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Chapter 3

Region of Interest Coding for Aerial Video Sequences Using Landscape Models

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Additional information is available at the end of the chapter

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1. Introduction

Video coding standards traditionally work in a block-based manner wherein every block basically receives the same treatment. For certain kinds of videos, such as movies for television, this might indeed be the sensible thing to do.

Depending on the use-case, though, it often is helpful to treat different areas of the image with different coding parameter sets or techniques even. In applications with focus on moving objects for example, a better resolution in the identified *Regions of Interest* (ROI) might help subsequent processing steps within a larger system. Existing video coding standards, such as MPEG-1,2,4 video or the ITU-T H.26x standards, only provide basic support for ROI coding. In e. g. MPEG-4 *Video Object Planes* (VOPs) and the separate encoding of these planes is included [1]. Unfortunately these features aren't used to the extent possible, even though several real-life applications could be enhanced by such systems. Surveillance and videoconferencing tasks for example can benefit from a special ROI coding approach, wherein objects are automatically selected by e. g. motion (surveillance), color [2] (videoconferencing), shape or have been selected manually beforehand. Those regions are then coded with a higher quality than the rest of the picture. Especially for narrow-band transmission channels as used e. g. in aerial surveillance, it is important to keep the amount of data to be transmitted for the conduct of the task at hand to a minimum. In ROI coding it is one possibility to reduce this amount of data by degrading the quality of the parts of the image that are not as useful to the application.

Instead of decreasing the image quality by coarser quantization, it is also possible to code non-ROI regions in skip-mode. In the case of a static camera this leads to loss of changes and local motion in those areas. In the case of a moving camera, the lost motion information might be predicted and compensated, when only linear global movement is taken into account.

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In general it is desirable to reconstruct high overall image quality at low data rates. For aerial video sequences, which often show predominantly static scenarios and only little changes in regions with moving objects, this can be done by allowing certain assumptions. One assumption to reduce data rates is the planarity of the landscape recorded. This simplification enables projecting the entire scene into one plane and rendering it as one big image when using *Global Motion Estimation/Compensation* (GME/GMC) at encoder side. At decoder side this opens the possibility of reconstructing the current image through outtakes of this so-called mosaic.

In existing GME/GMC approaches for aerial surveillance, GME is based on a projective transform [3]. To estimate the global motion of a scene, features have to be detected e. g. with a *Harris Corner Detector* [4] first. These features will be tracked from frame to frame e. g. with a KLT feature tracker to estimate their movements [5]. Finally, from all trajectories the global motion can be estimated based on an affine or projective transform. When transmitting the global motion parameters as additional side information, GMC can be applied at decoder side. With implementations employing GMC, data can be reduced dramatically for the example of aerial surveillance. However, to reconstruct moving objects at the decoder, additional data about those has to be transmitted. Consequently the achievable data rate reduction strongly depends on the number of moving objects in a scene. For scenes consisting of a static background and some moving objects, overall bit rate reductions of about 50 % can be easily achieved.

The true surface of most scenes however isn't flat at all. This leads to mapping errors during the GMC process due to the use of a projective transform. The effect will be more obvious for applications with low recording altitudes and scenes containing areas with large height differences, such as mountains or buildings. For aerial surveillance this leads to falsely detected moving objects and unnecessarily transmitted data when a difference-image-based moving object detector is used. For those cases a model that consists of several small planes, as it is realized through a mesh-based approach, takes into account the aforementioned differences. It prevents partial misregistration due to insufficient GMC of image content by better adapting to perceived local motion. The basic idea is that several feature points of an aerial video sequence are visible over consecutive frames and can therefore be tracked and triangulated into a mesh. All triangles of the mesh are motion compensated by using the motion vectors acquired during the tracking process. For motion compensation, only piecewise planarity is assumed, which is correct for small mesh patches.

In scenarios where interesting regions are identified by motion, the mesh approach yields several additional advantages and the rate of objects that are falsly classified as moving can be reduced by up to 90 % when compared to planar landscape model-based approaches [6].

This chapter gives a more real-life scenario oriented insight about the usage of different techniques for content adaptive video coding. The emphasis will lie on ROI coding and decoding for aerial sequences with a detailed view on:

- Assumption of planar earth surface: Projective transform-based global motion compensation and detection of moving objects
- Approximation of the earth surface using a mesh: Mesh-based global motion compensation and detection of moving objects

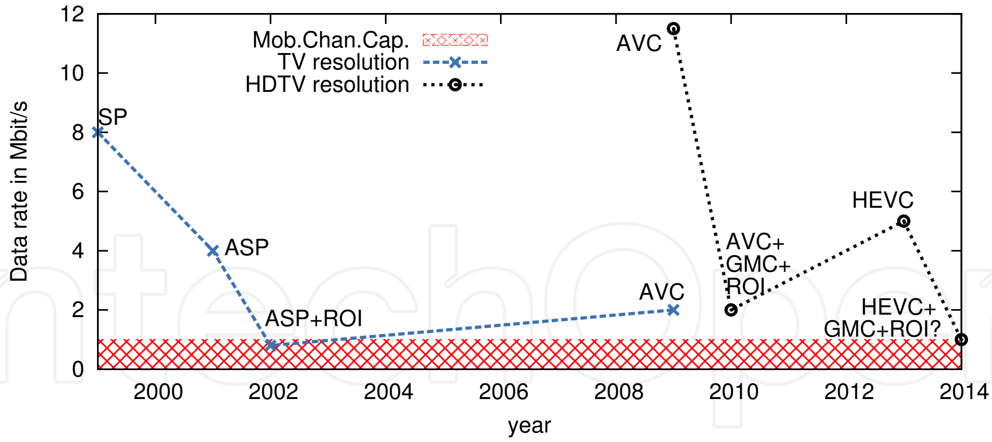

Figure 1. Data rates of different video codecs with and without *Region of Interest* (ROI) coding for aerial video sequences (*SP: MPEG-4 Simple Profile, ASP: MPEG-4 Advanced Simple Profile, AVC: Advanced Video Coding (MPEG-4 part 10/H.264), HEVC: High Efficiency Video Coding*).

1.1. Limits of standard-based coding

In its long tradition back to H.261 [7] from 1988, standardized digital video coding has reached amazing coding efficiency. *Advanced Video Coding* (AVC) is able to compress PCM (Pulse Code Modulation) coded data with a data rate of 166 Mbit/s for SDTV sequences (PAL resolution as used for DVB: 768 × 576 pel) to about 2–4 Mbit/s at a fairly high subjective quality. HDTV video with 1920 × 1080 pel can be compressed to about 10–20 Mbit/s depending on the video content. The latest standard, High Efficiency Video Coding (HEVC), needs only half the bitrate.

