Surveillance Centric Coding

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To my Parents and Family

Abstract

The research work presented in this thesis focuses on the development of techniques specific to surveillance videos for efficient video compression with better processing speed. The Scalable Video Coding (SVC) techniques are explored to achieve better compression efficiency. The framework of SVC is modified to support Surveillance Centric Coding (SCC). Motion estimation techniques specific to surveillance videos are proposed in order to speed up the compression process of the SCC.

Main contributions of the research work presented in this thesis are divided into two groups (i) Efficient Compression and (ii) Efficient Motion Estimation. The paradigm of Surveillance Centric Coding (SCC) is introduced, in which coding aims to achieve bit-rate optimisation and adaptation of surveillance videos for storing and transmission purposes. In the proposed approach the SCC encoder communicates with the Video Content Analysis (VCA) module that detects events of interests in video captured by the CCTV. Bit-rate optimisation and adaptation are achieved by exploiting the scalability properties of the employed codec. Time segments containing events relevant to surveillance application are encoded using high spatio-temporal resolution and quality while the irrelevant portions from the surveillance standpoint are encoded at low spatio-temporal resolution and / or quality. Thanks to the scalability of the resulting compressed bit-stream, additional bit-rate adaptation is possible; for instance for the transmission purposes. Experimental evaluation shows that significant reduction in bit-rate can be achieved by the proposed approach without loss of information relevant to surveillance applications.

In addition to better compression strategy, novel approaches to perform efficient motion estimation specific to surveillance videos are proposed and implemented with experimental results. A real-time background subtractor is used to detect the presence of any motion activity in the sequence. Different approaches for selective motion estimation, GOP based, Frame based and Block based, are implemented. In the former, motion estimation is performed for the whole group of pictures (GOP) only when moving object is detected for any frame of the GOP. While for the Frame based

approach; each frame is tested for the motion activity and consequently for selective motion estimation. The selective motion estimation approach is further explored to the lower level as Block based selective motion estimation. Experimental evaluation shows that significant reduction in computational complexity can be achieved by applying the proposed strategy. Apart from selective motion estimation, a tracker based motion estimation and fast full search using multiple reference frames has been proposed for the surveillance videos.

Extensive tests on different surveillance videos show benefits of application of proposed approaches to achieve the goals of the SCC.

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Table of Contents

Chapter 1

Introduction

The research presented in this thesis focused on diverse coding techniques specific to surveillance videos. The foremost aim of this work is to propose techniques to improve the storage capacity and bandwidth utilisation with less computational complexity. The proposed coding techniques to improve compression and processing efficiency have been described to achieve better performance compared to the conventional techniques.

One of the major building blocks of the modern digital video surveillance architecture is digital video coding. Its main role is to decrease the quantity of information essential to represent the original image sequence. Video coding techniques offer a compressed bit-stream representing the identical perceptual information with much less data for any given input video with a particular image frame rate and resolution. Superior compression performance can be accomplished with sophisticated video coding methods and/or bringing in visual artefacts.

Once compression is executed, the consequent bit-stream can be resourcefully propelled through a digital network or stored on a device. When a client needs to exhibit it or explore its contents, a decoding procedure requires to be applied on the compressed bit-stream. The decoding course of action recreates the original input video at its original resolution and frame rate.

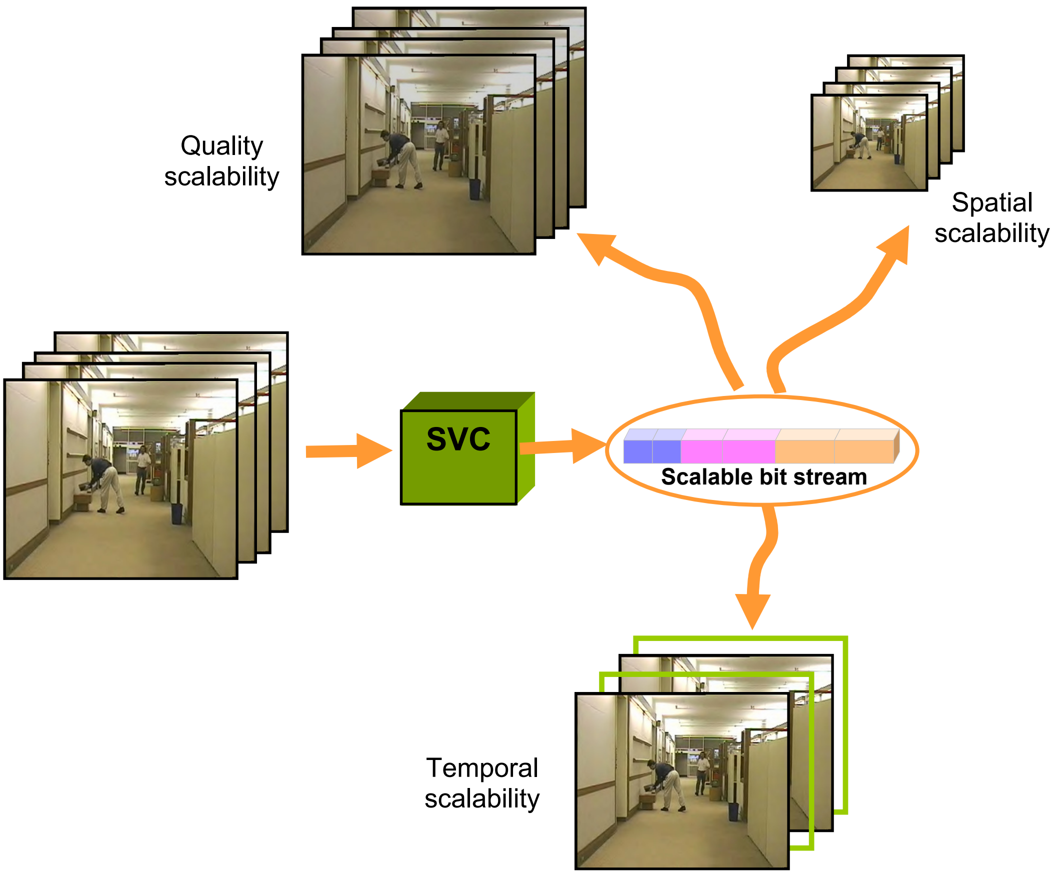

Figure 1: Scalable video coding

Scalable Video Coding (SVC) offers the equivalent compression functionality expressed above and is shown in Figure 1. Further more, the bit-stream is arranged with a hierarchical structure that facilitates a user to effortlessly pull out only a subpart of the data enclosed in the bit-stream while still being able to decode the original input video but at a lower frame rate and/or spatial resolution. The recursive application of this approach on a new bit-stream removed out of the original bit-stream can be utilised to carry out the process of successive extractions consequent to always lower resolutions.

