracted and compared to a projected model silhouette to identify the ground plane position and class of a vehicle. The system has been evaluated with the reference i-LIDS dataset from the UK Home Office, and leads to high precision results; 96.1% of good classification.

Lane occupancy and traffic density estimation can also provide interesting statistics to better manage the traffic. Ozkurt [15] presents vehicle classification and traffic density calculation methods using neural networks, with promising preliminary results for density estimation.

These different researches rapidly conducted to commercial products. The system proposed by ACIC [33] is a new generation of VCA products for traffic monitoring. High-performance algorithms allow to process multiple lanes of traffic in every outdoor or tunnel conditions, producing in real time individual vehicles and traffic flow data. Fig. 8 shows an example of traffic monitoring using a fix camera on a highway.

Fig. 8. Illustration of traffic monitoring. Copyright ©2008 ACIC.

B. Video analysis for transportation statistics gathering

As presented in previous sections, VCA provides crucial information to improve passenger's security and safety. But it can also be exploited for statistical purposes, in order to gather statistics and improve transportation infrastructure efficiency.

1) From People Counting to Crowd Analysis: People counting is a widely matured developed tool [45]. Knowing how many passengers use train infrastructure is necessary to get grants or justify adding or reducing service. Irisys infrared people counters [21] proposes a system using infrared cameras to count people. TrueView People Counter [11] is a product for the retail industry that provides easy-to-use and accurate people counting, with a superior accuracy (95-99%). Once people are detected, a logical way to continue researches is to detect groups, which provide social statistics on infrastructure usage in terms of type of occupancy (alone or in group) [19]. Hoogs [18] proposes an approach to consistent labeling also capable to fully characterize groups of people and to manage miss segmentations. Extensive experiments demonstrate the accuracy of the proposed method in detecting single and simultaneous handoffs, miss segmentations, and groups.

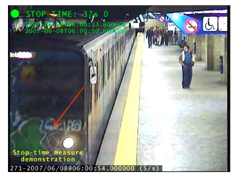
Going one step forward, crowd monitoring researches have exploded last decades. Concerning crowd density estimation, Marana [31] proposes a new method able to estimate densities ranging from very low to very high concentration of people, which is a difficult problem because in a crowd only parts of people's body appear. The SERKET project [23] aims at developing an innovative software approach where data coming from heterogeneous sensors are automatically analyzed. For example, a module of crowd monitoring has been developed to analyze crowd situations, detects abnormal events (e.g. thrown object or fight) and alert security personal. For the 2009 session, PETS workshop focuses on crowd image analysis, to devise and implement automatic systems for obtaining detailed information about the movements of, and collective behavior of, individuals and groups within a crowded scene observed by a single camera or by a network of cameras. Researches lead to numerous papers dealing with crowd monitoring [8].

2) User' behavior analysis: All these described techniques for people counting or density estimation can then be used to evaluate user' behavior in term of infrastructure usage. As an illustration, Naturel [34] monitors the general usage of a metro station equipment, with an emphasis on ticket vending machine and extract their statistics. The novelty of this method is that it does not require any tracking, events are directly recognized from image measurements. Fig. 9 presents an evaluation of the quite good performance of the system.

	GT	Results
Nb events	27	27
Mean duration(s)	32.5	34.9
Max duration(s)	1	6.8
Min duration(s)	99	94.6

Fig. 9. Illustration and test results of machine occupancy [34].

Carincotte [7] proposes to show how video data available in standard CCTV transportation systems can represent a useful source of information for transportation infrastructure management, optimization and planning if adequately analyzed. Two algorithms are proposed allowing to estimate the number of people on a platform and to measure the platform time-occupancy by trains as presented in Fig. 10. A statistical analysis of the results of both algorithms provides interesting insights regarding station usage; this analysis allows the identification of different behaviors depending on the time of day or the day of week, and thus the quantification of the knowledge intuitively gathered by operators (e.g. commuters behave differently than weekends shoppers).



	Week	Week-end
Detection Rate(nb)	96.86%	98.12%
Detection Rate(time)	96.47%	97.83%
Arrival delay (s)	0.657	0.6325
Departure delay (s)	0.812	0.73

Fig. 10. Illustration and test results of the platform time-occupancy by train [7].

These academic emerging researches lead to commercial products for detecting queues in transportation environments [35].

V. CONCLUSION

Video Content Analysis can be used in many contexts in transportation systems. Using embedded systems in train or vehicles, VCA is able to detects obstacles in front of the vehicle and avoid collision, thus increasing user's safety. Tracking and monitoring people behavior, VCA is used to analyze gestures and so to better enhance security in public places. Used as a statistical tool, VCA provide useful information to enhance efficiency in traffic or infrastructure management. These systems including VCA become more and more complex. Most of the recent studies tend to merge these applications. For instance, a traffic monitoring system provides information on traffic, in order to regulate the traffic, but also to detect incidents, like stopped vehicles.