If mobile channels like WCDMA/UMTS and LTE are used for transmission, channel capacity is limited to a few Mbit/s. Especially when looking towards upcoming scenarios such as video transmission from *Unmanned Aerial Vehicles* (UAVs), there definitely is a need for a higher level of compression than offered by standardized coding techniques at the moment. Municipal agencies have recently started utilizing such UAVs for environmental and disaster area monitoring, so this use-case is especially important to work on. It has to be noted that in real-life scenarios other basic requirements, besides from what is known from television signal transmission, have to be met. While in the latter application the overall video quality has to be satisfying, in disaster area monitoring scenarios it is of highest priority to encode static infrastructure (background) and moving objects in highest quality, to be able to capture the scene adequately and react in an appropriate manner using all the knowledge about the situation at hand. However, with simple bit redistribution schemes, the quality of one part of the video image can only be increased at the cost of other image parts. The principle of *sprite coding* (see Section 3.2) was introduced with MPEG-4 to encode a static background separated from moving objects, so that the needed transmissions could be reduced to a minimum. GMC is a part of this technique, which is why it has to be mentioned here. In Figure 1 the encoding capabilities of recent video coding standards such as *MPEG-4 Simple Profile* (SP), *MPEG-4 Advanced Simple Profile* (ASP), AVC and HEVC are compared to versions with additional ROI coding for aerial landscape video sequences to give an impression of the amount of bitrate needed for transmission. Regions of interest in this case are moving objects and newly emerging areas in the picture hailing from the movement of the camera and the UAV, respectively. Since the amount of data of aerial video sequences really benefits from GMC, but MPEG-4 sprite coding was not inherited to AVC due to its insufficient coding performance for regular TV movies, an adaption of the concept for the current AVC codec is useful. To get an idea about where to integrate adaptations for Region of Interest coding, a basic understanding of hybrid video coders is necessary.

2. Hybrid video coding

Hybrid video coding was first introduced with H.261 in 1988 [7]. Since then, technical progress led to many improved versions of hybrid video coders, which were standardized later on as MPEG-1 [8], MPEG-2 [9], AVC [10] as well as its latest successor HEVC [11].

A basic block diagram of a hybrid video coder can be found in Figure 2. It basically consists of three main stages: first a motion estimation followed by a motion compensated (MC) prediction step is performed. Afterwards the prediction error is transformed and quantized, e. g. with a DCT-based integer transform, to decorrelate the spatial signal. Finally, entropy coding is the last important step in modern encoders. All processing is done in a block-wise manner, which means that all pixels are grouped into larger units and consequently treated as one. A group of such blocks (i. e. 16×16 pel for AVC) is commonly known as *macroblock*.

Two different types of video frames have to be distinguished, so called *intra frames* and *inter frames*. The former can be decoded independently from any other frame, while inter frames use temporal correlations between consecutive frames to predict the image content. In the following only inter frames will be further discussed, for most data reduction techniques use the correlations within those.

The purpose of the aforementioned motion estimation/compensation process is to estimate the position of the current block in an earlier coded (reference) picture and only encode a motion vector representing its displacement along with the transformed and quantized error of the motion prediction, the so called residual. Motion estimation is employed block-wise by comparing the current block to a list of reference blocks and calculating the difference. The best match is then assigned in a Rate-Distortion-Optimization process. For complexity reasons an often used measure for this comparison is *Sum of Absolute Differences* (SAD), albeit the logarithmic measure *Peak Signal-to-Noise Ratio* (PSNR) is commonly employed for quality evaluation of coded video sequences compared to their uncompressed original. Even though block-wise motion compensated prediction is very efficient in general

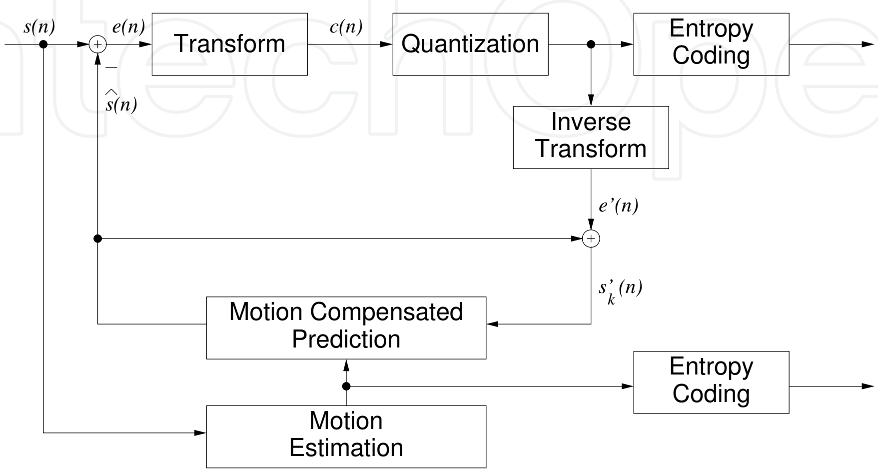

Figure 2. Simplified block diagram of a hybrid video coder.

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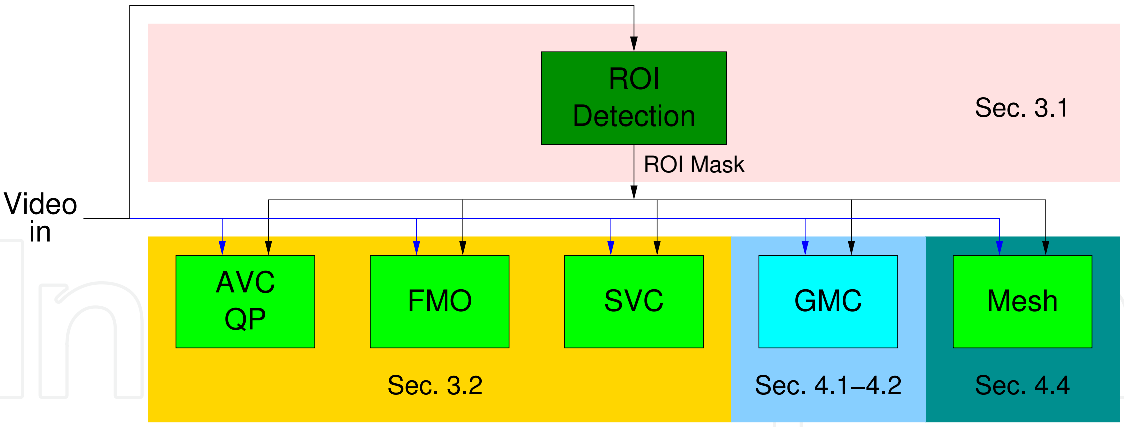

Figure 3. Schematic overview of ROI coding possibilities.

purpose coding, special scenarios can benefit from tailored solutions. In a number of real life use-cases, a differentiation of the scene in fore- and background can improve coding efficiency. Therefore, the background can be seen as a static scene (sprite image) which has to be reconstructed at decoder side. Afterwards, any moving objects can be mapped into the static background at appropriate positions. Systematic mapping errors caused by an inaccurate model assumption can emerge at block boundaries. For different moving objects with different directions contained in one macroblock, systematic problems occur, too. As a technique to code fore- and background separately, *sprite coding*, which will be explained in detail in Section 3.2, already existed in MPEG-4 and needed an adaption to AVC. By implementing this, benefits from the GMC-based coding concept from MPEG-4 sprite coding could be combined with the improved coding performance of AVC. Before being able to code fore- and background however, working solutions to separate the scene into these object layers have to be introduced.