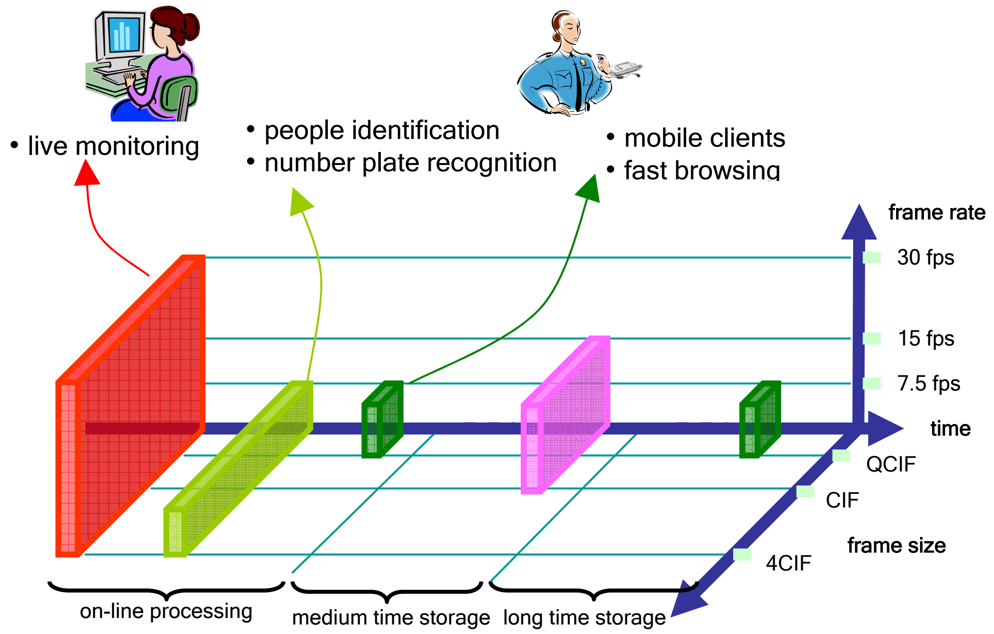

Figure 2: Surveillance application of SVC

There are numerous kinds of scalability and each of them can be available with different granularity. The most frequent type of scalability is the temporal scalability. For example, if the original image sequence consisted of 30 frames per second, temporal scalability would facilitate a user to decode a subpart of the bit-stream reconstructing a sequence with 15 frames per second or a lower number of frames per second. Spatial scalability is related to the opportunity to generate a bit-stream corresponding to the smaller spatial resolutions, for example, by decoding images with a resolution of CIF (common intermediate format: 352×288) out of an image sequence initially encoded at 4CIF (704×576). Quality scalability represents the possibility to decode the bit-stream at a lower quality. In this scenario, the temporal and spatial resolutions continue to be the same, but the recreated image sequence will emerge having additional artefacts or less details. In short, Scalable Video Coding (SVC) offers an exclusive representation of one image sequence permitting instantaneous access to the scene at different scales: spatial, temporal and quality. One of the many application scenarios of SVC is shown in Figure 2 where benefits of SVC for visual surveillance are evident.

Surveillance Centric Coding (SCC) is based on the SVC frame-work due to its potential benefits for surveillance applications. The main goal of this thesis is to develop such surveillance video specific coding techniques which offer a higher compression ratio so that storage and transmission resources may be utilized more efficiently. In addition to a better compression performance, some techniques to perform a quicker compression process are also focused for the SCC. All the developed techniques to accomplish these tasks are presented in consequent chapters of this thesis.

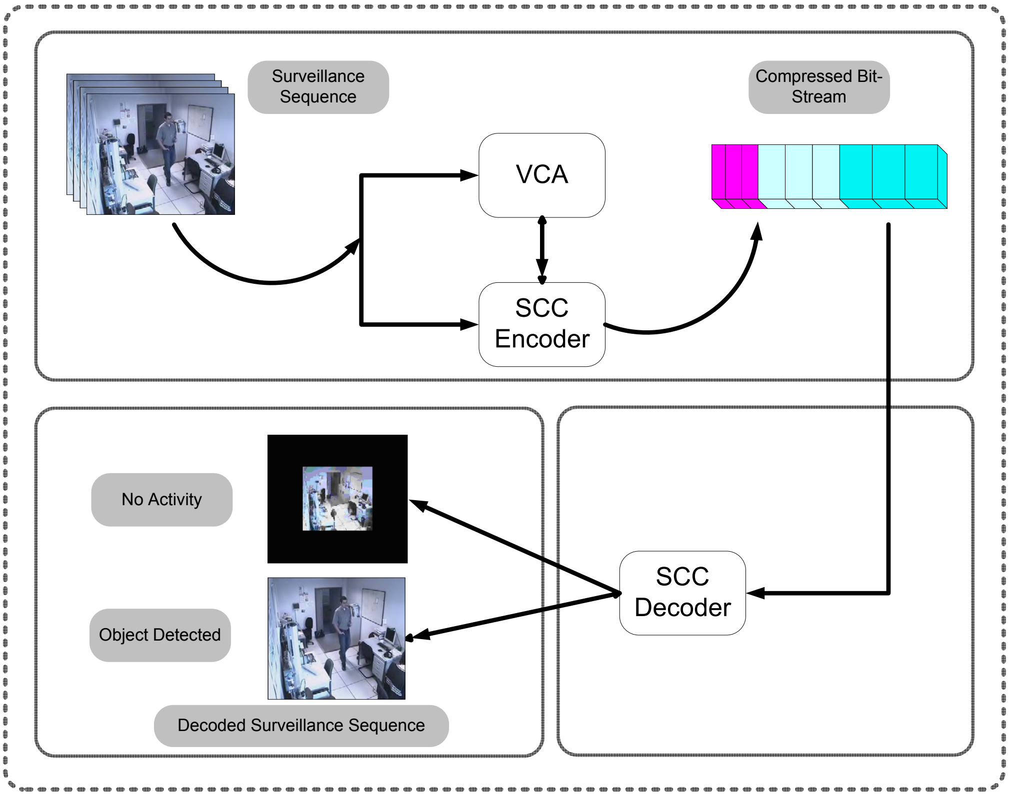

Figure 3: Surveillance centric coding system

An overview of the SCC system is shown in Figure 3. The Video Content Analyser (VCA) is used to detect any important activity corresponding to surveillance specific information. Based on this information, the reconstructed image resolution is specified. Thus, a lot of storage space is saved for the case when there is no motion activity. Now for the case of improving processing time, the focus of the attention goes to the motion estimation module due to its high processing power consumption. A high level system overview is illustrated in Figure 4. The process of motion estimation is driven on the basis of the information provided by the motion detection module. The final compressed bit-stream is available after the process of Entropy

Coding. The detailed discussion on the SCC system is presented in the dedicated chapters.

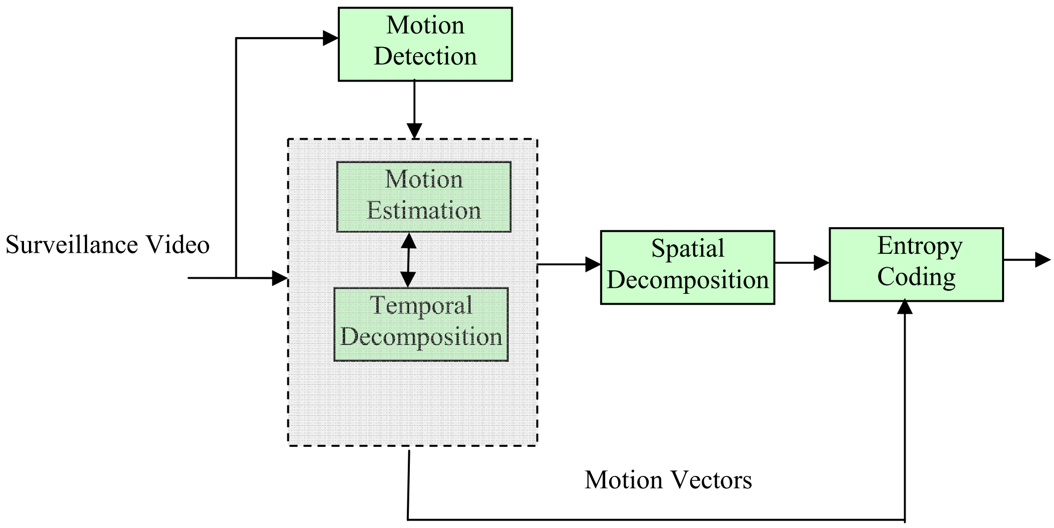

Figure 4: Surveillance centric coding system: Motion Estimation

1.1 Motivation

Security has been a critical issue in the world. Different security techniques have always been deployed according to different scenarios. Over the past decade or so, video-Surveillance has evolved as the most widely used security system today. It has seen great success and growth in the rate of deployment during recent times. Surveillance cameras can be found at almost every security-sensitive point as shown in Figure 5. The massive deployment of Closed Circuit Television (CCTV) cameras generates an enormous amount of data as can be observed in Figure 6. As the data keeps on increasing with 24/7 CCTV operation, the problem of data management escalates. The situation is further jeopardized when multi-view cameras are installed in highly security-sensitive locations.