These VCA systems are more and more used by governments for law enforcement. The detection of red light crossing, combined with a licence plate recognition allows to verbalize road users; a similar system is already in use in London [30]. An automatic number plate recognition system, embedded in policy vehicles, reads numberplates as vehicles enter the city center and check within police databases if this vehicle is allowed to enter London city center this day. Other VCA systems embedded in buses are able to detect illegal vehicle parking inside bus lanes.

VI. ACKNOWLEDGMENTS

This work is granted by the Walloon Region under the Itea Eureka Serket project.

REFERENCES

[1] D. Angiati, G.Gera, S. Piva, and C. Regazzoni, "A novel method for graffiti detection using change detection algorithm," in *Advanced Video and Signal Based Surveillance*, 2005, pp. 242–246.

[2] A. Anitha and V. Vaidehi, "Context based application level intrusion detection system," in *Networking and Services, 2006. ICNS '06. International conference on*, July 2006, pp. 16–16.

[3] D. Arsic, M. Hofmann, B. Schuller, and G. Rigoll, "Multi-camera person tracking and left luggage detection applying homographic transformation," *10th IEEE Int. Workshop on Performance Evaluation of Tracking and Surveillance*, 2007.

[4] N. D. Bird, O. Masoud, N. P. Papanikolopoulos, and A. Isaacs, "Detection of loitering individuals in public transportation areas," *IEEE Trans. on Intelligent Transportation Systems*, vol. 6, pp. 167–177, June 2005.

[5] N. Buch, J. Orwell, and S. Velastin, "Detection and classification of vehicles for urban traffic scenes," in *Visual Information Engineering, 2008. VIE 2008. 5th International Conference on*, Aug. 2008.

[6] M. Campbell, M. DeWitt, and E. Heilweil, "Static terahertz imaging at a distance for concealed weapon detection," in *15th Int. Conf. on Terahertz Electronics*, Sept. 2007, pp. 649–651.

[7] C. Carincotte, X. Naturel, M. Hick, J.-M. Odobez, J. Yao, A. Bastide, and B. Corbucci, "Understanding metro station usage using closed circuit television cameras analysis," in *11th Int. IEEE Conf. on Intelligent Transportation Systems (ITSC)*, Beijing, China, October 12-15 2008.

[8] A. B. Chan, M. Morrow, and N. Vasconcelos, "Analysis of crowded scenes using holistic properties," in *9th International Symposium PETS*, 2009.

[9] C.H.Chuang, J. Hsieh, L. Tsai, S. Chen, and K.C.Fan, "Carried object detection using ratio histogram and its application to suspicious event analysis," vol. 19, June 2009, pp. 911–916.

[10] H.-M. Chen, S. Lee, R. Rao, M. Slamani, and P. Varshney, "Imaging for concealed weapon detection: a tutorial overview of development in imaging sensors and processing," *Signal Processing Magazine, IEEE*, vol. 22, pp. 52–61, March 2005.

[11] CognimaticsAB, "Commercial leaflet: Trueview people counter."

[12] A. Colombo, J. Orwell, and S. Velastin, "Colour constancy techniques for re-recognition of pedestrians from multiple surveillance cameras," in *Workshop on Multi-camera and Multi-modal Sensor Fusion Algorithms and Applications*, 2008.

[13] C. Y. Fang, S. W. Chen, and C. S. Fuh, "Road-sign detection and tracking," *IEEE Trans. on Vehicular Technology*, vol. 52, 2003.

[14] A. Forchino, "On-board video surveillance with real-time wireless transmission: Turin metro case study," in *The Institution of Engineering and Technology Conference on Crime and Security*, London, UK, June 2006, pp. 386–389.

[15] R. Fraile and S. J. Maybank, "Automatic traffic density estimation and vehicle classification for traffic surveillance systems using neural networks," in *Mathematical and Computational Applications*, 2009.

[16] FUJITSU, "White paper: Perimeter intrusion detection systems (pids)," April 2006.

[17] P. F. Gabriel, J. G. Verly, J. H. Piater, and A. Genon, "The state of the art in multiple object tracking under occlusion in video sequences," pp. 166–173, September 2003.

[18] A. Hoogs, S. Bush, G. Brooksby, A. Perera, M. Dausch, and N. Krahnstoever, "Detecting semantic group activities using relational clustering," in *IEEE Workshop on Motion and video Computing*, Jan. 2008, pp. 1–8.

[19] R. Hosie, S. Venkatesh, and G. West, "Classifying and detecting group behaviour from visual surveillance data," *Int. Conf. on Pattern Recognition*, p. 602, 1998.

[20] J. Humphreys and A. Hunter, "Multiple object tracking using a neural cost function," *Image Vision Comput.*, vol. 27, pp. 417–424, 2009.

[21] InfraRed, "Commercial leaflet: Irysis people counting," 2009.

[22] iOmniscient, "Commercial leaflet: Iq-infinity - infinite intelligence rating," 2007.

[23] F. Josset and J. Mattioli, "Serket: An open software platform for preventive security in public crowded places and for large events," in *The 2nd International Conference on Safety and Security Engineering information*, June 2007.