3. Concept of ROI coding

A lot of research has been done in the field of segment- and object-based coding [12, 13]. Seeing that certain objects are indeed regions of interests, object-based coding can be considered ROI coding, which promises to grant more efficient coding of aerial video sequences (especially when employing landscape models). Therefore an overview of existing ROI coding techniques is a good starting point to introduce this concept, before additional assumptions for landscape model-based coding of aerial video sequences are presented.

The basic idea of *Region of Interest* (ROI) coding is to improve the quality of certain parts of the video. Therefore it first has to be clear, what the important or interesting regions of the image are, so that a fitting discriminatory factor to detect them can be determined. Afterwards, it has to be decided on how the ROI is treated in contrast to the rest of the image. The following sections are hence split according to these main issues:

1. How are ROIs detected?
2. How are ROIs encoded?

Figure 3 gives a schematic overview of the workflow including the different possibilities on how to encode ROIs with references to the appropriate sections of this chapter.

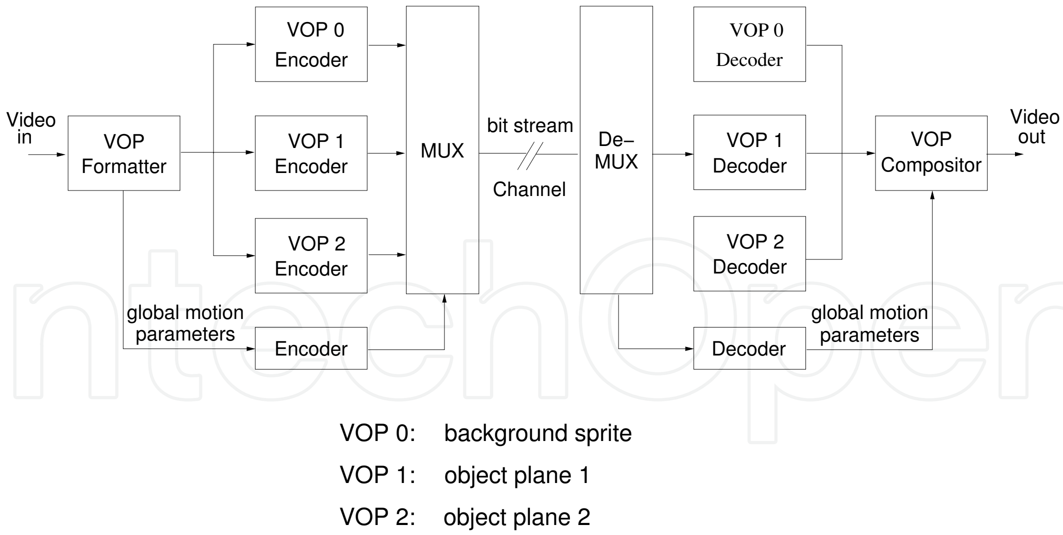

Figure 4. Simplified sprite-based MPEG4 coding.

3.1. ROI detection

The detection of ROIs can be arbitrarily realized, starting by the definition of fixed image positions (e. g. the center of the image) or skin color detection for teleconferencing systems [2, 14] to more sophisticated methods, which include several preprocessing steps, as described in the context of screen content coding [15], or the employment of a human attention model, even. A neural network-based approach is employed in [16] to determine foreground and background blocks. In [17] the *Sarnoff Visual Discrimination Model* is introduced to detect the *Just Noticeable Difference* (JND) by taking into account several parameters such as the distance from the observer to the image plane, the eccentricity of the image in the observer's visual field and the eye's point spread function. For coding aerial sequences regions of interest are often moving objects, such as cars and people. Generally, an easy way to find motion in pictures is to subtract the current from the preceding frame. If the background is relatively static, only the moving objects of the frame are left after this step. If an additional threshold or filter is added to decide whether the changed region is just noise or an actual object, the detection becomes even more accurate. The movement of the camera also causes newly emerging areas within a video sequence, which is another ROI in aerial video coding.

The suitable ROI detection method to *determine* a ROI depends on the application scenario.

3.2. ROI encoding

Different parts of one image may move into different directions, whereas motion vectors of objects with the same movement basically point in similar directions. These objects can be summarized as one *object plane*, in video coding referred to as *Video Object Plane* (VOP), as in MPEG-4 part 2 [18, 19]. VOPs can be of arbitrary shape and quality, thus different VOPs may be used for coding different ROIs (and the image background) independent of each other.

To efficiently encode composed scenes containing one background and one or more foreground planes, the concept of sprites was introduced [20], see Figure 4. The sprite represents the background either statically or dynamically. A static background sprite is a (off-line) preprocessed mosaic image, assembled from the background images of the whole

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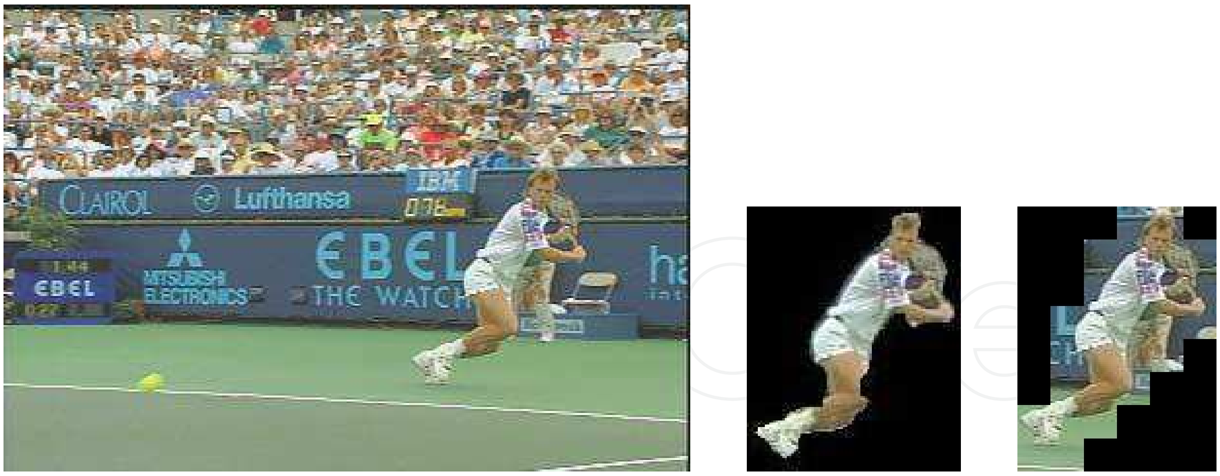
Figure 5. Example for ROI coding (white line emphasizes the *sharp* region).