Many researchers are drawing inspiration from this scenario and exploring new avenues in the CCTV system related research and areas like object recognition, object–based video segmentation, target detection and visual tracking etc. Apart from the problem of monitoring extracting video surveillance information, the huge amount of data imposes a problem of storage and transmission with limited resources like storage space and channel bandwidth.

In surveillance applications video captured by CCTV is usually encoded using conventional compression technology, such as MPEG-1/2 or H.264/AVC. These systems encode the video signal regardless the significance of events in the video. As an example, in many surveillance situations the scene remains essentially static for seconds and even minutes in some cases. During these periods of time nothing interesting happens from the surveillance standpoint, and the video resembles a still picture for long periods of time with no other activity than random environmental motion. This is the case of surveillance in metro stations during night hours or private car parking where the usual events are cars coming and leaving from time to time. When such videos are compressed using conventional coding techniques, each frame receives an equal level of importance. The conventional video compression techniques do not make a distinction between a frame having no special information and a frame having an object of interest with some motion activity.

Figure 5: Extensive deployment of surveillance cameras

The primary goal of developing any codec is to achieve highest compression while maintaining best possible visual quality. Therefore, all the modules and processes of the codec are optimised to achieve this goal. Thus, the video codecs available today have been optimised for visual sensitive applications. These codecs are not very efficient for surveillance systems. Therefore, we need to develop a coding scheme which is specific to surveillance system to improve the coding efficiency. Consequently, the utilisation of storage space and transmission of the channel bandwidth, especially in wireless channel, will improve.

Figure 6: CCTV system and control room

In Surveillance Centric Coding (SCC), the framework of scalable video coding shall be utilised for Rate-Distortion (RD) optimisation specific to surveillance videos. The SCC will be flexible in changing its coding parameters according to the significance of the video events. The SCC shall also code different regions of each frame with different fidelity. Moreover, the SCC shall have lower complexity compared to the current standards.

1.2 Scope of the Thesis

The major goal of the work presented in this thesis is to develop techniques specific to surveillance videos to achieve better compression at reduced computational complexity. The obvious characteristics of surveillance videos include static background or static cameras and a high importance for the video segments containing any event of interest like car entering a parking area. Such characteristics motivate to explore the Scalable Video Coding (SVC) frame work and computer vision techniques relevant to surveillance videos like the VCA. In order to reach to a meaningful conclusion, following research questions need to be addressed.

Will the SVC be helpful to achieve byte savings? Does the SVC framework have support to achieve goals of Surveillance Centric Coding (SCC)? How to utilise the SVC framework if it does not have a support for the SCC? Are there any possibilities of integrating computer vision techniques developed for surveillance videos in the framework of the SCC? How would computer vision techniques help to realise the SCC? What will be the effect of computer vision techniques on the complexity of the SCC? How will the negative points of computer vision techniques affect? What will be the effect of different scenarios on the deployment of the SCC?

This is worth-mentioning that the work presented in this thesis does not deal with the computer vision techniques and does not address the problems related to them. The computer vision techniques are explored and utilised to achieve the byte saving and reduction in computational complexity in the SCC. The thesis deals with the effects of integrating computer vision techniques in the framework of the SCC.

1.3 Contributions and Structure of the Thesis

According to the objectives laid down for the PhD research, some techniques have been developed for efficient compression and efficient motion estimation of surveillance videos. These techniques are discussed in the subsequent chapters of this thesis. The corresponding major contributions are discussed in the following subsections.

1.3.1 Efficient Compression

Scalable video coding (SVC) framework is selected as a basis to carry out the development of Surveillance Centric Coding (SCC) techniques after distinguishing the potential benefits of using the SVC techniques for surveillance videos. In order to deal at the Group of Pictures (GOP) level, the GOP dependency on the preceding and following GOPs is removed. The second step is to get the ability to deal with each GOP according to the SCC requirements while still maintaining the SVC properties. So, the communication linkage between Video Content Analysis (VCA) module and single GOP is established. The analysis of each GOP generated by the VCA under the requirements of SCC is utilised to exploit the SVC properties of each GOP. Thus, the bit-stream generated by the SCC consists of GOPs with different scalability features to compress the surveillance videos with higher compression efficiency while no compromise is made on the important information from the surveillance standpoint.

After the implementation of SCC paradigm, another novel approach is proposed to improve the compression efficiency. In this approach, foreground objects are detected by the VCA by forming rectangular windows around objects. The first frame of the sequence is used as background and rest of the frames contain only the foreground pixels while the background pixels are set to zeros. This shows efficient compression; but due to use of block based coding approaches, lack of sharpness at the object edges is observed. The major advantage of using this approach is its implementation in the SCC framework. Thus, in addition to avoiding shape coding and other object based coding techniques, the scalabilities features are inherited through the SCC framework offering the potential of improving the compression efficiency through exploiting the scalability features in each GOP.

1.3.2 Efficient Motion Estimation

As the motion estimation (ME) is the most processing intensive part of a codec; efficient techniques to perform fast motion estimation are explored. A novel approach of performing selective motion estimation is proposed where object detection information generated by the VCA is used to flag the frames which do not have any moving object. Based on this analysis, different selective motion estimation approaches were proposed which included: (i) GOP level selective motion estimation, (ii) Frame level selective motion estimation and (iii) block level motion estimation.

After the paradigm of selective motion estimation, a novel way of performing efficient motion estimation through reusing the information of surveillance video object tracker is proposed. In this approach, a real-time object tracker is used which generates information for each unique object with a unique track identity. In addition to this, objects are bounded in a rectangular box. So, instead of performing any kind of motion estimation for any block of the surveillance video, the motion vectors are calculated through the information generated by the object tracker.

Multiple reference frame based motion estimation increases the computational complexity with every extra reference frame. In order to address this problem, a fast full search for multiple reference frames based ME is proposed. This scheme is based on the successive elimination algorithm (SEA): a fast full search approach. This approach reduced the processing power for surveillance videos. Finally, another fast ME search algorithm, multi-pattern search algorithm, is proposed to find approximate calculations as in case of the well-known Diamond search.

1.3.3 Thesis Structure

Some background on the rate-distortion (RD) theory is presented in Chapter 2. In addition to the RD theory basics, some state-of-the-art strategies related to the surveillance videos are also presented. Chapter 3 describes the basic strategies for block-based video coding and wavelet-based scalable video coding. This chapter explains these techniques with the focus on the H.264/AVC standard which is the state-of-the-art block-based codec. Techniques of Motion Compensated Temporal Filtering (MCTF) and 2D DWT are explained for aceSVC: a wavelet-based video codec developed at QMUL. In chapter 4, object-based video coding implemented in MPEG-4 is presented. Object-based video coding has an attraction for surveillance videos because of independent handling of each object.

From Chapter 5 and onwards, research contributions for coding techniques specific to surveillance videos are discussed. Chapter 5 describes architectural modifications for a scalable video codec to convert it into the surveillance centric codec to improve the compression efficiency. A mathematical model of the modified architecture has been described. This chapter contains the experimental evaluation of the modified system as well as different experimental results for the road map towards a surveillance centric codec.

To overcome the problem of computational intensive motion estimation techniques, Chapter 6 describes a selective motion vector search technique based on the motion detection module. This technique maintains the visual quality of the video as that of full search yet improves the processing efficiency for the coding of the surveillance videos. A selective motion estimation approach has been proposed at different levels of selection (i) GOP level (ii) Frame level and (iii) Block level. All of these approaches are discussed with their challenges and experimental results.

Apart from selective motion estimation, a novel approach using a surveillance video object tracker will be discussed in Chapter 6. A unique motion track is calculated for each object of the surveillance video. The displacement of the object between the current and reference frame will be used to calculate motion vectors after identifying and matching the track in the two frames.

With the motive of maintaining the visual quality, Chapter 7 focuses on the fast full search approaches for efficient motion estimation. The concept of multiple reference frames based motion estimation is discussed. A fast full search technique based on multiple reference frames is proposed. This technique improves the processing efficiency for surveillance videos while maintaining the visual quality.