[24] A. Karim and H. Adeli, "Incident detection algorithm using wavelet energy representation of traffic patterns," *Journal of Transportation Engineering*, vol. 128, pp. 232–242, 2002.

[25] L. Khoudour and J. Bruyelle, "Falls on the track detection in public transport by artificial vision," in *Computers in Railways VI*, 1998.

[26] C. Legrand, V. Fremont, and F. Large, "Localization of objects in automotive scenes with spatial and temporal information," in *11th Int. IEEE Conf. on Intelligent Transportation Systems*, Oct. 2008.

[27] W. Liu, H. Zhang, B. Duan, H. Yuan, and H. Zhao, "Vision-based real-time lane marking detection and tracking," in *11th IEEE Int. Conf. on Intelligent Transportation Systems*, Beijing, China, October 2008.

[28] C. Machy, X. Desurmont, J.-F. Delaigle, and A. Bastide, "Introduction of cctv at level crossings with automatic detection of potentially dangerous situations," in *2nd SELCAT Workshop*, Marrakech, Morroco, November 22-23 2007.

[29] C. Machy, "System to assist train backing - http://www.multitel.be/image/services-business/machine-vision-applications/sncf-arv-use-case.php."

[30] T. M. Manson, "Automatic license plate recognition systems," in *Law and Order magazine*, December 2006.

[31] A. N. Marana, S. A. Velastin, L. F. Costa, and R. A. Lotufo, "Automatic estimation of crowd density using texture," *Safety Science*, vol. 28, 1998.

[32] B. Morris and M. Trivedi, "Improved vehicle classification in long traffic video by cooperating tracker and classifier modules," in *IEEE International Conference on Advanced Video and Signal Based Surveillance*, November 2006.

[33] MvTraffic, "Intelligent Video System Software, Copyright ©2008 ACIC." For further information, please visit `http://www.acic.eu/`.

[34] X. Naturel and J. dobez, "Detecting queues at vending machines: A statistical layered approach," in *19th International Conference on Pattern Recognition*, Dec. 2008, pp. 1–4.

[35] ObjectVideo, "Commercial leaflet: Ov: Transportation."

[36] M. Ohta, "Level crossing obstacle detection system using stereo cameras," RTRI, Tech. Rep., 2005.

[37] C. Parisot, J. Meessen, C. Carincotte, and X. Desurmont, "Real-time road traffic classification using on-board bus video camera," in *11th Int. IEEE Conf. on Intelligent Transportation Systems (ITSC)*, Beijing, China, October 12-15 2008, pp. 189–196.

[38] J. Pohl, W. Birk, and L. Westervall, "A driver-distraction-based lane-keeping assistance system," in *Proc. IMechE J. Systems and Control Engineering*, vol. 221, 2007.

[39] F. Porikli, Y. Ivanov, and T. Haga, "Robust abandoned object detection using dual foregrounds," *EURASIP J. Adv. Signal Process*, p. 30, 2008.

[40] S. Schauland, A. Kummert, S. Park, Y. Zhang, and U. Iurgel, "Vision-based pedestrian detection - improvement and verification of feature extraction methods and svm-based classification," in *IEEE Int. Conf. on Intelligent Transportation Systems*, 2006, pp. 97–102.

[41] K. Seiji, I. Katsuhiko, N. Makoto, U. Hiroyuki, and K. Hiroaki, "Introduction to lane-keeping assist system," Toyota Motor Corp., JPN, Tech. Rep., 2006.

[42] M. Shirvaikar, "Automatic detection and interpretation of road signs," in *Proc. of the 36th Southeastern Symposium on System Theory*, 2004.

[43] Z. Sun, G. Bebis, and R. Miller, "On-road vehicle detection: A review," *IEEE Trans. Pattern Anal. Mach. Intell.*, May 2006.

[44] Traficon, "Commercial leaflet: Traficon management system: Management, control and visualisation of traffic data and events," March 2008.

[45] S. Velipasalar, Y. li Tian, and A. Hampapur, "Automatic counting of interacting people by using a single uncalibrated camera," *Multimedia and Expo, IEEE International Conference on*, 2006.

[46] F. Waibel and S. Ishida, "The honda lane keeping assistance system."

[47] T. Wells and E. Toffin2, "Video-based automatic incident detection on san-mateo bridge in the san francisco bay area," in *12th World Congress on ITS*, November, 6-10 2005, pp. 189–196.

[48] F. Xu, X. Liu, and K. Fujimura, "Pedestrian detection and tracking with night vision," *IEEE Trans. on Intelligent Transportation systems*, vol. 6, pp. 309–321, March 2005.

[49] J. H. Yang, Z.-H. Mao, L. Tijerina, T. Pilutti, J. F. Coughlin, and E. Feron, "Detection of driver fatigue caused by sleep deprivation," in *IEEE Trans. on Systems, Man and Cybernetics*, vol. 39, July 2009.

[50] Z. Zhang and J. shu Zhang, "Driver fatigue detection based intelligent vehicle control," in *IEEE Int. Conf. on Pattern Recognition*, Washington, DC, USA, 2006, pp. 1262–1265.