sequence, which is generated at encoder side. It is transmitted as the first frame of a sequence and handled as a VOP. At decoder side, the background of the current frame is reconstructed from the sprite image. Global motion parameters are employed to determine the section to use from the sprite image. Afterwards, any other VOPs – containing foreground objects – can be mapped into the current frame. Basically, dynamic sprites are very similar, but they are able to change over time. The dynamic sprite is estimated during the encoding process utilizing global motion compensation (GMC). The current background image is composed out of an image generated from the warped sprite and the prediction error [21]. Any foreground objects are subsequently mapped into the image as it is done for static sprites. A detailed view into global motion estimation techniques will be given in Section 4.1.

Due to the mostly static landscapes in aerial video sequences, sprite coding can be quite useful. Thus, an adaption of sprite coding to AVC is of interest. To understand, how sprite-based-like coding can be introduced into a block-based coder, a closer look at certain AVC features is needed:

In AVC the basic independently decodeable part of one image is called *slice*. It consists of a group of macroblocks. The concept of *Flexible Macroblock Ordering* (FMO) initially was introduced into AVC for error resilience. The idea of FMOs is to order macroblocks in well defined different slices. Yet it also can be employed for ROI coding of different parts of the video image, since different slices can be coded in different qualities. Instead of setting the *Quantization Parameter* (QP) per slice, an alternative would be the direct QP variation on macroblock level according to the importance of an image region (low QP for important regions, higher QP for the rest). Since every QP change has to be signaled, this method is expensive in terms of bitrate [15]. A similarly simple, yet effective approach is to discard all residual data for non-ROI areas [22]. A basic assumption of this approach is, that the motion vectors have to match the real motion. Bitrate saved for residual data can be redistributed to improve ROI's quality. Recent developments also investigate the ROI coding with scalability features as e. g. proposed in [23].

All these approaches, which can be realized by a standard AVC coder, are based on the redistribution of bits: to encode ROIs in higher quality than in general video coding, more



(a) Complete frame 176 from *Stefan*. (b) Segmented foreground. (c) Block raster for coding.

Figure 6. Example of object segmentation for test sequence *Stefan* [24].

of the overall available bits are needed. These bits are saved at the cost of regions of lower importance whereby those are degraded in quality. An example of such a method is shown in Figure 5. A solution to overcome this issue for aerial video sequences is presented in Section 4.2.

Figure 6 illustrates the principle of *sprite coding*. Figure 6(a) shows one example frame from the test sequence *Stefan*, the *Region of Interest* segmentation was determined with the approach described in [24]. Therein a gradient-based approach with pixel-wise accuracy, which relies on an eight parameter perspective motion model to register two images, is employed. The error between the current image and the adjacent motion-compensated reference image is then calculated to produce a coarse segmentation of the frame. After binarization and morphological filtering, any moved (foreground) object remains in the error image (Figure 6(b)). Based on this detection method some details or even parts of any ROI can get lost. For instance, in Figure 6(b) parts of the hair and legs are missing. For encoding, this segmentation is expanded to fit the macroblock structure (Figure 6(c)). [3] uses similar techniques but considers low-complexity constraints for landscape-based aerial video sequence coding, which results directly in a block-based structure. The complete coding system is explained in detail in Section 4.2.

4. Video coding of aerial sequences using landscape models

This chapter focuses on video coding methods suitable for the coding of aerial sequences. Therefore the idea of ROI coding is extended by employing landscape models, which can save additional bit rate when compared to general video coding. Also one weakness of other existing ROI coding approaches, which is to improve certain areas while degrading other image parts in quality, will be overcome – basically by reassigning some more bits to *important regions* than to *non-important* ones.

A landscape model can be employed and used at en- and decoder side to estimate the movement of certain image parts. If the model is employed at both sides of the coding chain, only data not known from previous frames has to be transmitted. Image parts at

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the borders (*New Areas*) emerge in every frame and thus cannot be estimated from previous data. Moving objects like cars also cannot be covered by a landscape model due to their erratic movements. Handling these image parts as ROI is beneficial since existing ROI coding techniques can be applied and extended.

A generic block diagram for landscape model-based coding is depicted in Figure 7: a landscape model is applied to the video input stream, first. Although different landscape models will be discussed later on, further processing steps basically stay the same. Landscape extraction commonly begins with an estimation of the perceived global motion of the background of a scene. Details will be given in Section 4.1. The parameters of the landscape model necessary for decoding, have to be transmitted as side-information. In the case of a planar landscape model (GMC-based approach) no additional landscape model information beside the GMC mapping parameters are needed.

Simultaneously working *Region of Interest Detectors* are used for extracting different ROIs, such as *New Areas* (ROI-NA) or *Moving Objects* (ROI-MO), which will be prioritized in the following encoding. These two ROI detectors are specially tailored for aerial sequence coding and are included in the block diagram, but in principle any ROI detector, e. g. shape-based detectors for special buildings, can be added.

Before everything else, the benefits of general landscape model-based coding are introduced and the concept of model-based coding is depicted. The estimation of the perceived background motion is one essential part of it, hence a detailed explanation will be given first. Afterwards, a closer look into a practical coding system employing a GMC-based approach is taken, including detection of ROI, encoding and corresponding decoding. Finally, different landscape models are introduced and their special advantages and disadvantages are discussed.

4.1. Basic principles of background motion estimation

To estimate the global motion in a frame of a video sequence, it is necessary to know about the movement of the camera, which is fixed at an airplane or UAV. Given the accuracy limitations of GPS and drift problems of INS, features within the video sequence have to be used to get information about the motion [25].

At the common speed and flight height of an UAV, most of the content of one frame is available in the previous frame as well. This is illustrated in Figure 8.

To align two frames, there are several well-known possibilities to find significant features within each frame, e. g. feature-based approaches like SIFT [26] or corner detectors such as the *Harris Corner Detector* [4]. The latter was used in [3] and will be described in detail in the following.

The Harris Corner Detector is employed to detect corners within a frames. This detector is based on a two-dimensional gradient method which uses the luminance (gray values) within the picture. Features are defined as corners with high gradients in horizontal and vertical direction.