Chapter 8 is related to efficient motion estimation. A multi-pattern based motion vector search technique has been proposed. The experimental evaluation of this approach is tested and compared against the popular diamond search and cross-diamond-hexagonal search techniques. This multi-pattern based search improves the processing efficiency at the cost of visual quality of the video. Finally, Chapter 9 gives the conclusions on the work presented in this thesis.

Chapter 9

Conclusions

The research presented in this thesis focused on diverse coding techniques specific to surveillance videos. The foremost aim of this work was to propose such approaches to improve the storage capacity and bandwidth utilisation with less computational complexity. The proposed coding techniques to improve compression and processing efficiency have been described to improve on the conventional techniques. These techniques are developed under the motives laid down in Chapter 1. Most of the work has been tested and evaluated on a set of typical surveillance videos.

9.1 Conclusions

In the previous chapters, the basic techniques for video coding in the state-of-the art video coders have been presented. The object-based coding approach in MPEG-4 has been explained. After the background study of state-of-the art approaches, the achievements in developing the surveillance centric coding techniques can be summarised as below.

1. A technique to improve on the compression efficiency for surveillance videos has been presented. Architecture of the scalable video coding has been modified to become surveillance centric coding. The modified architecture offers a better byte saving performance. The architectural modifications in the SVC help to deal each GOP of the video with different coding parameters. This approach shows that the application of scalable video coding with an event driven approach improves the transmission and storage efficiency.

2. After introducing the SCC architecture, a novel approach to implement foreground based SCC has been proposed. The foreground pixels are selected by using the bounding boxes of the VCA modules. This approach has the benefits of being free from shape coding and background coding as compared to MPEG-4 object based coding. In addition to this, scalable video codec can be used to exploit the scalability features as described in the SCC.

3. Different experimental results showed that the motion compensated temporal filter (MCTF) with higher levels of filtering helps to remove temporal redundancies present in the surveillance videos. This approach has better RD-performance than the block-based coding approaches, H.264.

4. A search technique with better processing efficiency with a visual quality equivalent to the full search approach, selective search strategy specific to surveillance videos is presented. Two approaches to perform selective motion estimation, GOP based and Frame based, are described where Frame based approach performed better. The visual quality for both the approaches is the same as that of the full search.

5. To improve the selective motion estimation further, a selective block search technique has been proposed. The selection of the block is based on the novel approach where a motion detection module is used to provide the location of candidate blocks. Although, this approach performs a lesser number of block matching steps yet the overall processing efficiency of the system is close to a

Frame based selective search. This is because of the overhead complexity added by the bounding box matching algorithm to locate the candidate block in the SCC.

6. After introducing selective motion estimation approaches, another novel approach, tracker-based motion estimation has been proposed where surveillance video object motion tracker information is used to calculate the motion vectors. A unique motion track is calculated for each object of the surveillance video. The displacement of the object between current and reference frame used to calculate motion vectors after identifying and matching the track in the two frames. This approach performs a faster calculation of the motion vectors but it degrades the visual quality of the video depending on the nature of the movement represented by the foreground object.

7. Finally, under the same motivation of achieving processing efficiency without loss in visual quality, fast full search approaches are explored. A fast search approach for multiple reference frames specific to surveillance videos has been proposed. This approach is based on considering different points between the two consecutive reference frames and then using these different points to avoid unnecessary block matching steps. This search approach is specific to surveillance videos with motion estimation based on multiple reference frames.

8. To improve the processing efficiency of the SCC, a multi-pattern search approach is proposed. This approach improves the processing efficiency with some loss in visual quality compared to full search technique. However, it maintains comparable visual quality with respect to other fast search techniques for example the diamond search.

The current achievements described above show the performance of the SCC in terms of compression efficiency and processing efficiency.

9.2 Key Contributions

With the motivation to achieve objectives laid down in Chapter 1, several contributions have been made. These contributions are classified into two groups: Efficient Compression and Efficient Motion Estimation.

9.2.1 Efficient Compression

After distinguishing the potential benefits of using the Scalable Video Coding (SVC) techniques for surveillance videos, the SVC framework was adopted to implement the Surveillance Centric Coding (SCC) paradigm introduced in Chapter 5. One of the hitches in using the SVC framework for the SCC was the sliding filtering window between the consecutive GOPs. This sliding window was acting like a bond between the two GOPs, restraining the possibility of treating each GOP independently. So, the architectural modifications proposed and presented in Chapter 5 helped to break up this inter-GOP bondage. After the removal of the GOP dependency, the second step accomplished was to get the ability to deal with each GOP according to the SCC requirements while still maintaining the SVC properties. So, the communication link between the Video Content Analysis (VCA) module and a single GOP was established. The analysis of each GOP generated by the VCA under the requirements of the SCC was used to exploit the SVC properties of each GOP. Thus, the bit-stream generated by the SCC consisted of GOPs with different scalability features to compress the surveillance videos with higher compression efficiency while it did not compromise the important information from the surveillance standpoint.

> So, a flexible framework of the SCC was developed after proposing the architectural modifications for the SVC. Higher compression efficiency was achieved by establishing the link between the SCC and the VCA.

After the implementation of the SCC paradigm, another novel approach was proposed to improve the compression efficiency. In this approach, foreground objects are detected by the VCA by forming rectangular windows around objects. The first frame of the sequence is used as background and rest of the frames contain only the foreground pixels while the background pixels are set to zeros. This showed efficient compression but due to the use of block based coding approaches; lack of sharpness in the foreground boundary was observed. The major advantage of using this approach is its implementation in the SCC framework. Thus, in addition to avoiding shape coding and other object based coding techniques, the scalabilities features are inherited through the SCC framework offering the potential of improving the compression efficiency by exploiting the scalability features in each GOP.

So, a novel approach focusing on the foreground pixels was proposed and implemented in the framework of the SCC to achieve a better compression efficiency.

9.2.2 Efficient Motion Estimation

Apart from storage issues for surveillance videos, the main challenge was to compress the surveillance videos as quickly as possible. As the Motion Estimation (ME) is the most processing intensive part of a codec; therefore, efficient techniques to perform fast motion estimation were explored. In addition to proposing some efficient motion estimation algorithms, the task of using the SCC framework described in the last section in terms of integrating proposed motion estimation algorithms was accomplished.

A novel approach for performing selective motion estimation was proposed where object detection information generated by the VCA was used to flag the frames which did not contain any moving object. Based on this analysis, different selective motion estimation approaches were proposed which included: GOP level selective motion estimation, Frame level selective motion estimation and block level motion estimation.

In the GOP level selective motion estimation, the decision to perform or skip the motion estimation was enforced at the GOP level. So, the only way of skipping the motion estimation for a particular GOP was the scenario where there was not a single frame of the GOP identified as containing a moving object. Due to the very low probability of such a scenario, this scheme had little improvement even for moderately busy locations. The second drawback of the GOP level selective motion estimation was its dependency on the GOP size. So, with smaller GOP size, there was a higher probability of such GOPs occurring which do not have any frame detected containing a moving object. To counter the issues faced in the GOP level selective ME, a Frame level selective ME was proposed where the decision to perform or skip the ME was taken for each frame independent of other frames. Once again, this approach was integrated into the SCC framework keeping the contact with the SCC framework. Evidently, the Frame level selective ME performed better than the GOP level. The key observation for the Frame level ME was the imposing of the ME decision for all the blocks of the frame irrespective of the location and size of the moving objects in the frame.

> Novel approaches to perform fast motion estimation were proposed. By using the VCA, selective motion estimation helped to speed up the compression process by avoiding unnecessary computations.

With the motivation of evolving selective ME from Frame to macroblock level, a block level selective ME was proposed. Two major challenges to implementing this approach were (i) identification of the macroblock as part of a moving object and (ii) locating those blocks while performing ME. As explained in Chapter 5, the foreground pixels identified by the VCA were isolated from the background pixels by using the information of the rectangular bounding boxes. The similar approach was used to implement the Block level selective motion estimation.

> A novel approach to implement the block level selective motion estimation was proposed.

After the paradigm of selective motion estimation, a novel way of performing efficient motion estimation through reusing the information of a surveillance video object tracker was proposed. In this approach, a real-time object tracker was used which generates information for each unique object with a unique track identity. In addition to this, objects were bounded in a rectangular box. So, instead of performing any kind of motion estimation for any block of the surveillance video, the motion vectors are calculated through the information generated by the object tracker. This approach had a drawback of miscalculating some of the motion vectors corresponding to the same object; ultimately, reducing the visual quality.

Another novel approach for fast motion estimation was proposed where instead of using motion estimation module of the SCC, surveillance video tracker provided the information to calculate the motion vectors.

Multiple reference frame based motion estimation increases the computational complexity with every extra reference frame. In order to address this problem, a fast full search for multiple reference frames based ME was proposed. This scheme was based on the Successive Elimination Algorithm (SEA): a fast full search approach. This approach reduced the processing power for surveillance videos. One drawback was the extra memory used.

Fast multi-frame motion estimation for surveillance videos was proposed in order to maintain visual quality.

Finally, another fast ME search algorithm, multi-pattern search algorithm, was proposed to find approximate calculations as in case of the Diamond search. This algorithm is valid for any kind of videos, surveillance or non-surveillance.

A fast motion estimation search algorithm was proposed. Computational complexity is reduced through acceptable compromise on visual quality.

9.3 List of Publications

The work presented in this thesis has lead to the following research publications. The author of the thesis is the main contributor to propose the strategies, developing algorithms, implementations and writing publications.

1. M. Akram and E. Izquierdo, "Fast multi-frame motion estimation for surveillance videos," *in the Proc. of IEEE 17th International Conference on Image Processing (ICIP 2010),* pp. 753-756, September 2010.
2. M. Akram and E. Izquierdo, "Selective block search for surveillance centric motion estimation," *in the Proc. of IEEE 52nd International Symposium ELMAR 2010,* pp. 93-96, September 2010.

3. M. Akram and E. Izquierdo, "A multi-pattern search algorithm for block motion estimation," *in the Proc. of IEEE 12th International Asia-Pacific Web Conference (APWEB 2010),* pp. 407-410, April 2010.
4. M. Akram, N. Ramzan, and E. Izquierdo, "Selective motion estimation for surveillance videos," *in the Proc. of International Conference on User Centric Media (UCMEDIA 2009),* pp. 199-206, Dec 2009.
5. M. Akram, N. Ramzan, and E. Izquierdo, "Efficient motion estimation for video coding in wireless surveillance applications," *in the Proc. of IEEE International Conference on Ultra Modern Telecommunications (ICUMT 2009),* Oct 2009.
6. M. Akram, N. Ramzan, and E. Izquierdo, "Event based video coding architecture," *in the Proc. of IET 5th International Conference on Visual Engineering (VIE 08),* pp. 807-812, July 2008.
7. T. Zgaljic, N. Ramzan, M. Akram, and E. Izquierdo, "Surveillance centric coding," *in the Proc. of IET 5th International Conference on Visual Engineering (VIE 08)*, pp. 835-839, July 2008.

References

[1] C. E. Shannon, “Coding theorems for a discrete source with a fidelity criterion,”in Information and Decision Processes, R.E. Machol, Ed. New York: McGraw-Hill, 1960, pp. 93-126.

[2] S. Wan, “Rate-Distortion optimization for motion-compensated prediction in video coding,” *PhD thesis, Department of Electronic Engineering, Queen Mary, University of London*, 2007.

[3] R. Gallager, Information theory and reliable communication. New York: JohnWiley and Sons, 1968.

[4] D. Slepian, Ed., Key papers in the development of information theory. NewYork: IEEE Press, 1974.

[5] C. E. Shannon, “A mathematical theory of communication,” *Bell System Technical Journal*, vol. 27, pp. 379-423 & 623-656, Jul. & Oct. 1948.

[6] A. Ortega and K. Ramchandran, “Rate-distortion methods for image and video compression,” *IEEE Signal Processing Magazine*, vol. 15, no. 6, pp. 23-50, Nov. 1998.

[7] M. Brotherton, H. Quan, D. Hands, and K. Brunnstrom, “Subjective multimedia quality assessment,” *IEICE Transactions on Fundamentals*, vol. E89-A, no. 11, pp. 2920-2932, Nov. 2006.

[8] VQEG Report, “Final report from the video quality experts group on the validation of objective models of video quality,” Jun. 2000.

[9] VQEG Report, “Draft final report from the video quality experts group on the validation of objective models of video quality assessment,” Aug. 2003.

[10] H. Everett, “Generalized Lagrange multiplier method for solving problems of optimum allocation of resources,” *Operations Research*, vol. 11, no. 3, pp. 399- 417, 1963.

[11] Y. Shoham and A. Gersho, “Efficient bit allocation for an arbitrary set of quantizers,” *IEEE Transactions on Acoustics, Speech and Signal Processing*, vol. 36, no. 9, pp. 1445-1453, Sept. 1988.

[12] K. Ramchandran and M. Vetterli, “Best wavelet packet bases in a rate-distortion sense,” *IEEE Transactions on Image Processing*, vol. 2, no. 2, 160-175, Apr. 1993.

[13] G. M. Schuster and A. K Katsaggelos, “An optimal quadtree-based motion estimation and motion-compensated interpolation scheme for video compression,” *IEEE Transactions on Image Processing*, vol. 7, no. 6, pp. 909- 912, Nov. 1998.

[14] G. J. Sullivan and T. Wiegand, “Rate-distortion optimization for video compression,” *IEEE Signal Processing Magazine*, vol. 15, no. 6, pp. 74-90, Nov. 1998.

[15] T. Chiang and Y.-Q. Zhang, “A new rate control scheme using quadratic rate distortion model,” *IEEE Transactions on Circuits Systems for Video Technology*, vol. 7, no. 1, pp, 246-250, Feb. 1997.

[16] A. Vetro, T. Haga, K. Sumi, H. Sun, “Object-based coding for long-term archive of surveillance video,” *Technical Report*, TR-2003-98, MERL, 2003.

[17] Mrak M., Sprljan N., Izquierdo E., "Motion estimation in temporal subbands for quality scalable motion coding", *IET Elect. Letters*, Volume 41, Issue 19, Pages 1050-1051

[18] Mrówka E., Dorado A., Pedrycz W., Izquierdo E., "Dimensionality Reduction for Content-Based Image Classification", *IEEE Proceedings 8th International Conference on Information Visualisation*, London, England, 14-16 July 2004, Pages 435-438

[19] Dorado A., Izquierdo E., "Semantic Labeling of Images Combining Color, Texture and Keywords", *IEEE Proceedings 10th International Conference on*

Image Processing (ICIP 2003), Barcelona, Catalonia, 14-18 September 2003, Pages 9-12

[20] Izquierdo E., "Using Invariant Image Features for Synchronization in Spread Spectrum Image Watermarking", *EURASIP J. on Advances in Signal Processing*, Issue 4

[21] Dong L., Izquierdo E., "A Biologically Inspired System for Classification of Natural Images", *IEEE Transactions on Circuits and Systems for Video Technology*, Volume 17, Issue 5, Pages 590-603

[22] Mrak M., Abhayaratne C., Izquierdo E., "On the influence of motion vector precision limiting in scalable video coding", *IEEE Proceedings 7th International Conference on Signal Processing*, Beijing, September 2004, Volume 2, Pages 1143-1146

[23] Essid S., Izquierdo E., at al.,, "A multi-modal dance corpus for research into interaction between humans in virtual environments", *Springer Journal on Multimodal User Interfaces*, Volume 7, Issue 1-2, Pages 157-17.

[24] ITU-T Rec. H.264/ISO/IEC 11496-10, "Advance Video Coding," *Final Committee Draft, Document JVT-E022*, September 2002.

[25] ITU-T Rec. H.264/ISO/IEC 11496-10, "Advance Video Coding," *Final Committee Draft, Document JVT-g050*, March 2003.

[26] T. Wiegand, G. J. Sullivan, G. Bjontegaard, and A. Luthra, "Overview of the H.264/AVC video coding standard," *IEEE Trans. on Circuits and Systems for Video Technology*, vol. 13, no. 7, pp. 560-576, July 2003.