Afterwards, a correspondence analysis is performed, employing the KLT (Kanade-Lucas-Tomasi) feature tracker [5, 27]. Based on a local optical flow method the position of all features from frame $k-1$ can be aligned with those in the consecutive frame k.

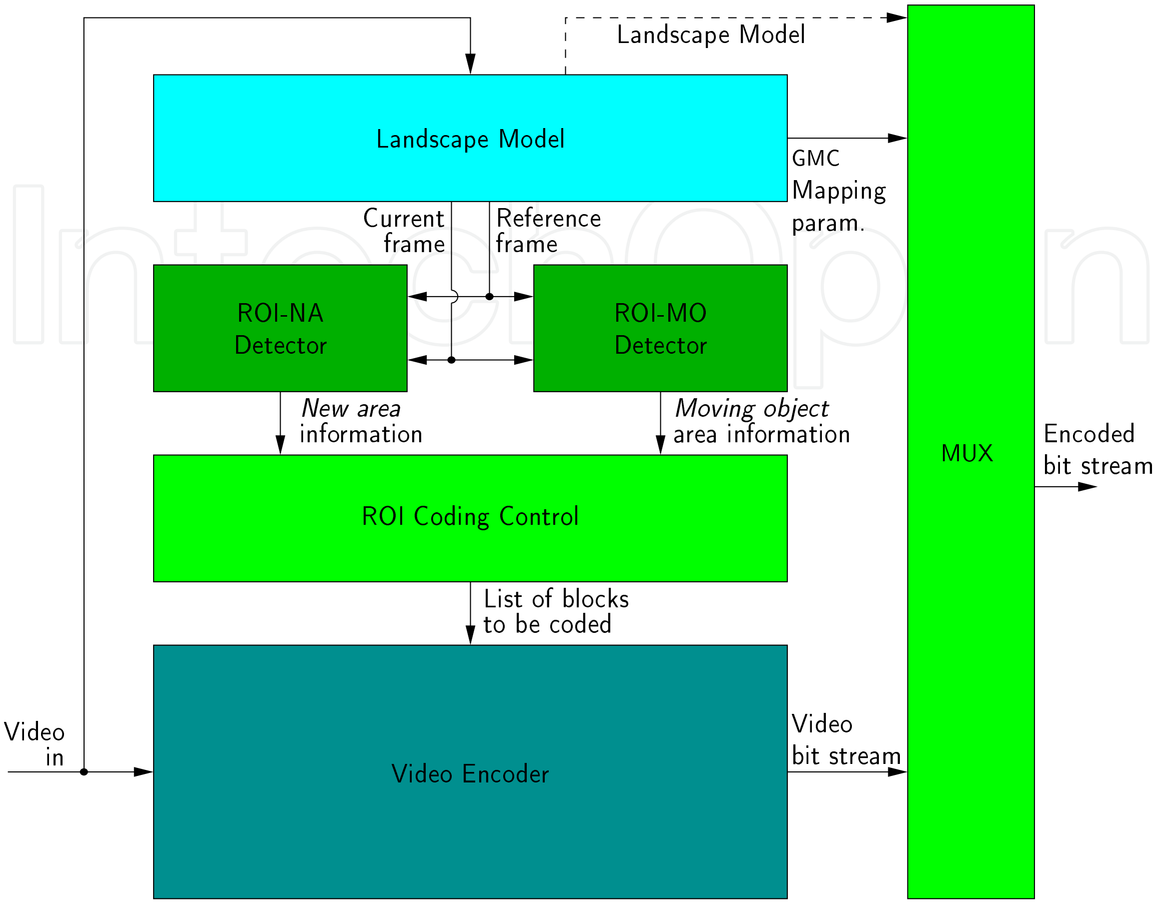

Figure 7. Block diagram of landscape model-based coding (dashed lines: optional, depending on the use-case). ROI-NA is a *Region of Interest detector for New Areas* (newly emerging areas within the picture, for example at the edge of one frame), whereas ROI-MO is a *Region of Interest detector for Moving Objects*, such as cars etc.

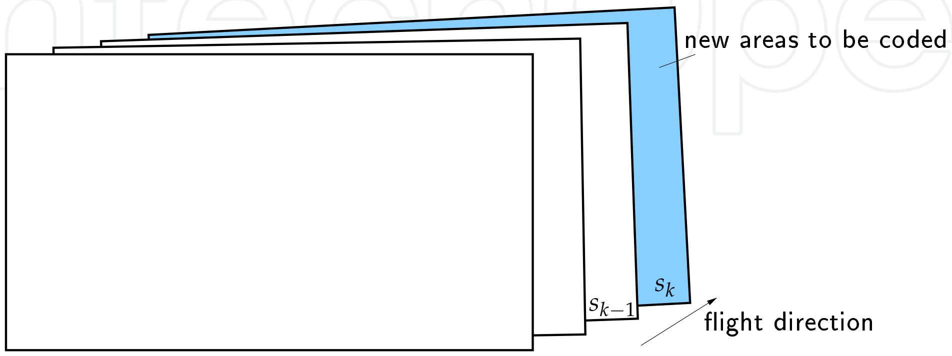

Figure 8. Detection of new areas by global motion compensation (GMC).

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Block-matching as described in [28] would be an alternative, wherein the blocks of one frame are searched within the next one and their positions are used to align the frames. Seeing that in aerial video material lots of blocks look similar speaks against using this approach, though.

4.2. Video coding using a planar landscape model

Since from big flight heights the movement at the ground seems approximately translational, using a homography leads to a simple landscape model for the decoder, i. e. the landscape is assumed to be planar.

First, a matching process of corners in two consecutive frames is performed as explained in Section 4.1. With the assumption of a planar ground, it is possible to transform one entire frame into another using 8 parameters (perspective or projective transform parameters), Equation (1).

$$a_k = (a_{1,k}, a_{2,k}, \ldots, a_{8,k})^T \tag{1}$$

The projection describes for every pel x and y in frame $k-1$ a matching pel $\vec{p} = (x, y)$ in the succeeding frame k with the mapping parameter set $\vec{a_k}$.

$$F(\vec{p}, \vec{a_k}) = \frac{a_{1,k} \cdot x + a_{2,k} \cdot y + a_{3,k}}{a_{7,k} \cdot x + a_{8,k} \cdot y + 1}, \frac{a_{4,k} \cdot x + a_{5,k} \cdot y + a_{6,k}}{a_{7,k} \cdot x + a_{8,k} \cdot y + 1} \tag{2}$$

The parameters a_3 and a_6 stand for a translational movement in direction of x and y, whereas parameters a_1, a_2, a_4 and a_5 describe shearing and rotation.