[27] I. E. G. Richardson, "Tutorial on H.264/AVC Video Compression Standard," April 2003.[online]. Available: http://www.vcodex.com/h264.html [Accessed: November 19, 2010].

[28] G. J. Sullivan, P. Topiwala, and A. Luthra, "The H.264/AVC advance video coding standard: overview and introduction to the fidelity range extension," *in the Proc. of the SPIE Conference on Applications of Digital Image Processing XXVII*, August 2004.

[29] T. Schierl, T. Wiegand, "Mobile video transmission using SVC", *IEEE Trans. Circuits Syst. Video Technology*, vol. 17, no. 9, September 2007.

[30] M. Wien, R. Cazoulat, A. Graffunder, A. Hutter, P. Amon, ”Real-time system for adaptive video streaming based on SVC”, *IEEE Trans. Circuits Syst. Video Technology*, vol. 17, no. 9, pp. 1227-1237, September 2007.

[31] H. Schwarz, D. Marpe, and T. Wiegand, “Overview of the scalable video coding extension of the H.264/AVC standard,” *IEEE Trans. on Circuits and Systems for Video Technology*, vol. 17, no. 9, pp. 1103-1120, 2007.

[32] F. Ziliani, “The importance of ‘Scalability’ in video surveillance architectures”, *IEE International Symposium on Imaging for Crime Detection and Prevention*, June 2005.

[33] May, J. The, P. Hobson, F. Ziliani, J. Reichel, “Scalable video requirements for surveillance applications”, *IEE Intelligent Distributed Surveillance System*, pp. 17–20, Feb. 2004.

[34] M. Mrak, N. Sprljan, T. Zgaljic, N. Ramzan, S. Wan and E. Izquierdo, “Performance evidence of software proposal for Wavelet Video Coding *Exploration group”, Technical Report ISO/IEC JTC1/SC29/WG11/MPEG2006/M13146*, (2006).

[36] Praks P., Grzegorzek M., Moravec R., Válek L., Izquierdo E., "Wavelet and Eigen-Space Feature Extraction for Classification of Metallography Images", *IOS Press 17th European-Japanese Conference on Information Modelling and Knowledge Bases XIX* (EJC 2007). Pori, Finland, 4-7 June 2007

[37] Zhang Q., Izquierdo E., "Optimizing Metrics Combining Low-Level Visual Descriptors for Image Annotation and Retrieval", *IEEE 31st International Conference on Acoustics, Speech, and Signal Processing,* Toulouse, France, 14-19 May 2006, Volume 2, Pages 405-408

[38] Piatrik T., Izquierdo E., "Image classification using an ant colony optimization approach", *Springer First International Conference on Semantics and Digital Media Technologies, SAMT 2006,* Athens, Greece, December 6-8 2006, Pages 159-168

[39] M. Mark and E. Izquierdo, “Spatially adaptive wavelet transform for video coding with multi-scale motion compensation” *Proc. IEEE International Conference on Image Processing*, vol. 2, pp. 317–3320, Sep. 2007.

[40] T. Zgaljic, N. Sprljan and E. Izquierdo, “Bitstream syntax description based adaptation of scalable video”, *Integration of Knowledge, Semantics and Digital Media Technology (EWIMT 2005)*, pp. 173–176, 30 Nov. 2005.

[41] M. Mrak, “Motion scalability for video coding with flexible spatio-temporal decompositions”, *PhD thesis, Department of Electronic Engineering, Queen Mary, University of London*, 2007.

[42] T. Zgaljic, N. Sprljan and E. Izquierdo, “Bit-stream allocation methods for wavelet based scalable video coding”, *Proc. 2nd International Mobile Multimedia Communications Conference (Mobimedia 2006)*, September 2006.

[43] V. Bottreau, M. Benetiere, B. Felts, B. Pesquet-Popescu, “A fully scalable 3D subband video codec”, *Proc. of IEEE Conference of Image Processing*, vol.2, pp. 1017–1020, October 2001.

[44] Izquierdo E., Ghanbari M., "Nonlinear Gaussian filtering approach for object segmentation", *IET Proceedings - Vision, Image and Signal Processing*, Vol. 146, Issue 3, Pages 137-143

[45] Izquierdo E., Feng X., "Modeling Arbitrary Objects Based on Geometric Surface Conformity", *IEEE Transactions on Circuits and Systems for Video Technology*, Volume 9, Issue 2, Pages 336-352

[46] Shanableh T., Peixoto E., Izquierdo E., "MPEG-2 to HEVC video transcoding with content-based modeling", I*EEE Transactions on Circuits and Systems for Video Technology*, Issue 99, Pages 1-7

[47] Tsomko E., Kim H., Izquierdo E., "Linear Gaussian blur evolution for detection of blurry images", *IET Image Processing*, Volume 4, Issue 4, Pages 302-312

[48] Athanasiadis T., Izquierdo E., et al. "Integrating Image Segmentation and Classification for Fuzzy Knowledge-Based Multimedia Indexing", *Springer 15th International Multimedia Modeling Conference*, France, 7-9 Jan. 2009, Pages 263-274

[49] Chandramouli K., Stewart C., Brailsford T., Izquierdo E., "CAE-L: An Ontology Modelling Cultural Behaviour in Adaptive Education", *IEEE Third International Workshop on Semantic Media Adaptation and Personalization*, Prague, 2008

[50] Praks P., Kucera R., Izquierdo E., "The sparse image representation for automated image retrieval", *15th IEEE International Conference on Image Processing* (ICIP 2008). San Diego, CA, 12-15 October 2008, Pages 25-28

[51] Pinheiro A., Izquierdo E., Ghanhari M., "Shape Matching using a Curvature Based Polygonal Approximation in Scale-Space", *IEEE Proceedings*

International Conference on Image Processing, Vancouver, Sept. 2000, Volume 2, Pages 538-541

[52] Dorado A., Izquierdo E., "Semi-Automatic Image Annotation Using Frequent Keyword Mining", *IEEE Proceedings 7th International Conference on Information Visualisation (IV 2003)*. London, 2003, Pages 532-535

[53] Wang Y., Izquierdo E., "High-Capacity Data Hiding in MPEG-2 Compressed Video", *9th International Workshop on Systems, Signals and Image Processing (IWSSIP 2002),* England, 7-8 November 2002, Pages 212-218

[54] T. Zgaljic, N. Sprljan, E. Izquierdo, “Scalable video adaptation based on bitstream syntax description”, *Proc. Workshop on Immersive Communication and Broadcast Systems (ICOB 2005)*, October 2005.

[55] MPEG-4 Requirements version 17, ISO/IEC JTC1/SC29/WG11 N4319, Sydney, July 2001.

[56] E. S. Jang, “Low-Complexity MPEG-4 shape encoding towards realtime Object-Based applications”, *ETRI Journal*, vol. 26, no. 2, April 2004.

[57] T. Ebrahimi, C. Horne, “MPEG-4 natural video coding – an overview”, *Signal Processing: Image Communication*, vol. 15, no. 4–5, 2000.

[58] M. Ghanbari, “The cross search algorithm for motion estimation,” *IEEE Trans. Communication.*, vol. 38, no.7, pp. 950 – 953, July 1990.

[59] Dorado A., Izquierdo E., "Fuzzy Color Signatures", *IEEE Proceedings International Conference on Image Processing*, New York, 22-25 Sep. 2002, Vol. 1, Pages 433-436

[60] Peixoto E., Izquierdo E., "A Complexity-scalable Transcoder from H.264/AVC to the New HEVC Codec", *IEEE Proceedings 19th International Conference on Image Processing (ICIP 2012),* Orlando, 30 September - 3 October 2012, Pages 737-740

[61] Borges P., Mayer J., Izquierdo E., "Robust and Transparent Color Modulation for Text Data Hiding", *IEEE Transactions on Multimedia*, Volume 10, Issue 8, Pages 1479-1489

[62] Zgaljic T., Sprljan N., Izquierdo E., “Bitstream Syntax Description based Adaptation of Scalable Video”, *2nd European Workshop on the Integration of Knowledge, Semantics and Digital Media Technology*, London, England, 30 November - 1 December 2005

[63] Borges P., Mayer J., Izquierdo E., "Efficient visual fire detection applied for video retrieval", *European Signal Processing Conference*, Lausanne, Switzerland, 2008

[64] Izquierdo E., Ernst M., “Motion/Disparity analysis for 3D-Video-Conference Applications”, *1995 International Workshop on Stereoscopy and 3-Dimensional Imaging (IWS3DI 1995).* Santorini, Greece, September 1995

[65] Kay S., Izquierdo E., "Robust Content Based Image Watermarking", 3rd Workshop on Image Analysis for Multimedia Interactive Services (WIAMIS 2001), Tampere, Finland, 16-17 May 2001, Pages 53-56 [66]

[66] L-M. Po and C-H. Cheung, “A novel kite-cross-diamond search algorithm for fast block matching motion estimation,” *IEEE ISCAS*, vol. 3, pp. 729 – 732, May 2004.

[67] X. Yi and N. Ling, “Rapid block-matching motion estimation using modified diamond search,” *IEEE ISCAS*, vol. 6, pp. 5489 – 5492, May 2005.

[68] C-H. Cheung and L-M. Po, “Novel cross-diamond-hexagonal search algorithm for fast block motion estimation,” *IEEE Trans. Circuit Syst. Video Technol.*, vol. 7, no.1, pp. 16 – 22, Feb. 2005.

[69] Y. Nie and K. K. Ma, “Adaptive rood pattern search for fast block matching motion estimation,” *IEEE Trans. Image Process.*, vol. 11, no.12, pp. 1442 – 1449, Dec. 2002.

[70] C. Stauffer, and W.E.L. Grimson, “Learning patterns of activity using real time tracking,” *IEEE Trans. on Pattern Analysis and Mach. Intel.,* vol. 22, pp. 747-757, 2000.

[71] M. Mrak, N. Sprljan, T. Zgaljic, N. Ramzan, S. Wan and E. Izquierdo, “Performance evidence of software proposal for wavelet video coding exploration group,” *Technical Report ISO/IEC JTC1/SC29/WG11/MPEG2006/M13146,* (2006)

[72] T. Zgaljic, N. Ramzan, M. Akram, E. Izquierdo, R. Caballero, A. Finn, H. Wang and Z. Xiong, “Surveillance centric coding,” *In 5th International Conference on Visual Information Engineering (VIE 2008)*, pp. 835-839, July 2008.

[73] M. Akram, N. Ramzan and E. Izquierdo, “Event based video coding architecture,” *In 5th International Conference on Visual Information Engineering (VIE 2008),* pp. 807-812 July 2008.

[74] T. Zgaljic, N. Sprljan and E. Izquierdo, "Bit-stream allocation methods for scalable video coding supporting wireless communications," *Signal Processing: Image Communications*, vol. 22, pp. 298-316, March 2007.

[75] Recommendation ITU-T BT 500.10: Methodology for the Subjective Assessment of the Quality of Televisions Pictures, (2000).

[76] W. Li and E. Salari, "Successive elimination algorithm for motion estimation," *IEEE Trans. Image Processing*, vol. 4, pp. 105—107, Jan. 1995.

[77] H-S. Wang and R. M. Mersereau, "Fast algorithm for the estimation of motion vectors," *IEEE Trans. Image Processing*, vol. 8, pp. 435—438, Mar. 1999.

[78] X. Q. Gao, C. J. Duanmu and C. R. Zou, "A multilevel successive elimination algorithm for block matching motion estimation," *IEEE Trans. Image Processing*, vol. 9, pp. 501—504, Mar. 2000.

[79] S-M. Jung, S-C. Shin, H. Baik and M-S. Park, "New fast successive elimination algorithm," *In proc. 43rd IEEE Midwest Symp. on Cct. and Sys.*, pp. 616—619, Aug. 2000.

[80] S-M. Jung, S-C. Shin, H. Baik and M-S. Park, "Nobel successive elimination algorithm for the estimation of motion vectors," *In proc. 43rd IEEE Microelectronic System Education*, pp. 332—335, 2000.

[81] J-N. Kim, S-C. Byun, Y-H. Kim and B-H. Ahn, "Fast full search motion estimation algorithm using early detection of impossible candidate vectors," *IEEE Trans. Signal Processing*, vol. 50, pp. 2355—2365, Sept. 2002.

[82] S-M. Jung, H. Baik, S-H. Lee and M-S. Park, "Advanced multilevel successive elimination algorithms using the locality of pixels in block," *Journal of Korean Society for Industrial and Applied Mathematics-IT seris,* vol. 8, pp. 75—86, 2004.

[83] Y. Song, Z. Liu, T. Ikenaga, and S. Goto, "Enhanced strictly multilevel successive elimination algorithm for fast motion estimation," *IEEE Symp. on Cct. and Sys.*, pp. 3659—3662, May 2007.

[84] ITU-T Rec. H.264/ISO/IEC 11496-10, "Advance Video Coding," *Final Committee Draft, Document JVT-E022*, September 2002.

[85] ITU-T Rec. H.264/ISO/IEC 11496-10, "Advance Video Coding," *Final Committee Draft, Document JVT-g050*, March 2003.

[86] H. F. Ates and Y. Altunbasak, “SAD resuse in hierarchical motion estimation for the H.264 encoder,” *In proc. IEEE Acoustics, Speech and Signal Processing (ICASSP),* pp. 905—908, 2005.

[87] Y. Su and M.-T. Sun, “Fast multiple reference frame motion estimation for H.264/AVC,” *IEEE Trans. Circuits and Systems for Video Tech.*, vol. 16, pp. 447—452, Mar. 2006

[88] M.-J. Chen, G.-L. Li, Y.-Y. Chiang and C-T. Hsu, “Fast multiframe motion estimation algorithm by motion vector composition for the MPEG-4/AVC/H.264 standard,” *IEEE Trans. Multimedia*, vol. 8, pp. 478—487, June. 2006

[89] S.-C. Hsia and Y.-C. Hung, "Fast multi-frame motion estimation for h264/avc system," *Journal of Signal, Image and Video Processing (SIViP)*, Feb. 2009.

[90] A. Pietrowcew, A. Buchowicz, W. Skarbek, "Bit-rate control algorithm based on local image complexity for video coding with ROI," *IEEE Conference on Advanced Video and Signal Based Surveillance*, pp.582-587, 2005.

[91] S. V. Leuven1, K. V. Schevensteen, T. Dams, and P. Schelkens, “An Implementation of multiple region-of-interest models in H.264/AVC,” *6th International Conference on Signal-Image Technology and Internet-Based Systems*, pp. 502 – 511, 2006.

[92] Y. Liu, Z. G. Li, Y. C. Soh and M. H. Loke, “Conversational video communication of H.264/AVC with region-of-interest concern,” *IEEE Conference on Image Processing (ICIP)*, pp. 3129 – 3132, Oct. 2006.

[93] P. Lambert, W. De Neve, Y. Dhondt, R. V. De Walle, “Flexible macroblock ordering in H.264/AVC,” *Journal of Visual Communication and Image Representation*, Volume 17, Issue 2, Introduction: Special Issue on emerging H.264/AVC video coding standard, April 2006, Pages 358-375, 2005.

[94] P. Baccichet, X. Zhu, and B. Girod, "Network-Aware H.264/AVC Region-of-Interest Coding for a Multi-Camera Wireless Surveillance Network", *Proc. Picture Coding Symposium, (PCS-06)*, Beijing, China, April 2006.

[95] P. Sivanantharasa, W.A.C. Fernando, H. Arachchi and Kodikara, “Region of interest video coding with flexible macroblock ordering,” *International Conference on Industrial and Information Systems*, pp. 596 – 599, Aug. 2006.

[96] Y. Zheng, J. Feng, H. Ma, and Y. Chen, “H.264 ROI coding based on visual perception,” *5th International Conference on Visual Information Engineering (VIE)*, pp. 829 – 834, Aug. 2008.