The point-correspondences are used to register two consecutive frames and thus estimate the global motion of the camera. Therefore, an overdetermined linear equation system is set up for an estimation of the 8 parameters of the projective transform. By minimizing the *Mean Squared Error* (MSE), *Random Sample Consensus* (RANSAC) [29] estimates the resulting projection parameters, which are then used to align two frames and are employed for global motion compensation.

Since with GMC only shifting of the background can be described, additional efforts for coding of the areas not contained in the first frame have to be made. To cope with these image parts, a *New Area ROI* detector (ROI-NA) is employed. Like this an adaption of MPEG-4 sprite coding can be introduced into AVC as explained in [24]. [3] presented a similar approach especially fitting for landscape model-based coding, taking into account the computational possibilities on board of UAVs. Whereas the former approach was designed as a general video coder, the latter utilizes the planarity assumption of aerial landscape video sequences for further data rate reduction employing a GMC-based coding (without transmission of an additional prediction error). This coding scheme will be summarized shortly in the following. Drawbacks as well as their possible solutions are discussed in Section 4.4.

The block diagram of the coding scheme equals Figure 7 when replacing the block *Landscape Model* with *Global Motion Estimation & Compensation*. In this case background representation is similar to MPEG-4 dynamic sprites but employs improved AVC coding instead of MPEG-4.

As mentioned above, the camera movement is estimated with global motion estimation in the beginning. This estitmate is then used for detecting areas at border of the current frame s_k, which were not already part of the previous frame s_{k-1}. They are considered to be a *new area* and marked as ROI. The decoder only needs information about the global motion to warp the content of the previous frame to the current position. The *new area* is padded to the appropriate position at decoder side and thus, a mosaic is generated (Section 4.2.1) from which the complete current frame can be cut-out. This global motion compensated approach not only prevents the retransmission of redundant image parts but also freezes the noise so that data rate can be saved. On the downside moving objects like cars are also frozen at the position of their first occurrence in the video sequence. To solve this a *Moving Object detector* is employed (ROI-MO): a difference picture between two frames is derived in order to detect moving objects and uncovered background. To reduce false detections because of noise, the average of a 3×3 block is calculated and values below a predefined threshold t_1 are considered to be noise. If a region is larger than a predefined minimum m, a moving object is registered and the corresponding macroblock is additionally marked as ROI for further processing. Any desired other detectors could be added to work in parallel, e. g. shape-based ROI detectors for industrial buildings or image-based ROI detectors for hospitals or the like.

The *ROI Coding Control* combines all macroblocks containing any ROI and forwards the information to a video encoder, i. e. an AVC encoder. Thus, any macroblock (of size 16×16 pel) containing at least one ROI is considered to be encoded in high quality, whereas other macroblocks are encoded in skip mode, i. e. not encoded at all.

4.2.1. Decoding and Visualization of a ROI Controlled Bitstream

Since AVC does not support global motion compensation which is employed to transform the background image to the appropriate position, a GMC capable AVC decoder, here referred to as *ROI decoder*, has to be used.

A block diagram of this ROI decoder is depicted in Figure 9.

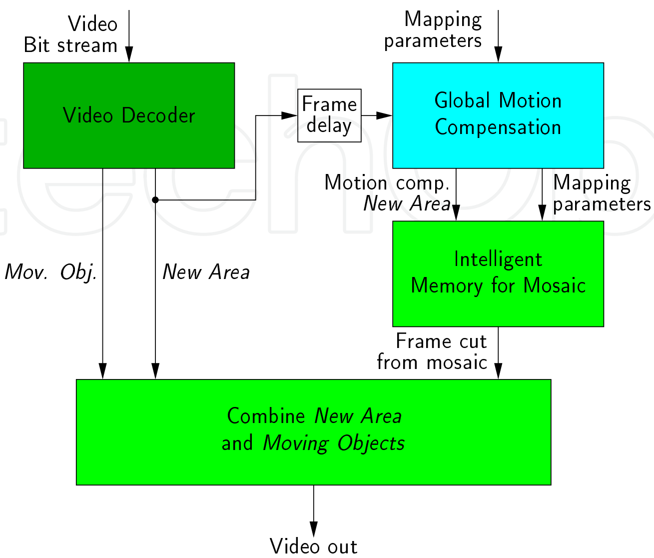


Figure 9. ROI decoder for combining GMC background with additional moving objects [3].

It basically shows that a video or a mosaic is created from the ROI-NA encoded data and afterwards ROI-MO blocks are inserted into the resulting video sequence or the mosaic at appropriate positions, respectively. This method is comparable to MPEG-4 sprite decoding and inserting other *objects*, e. g. from other VOPs. It is necessary to transmit the mapping parameters as side-information to the receiver in order to apply a GMC at the decoder. This can be done without modification of the standardized bit-stream when encapsulating the mapping parameters as SEI (*Supplemental Enhancement Information*) in the data stream. Information about the position of moving objects containing macroblocks has to be transmitted also.

(a) Generation of the decoded video sequence out of *new area*.

(b) Principle of creating a mosaic. Black lines between frames are for illustration purpose.

Figure 10. Principle of decoding a ROI coded video sequence (sequence from 500 m flight height).

To reconstruct the initially intra coded frame from the background sprite, here referred to as mosaic, *new area* macroblocks are registered employing the transmitted mapping parameters to their final position in the mosaic. Like this the mosaic is growing with every new area stripe. Figure 10(a) shows the principle of stitching stripes of ROI-NA together. Figure 10(b) gives a closer look at the growing-process of the mosaic: it shows some succeeding stripes of new area which are stitched to the reference frame. The black marker lines between the single frames only serve illustration purposes.

The receiver can generate a decoded video sequence from the created mosaic. Therefore, the position of the current frame in the mosaic back to the last reference frame has to be derived using global motion parameters. Using the global coordinates of the current background frame as well as the binary mask for the current frame indicating the positions of macroblocks with moving objects (and the uncovered background as well), an entire frame with high-resolution background and moving objects can be reconstructed.

A complete mosaic is shown in Figure 11, with the level of details shown in magnification. The mosaic has a size of 21104×4500 pel, which corresponds to about 30 seconds of flight in a flight height of 350 m.

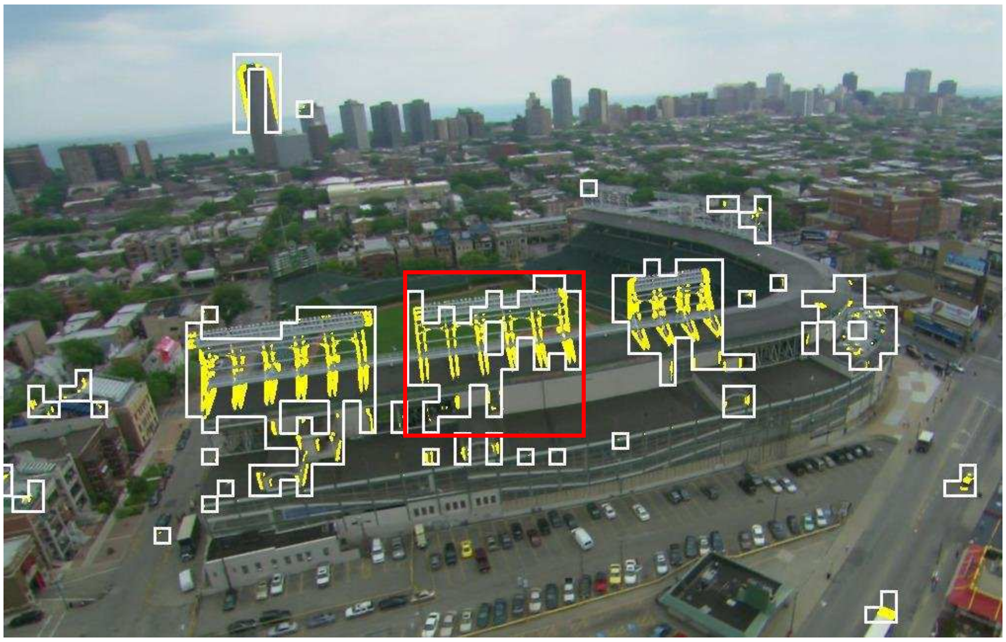
A decoded frame from the ROI decoder is shown in Figure 12, whereas white lines emphasize ROI [3].

Figure 11. Mosaic and magnification (sequence from 350 m flight height).

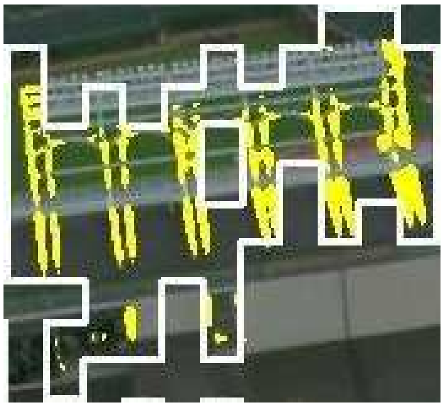
Figure 12. Output frame from the ROI coding system, white lines emphasize ROI.

4.2.2. Limits of Global Motion Compensation-based Techniques

The previous approach works quite well for planar landscapes, where the coder is able to project one frame into another by use of global motion compensation. However, as the real landscape often can't be approximated by the assumption of a planar ground, several model violations can occur in aerial video sequences. Especially if recorded from a lower altitude, where the perceived diverging speeds of different image areas become obvious, the simplifications made do not hold true. An illustration of such a case can be found in Figure 13: while global motion compensation can handle most of the similar housings



(a) Example frame including correctly classified moving objects and wrongly classified static structures.

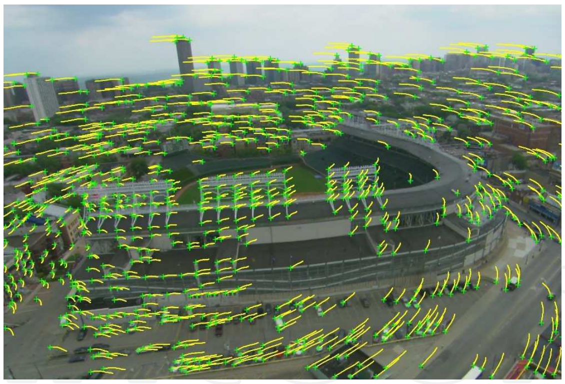


(b) Magnification of one static structure detected as moving.

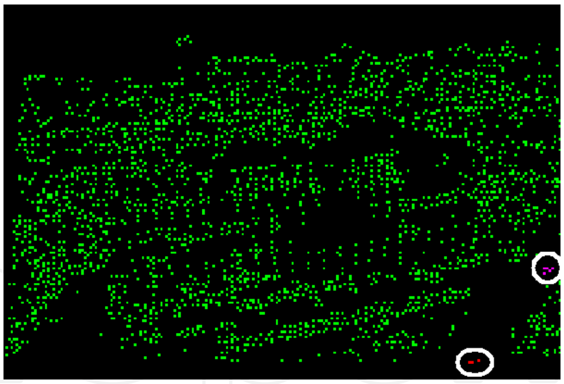
Figure 13. Limits of translatory block matching. Yellow: motion candidates, white rectangles: areas found to contain moving objects. Test sequence *Chicago*.

correctly, the high structures of the stadium in the foreground are closer to the camera and seem therefore to be moving faster when compared to their surroundings (Figure 13(b)). Their approximated motion doesn't fit the global estimate and as a consequence the structures are classified as moving objects.

Since the corresponding macroblocks are handled as ROI, many false positive macroblocks have to be encoded and transmitted, leading to an increased data rate. To keep the needed bandwidth constant when faced with the worst case scenario in which all parts of the scene were recognized as ROIs, the overall quality of the image would have to be degraded. To avoid false detections and keep the transmitted data to a minimum while preserving details, other ways to model the surface of the scene had to be explored.



(a) Selected features (green crosses) and their trajectories (yellow lines).



(b) Green regions are considered background, while other colors are candidates for moving objects.

Figure 14. Feature selection, tracking (left) and clustering results (right).

4.3. Video coding using piecewise approximation of the Earth surface by planes

The global motion approach which uses only a single plane to approximate the earth surface leads to mistakes as described in Section 4.2.2. Several objects in aerial video sequences, houses for example, however, can be described as piecewise planar and therefore an approximation using more than just one plane seems natural.

One way to realize this is by computation of oriented tangential planes for a number of significant points as described in [30] and using those planes as a local linear approximation of the surface. Another method is introduced by [31], where the production of a piecewise planar model from a continuous aerial video stream is done in three stages: First half-planes are computed, afterwards lines are grouped and completed based on those planes, followed by a plane delineation and verification process which concludes the model building process. In both cases motion would be estimated and compensated for each of the computed planes separately in the same way described for the single-plane approach. A more purpose-built approach is described by [32], in which planar surfaces are first detected and segmented within a point cloud to seek out buildings from an aerial sequence. Using this step as a priori information could help to compensate the perceived motion of the different image parts, when motion is estimated for all of those found surfaces instead of just the assumed base plane.

4.4. Video coding using a mesh-based approach

When approximating a more complex surface structure, a sophisticated piecewise approach with whole planes often ignores smaller faces and becomes computationally difficult. In the case of UAVs, this can easily lead to problems, as there is only so much computational capacity available on-board. An alternative is using the points and correspondences already available through the corner detector and tracking mechanism introduced earlier for recognizing the moving objects. In Figure 14(a) an example for selected features is shown by the green crosses. The yellow lines mark the trajectories on which those features have moved over time.