[97] Y. Shi, S. Yue, B. Yin and Y. Huo, “A novel ROI based rate control scheme for H.264,” *9TH International Conference for Young Computer Scientist*, pp. 77 – 81, 2008.

[98] Y. Liu, Z. G. Li and Y. C. Soh, “Region-of-interest based resource allocation for conversational video communication of H.264/AVC,” *IEEE Trans. on Cct. and Sys. for Video Tech.*, vol. 18, pp. 134 – 139, Jan. 2008.

[99] P. Lambert and R. V. de Walle, “Real-time interactive region of interest in H.264/AVC,” *Journal of Real-Time Image Processing*, vol. 4, pp. 67 – 77, March 2009

[102] Calic J., Izquierdo E., “Temporal Segmentation of MPEG Video Streams”, *EURASIP Journal on Applied Signal Processing*, Issue 6, Pages 561—565, 2002/6/26

[103] Izquierdo E., Casas J., Leonardi R., Migliorati P., O'Connor N., Kompatsiaris I., Strintzis M., "Advanced Content-Based Semantic Scene Analysis and Information Retrieval: The Schema Project", *4th European Workshop on Image Analysis for Multimedia Interactive Services (WIAMIS 2003)*, World Scientific Publishing, London, England, 9-11 April 2003, Pages 519-528

[104] Chandramouli K., Izquierdo E., “Image Classification using Self-Organising Feature Map and Particle Swarm Optimisation”, *7th International Workshop on Image Analysis for Multimedia Interactive Services (WIAMIS 2006)*. Incheon, Korea, 19-21 April 2006, Pages 313-316

[105] Izquierdo E., Ghanbari M., "Key Components for an Advanced Segmentation System", *IEEE Transactions on Multimedia*, Volume 4, Issue 1, Pages 97-113

[106] Zhang Q., Izquierdo E., “A Multi-Feature Optimization Approach to Object-Based Image Classification”, *5th International Conference Image and Video Retrieval (CIVR 2006)*. Tempe, Arizona, 13-15 July 2006, Pages 310—319

[107] Kliegr T., Chandramouli K., Nemrava J., Svatek V., Izquierdo E., “Combining Image Captions and Visual Analysis for Image Concept Classification”, *9th International Workshop on Multimedia Data Mining*”, Las Vegas, 2008

[108] Calic J., Izquierdo E., “A Multiresolution Technique for Video Indexing and Retrieval”, *2002 International Conference on Image Processing (ICIP 2002),*

Rochester, NY, September 22-25, 2002, Volume 1, Pages 952—955

[109] Ramzan N., Wan S., Izquierdo E., “Joint Source-Channel Coding for Wavelet-Based Scalable Video Transmission Using an Adaptive Turbo Code”, *EURASIP Journal on Image and Video Processing*, Volume 2007, Pages 1-12

[110] Zgaljic T., Sprljan N., Izquierdo E., “Bit-stream allocation methods for scalable video coding supporting wireless communications”, *Signal Processing: Image Communication*, Volume 22, Issue 3, Pages 298-316

[111] Calic J., Sav S., Izquierdo E., Marlow S., Murphy N., O'Connor N., "Temporal Video Segmentation For Real-Time Key Frame Extraction", *27th IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP 2002)*. Orlando, FL, 13-17 May 2002, Volume 4, Pages 3632-3635

[112] Ramos J., Guil N., González J., Zapata E., Izquierdo E., “Logotype detection to support semantic-based video annotation”, *Journal Signal Processing: Image Communication*, Volume 22, Issue 7-8, Pages 669-679

[113] Seneviratne L., Izquierdo E., “An Interactive Framework for Image Annotation through Gaming”, *11th ACM international conference on Multimedia Information Retrieval (MIR 2010).* Philadelphia, Pennsylvania, 29-31 March 2010, Pages 517-526

[114] Calic J., Izquierdo E., "Towards Real-Time Shot Detection in the MPEG Compressed Domain", *3rd Workshop on Image Analysis for Multimedia Interactive Services (WIAMIS 2001)*, Tampere, Finland, 16-17 May 2001, Pages 1-5

[115] Lee J., Simone. F., Ebrahimi T., Ramzan N., Izquierdo E., "Quality assessment of multidimensional video scalability", *IEEE Communications Magazine*, Volume 50, Issue 4, Pages 38-46

[116] Hanke M., Izquierdo E., März R., "On Asymptotics in Case of Linear Index-2 Differential-Algebraic Equations", *SIAM Journal on Numerical Analysis* 1998, Volume 35, Issue 4, Pages 1326-1346

[117] Wan S., Izquierdo E., “Rate-distortion optimized motion-compensated prediction for packet loss resilient video coding”, *Image Processing, IEEE Transactions on*, Volume 16, Issue 5, Pages 1327-1338

[118] Chandramouli K., Kliegr T., Nemrava J., Svatek V., Izquierdo E., “Query Refinement and User Relevance Feedback for Contextualized Image Retrieval”, *5th International Conference on Visual Information Engineering (VIE 2008).* Xi'an, China, 29 July - 1 August 2008, Pages 453—458

[119] Zhang Q., Izquierdo E., “Combining Low-Level Features for Semantic

Inference in Image Retrieval”, *Journal on Advances in Signal Processing*, 2007/4

[120] Izquierdo E., Guerra V., "An Ill-Posed Operator for Secure Image Authentication", *IEEE Transactions on Circuits and Systems for Video Technology*, Volume 13, Issue 8, Pages 842-852

[121] O'Connor N., Izquierdo E., et al, "Region and Object Segmentation Algorithms in the Qimera Segmentation Platform", *3rd International Workshop on Content-Based Multimedia Indexing (CBMI 2003)*, Rennes, France, 22-24 September 2003, Pages 1-8

[122] Mrak M., Sprljan N., Zgaljic T., Ramzan N., Wan S., Izquierdo E., "Performance evidence of software proposal for Wavelet Video Coding Exploration group", *Conference 76th MPEG Meeting*, 2006/4/7

[123] Izquierdo E., Kruse S., "Image Analysis for 3D Modeling, Rendering, and Virtual View Generation", *Elsevier Journal Computer Vision and Image Understanding*, 1998, Volume 71, Issue 2, Pages 231-253

[124] Sprljan N., Mrak M., Abhayaratne C., Izquierdo E., "A Scalable Coding Framework for Efficient Video Adaptation", *6th International Workshop on Image Analysis for Multimedia Interactive Services*, Switzerland, 2005, 13-15 April 2005, Pages 1-4

[125] Wilkins P., Izquierdo E., et al., "K-Space at TRECVid 2006", *4th TRECVID Workshop (TRECVID 2006).* Gaithersburg, Maryland, 13-14 November 2006

[126] Izquierdo E., Ohm J., "Image-based rendering and 3D modeling: a complete framework", *Signal Processing: Image Communication*, Volume 15, Issue 10, 2000

[127] Chandramouli K., Izquierdo E., "Image Classification using Chaotic Particle Swarm Optimization", *13th IEEE International Conference on Image Processing* (ICIP 2006), Atlanta, Georgia, 8-11 October 2006, Pages 3001-3004

[128] Ramzan N., Park H., Izquierdo E., "Video streaming over P2P networks: Challenges and opportunities", *Elsevier Journal Signal Processing: Image Communication*, Volume 27, Issue 5, Pages 401-411

[129] Lee J., Izquierdo E., et al., "Subjective evaluation of scalable video coding for content distribution", *18th ACM International Conference on Multimedia,* Italy, 2010

[130] Ramzan N., Izquierdo E., et al., "Peer-to-peer streaming of scalable video in future Internet applications", *IEEE Communications Magazine*, Vol 49, Issue

3, Pp 128-135

[131] Izquierdo E., "Stereo Image Analysis for Multi-viewpoint Telepresence Applications", *Elsevier Journal Signal Processing: Image Communication*, Volume 11, Issue 3

[132] T. Zgaljic, N. Ramzan, M. Akram, and E. Izquierdo, "Surveillance centric coding," *in the Proc. of IET 5th International Conference on Visual Engineering (VIE 08)*, pp. 835-839, July 2008.