The tracked features lead to a motion vector field which has to be cleared of outliers that were caused by false tracking. This is done by testing the motion vectors against a motion model

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and remove vectors that are not supported by it. Typically the model is a projective transform which is then treated by RANSAC for a global solution. In the case of a mesh-based motion estimation however, there is no global solution without a full 3D model available, which means another approach has to be chosen here. In [33] a region growing approach based on vector field smoothness is described: the spatial distance (Equation (3)) and displacement difference (Equation (4)) of adjacent motion vectors are compared to an adaptive threshold.

$$\|\vec{r}_k(x,y) - \vec{n}_k(x,y)\| < t_{d1} \tag{3}$$

$$\|\vec{d}_{\vec{r}_k}(x,y) - \vec{d}_{\vec{n}_k}(x,y)\| < t_{d2} \tag{4}$$

$\vec{r}_k(x,y)$ describes the position of the classified motion vector nearest to the yet unclassified motion vector $\vec{n}_k(x,y)$ in frame k, while $\vec{d}_{\vec{r}_k}$ and $\vec{d}_{\vec{n}_k}$ are displacement vectors of the associated motion vectors pointing to their position in the preceding frame. Through this representation the movement of a region is only described by the motion vectors at its boundaries. In contrast to this, block-based methods use the motion vector from the center of the block as a representation. If they are smaller than the threshold, the vectors are clustered into one object, otherwise they remain unclassified. In case none of the unclassified motion vectors fulfills the requirements mentioned, a new object is created. Large regions, in which the same motion vector prevails, are treated as background, smaller regions are considered to be potentially moving objects. Objects containing less than a certain threshold are considered outliers and are consequently removed. In Figure 14(b) the results of the process are given.

At this point, only the motion of the selected feature points is known. With the help of these features in combination with the information about their movement, the displacement of each pel (x_{t_k}, y_{t_k}) of the image can be interpolated. The found feature points form a point cloud, which can be transformed into a mesh through a triangulation algorithm ([6]). Delaunay Triangulation, as described in [34], is one example to complete this task. This method basically tries to connect the points of a plane in such a manner, that no other point within the circumcircle of a triangle exists and the minimum angle of all triangles gets maximal at the same time. The mesh derived for the stadium example can be found in Figure 15.

The planar assumption is then used on all of the resulting patches, which is an accurate estimation if the patches are small. By defining this, it is now possible to model each patch by an affine transform, whose parameters A_{t_k}, B_{t_k} , C_{t_k}, D_{t_k}, E_{t_k} and F_{t_k} can be calculated using the feature points that span the triangle t_k in the current frame k, as well as their position $(x_{t_{k-1}}, y_{t_{k-1}})$ in the preceding one $(k-1)$. Each position of a pel within a triangle can be connected to its eqivalent coordinate in the old frame via

$$\begin{pmatrix} x_{t_{k-1}} \\ y_{t_{k-1}} \end{pmatrix} = \mathbf{T_{t_k}} \cdot \begin{pmatrix} x_{t_k} \\ y_{t_k} \end{pmatrix} + \mathbf{b_{t_k}} \tag{5}$$

wherein

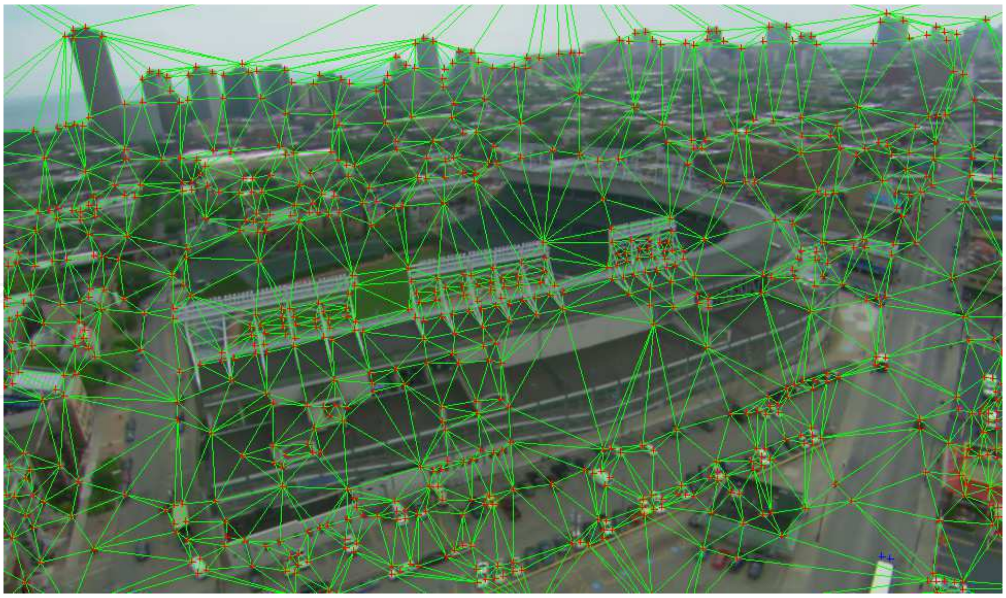


Figure 15. Triangulated mesh from selected features.

$$\mathbf{T_{t_k}} = \begin{bmatrix} A_{t_k} & B_{t_k} \\ C_{t_k} & D_{t_k} \end{bmatrix} \tag{6}$$

and

$$\mathbf{b_{t_k}} = \begin{pmatrix} E_{t_k} \\ F_{t_k} \end{pmatrix}. \tag{7}$$

To get the integer position pixel values, a final interpolation has to be performed. One example to get the needed accuracy is the usage of a two-stage filter as proposed in [6], where half-pel positions are calculated using a six tab Wiener filter and quarter-pel positions through bilinear filtering. Moving objects within the scene can be found by comparing the resulting motion compensated frame with the preceding one by e.g. sum of squared differences (SSD) and a subsequent low-pass filtering. Motion candidates are then determined by thresholding. When examining the result of the moving object detection hailing from the mesh-based method (Figure 16(a)) in contrast with the results from the earlier introduced single-plane approach (Figure 13), it becomes apparent that the number of falsely detected moving objects has reduced quite a lot. Only smaller regions of the high structures are still misclassified, the moving cars, which doesn't fit the model, however are correctly recognized. Overall the mesh-based approach leads to about 90 % less false positive detections.

Some moving objects however show only little motion from one frame to the next. If their surface is relatively uniform, as it is the case with car roofs for example, a comparison between adjacent frames would only show pieces of the object moving. This is because only changing parts of the image can be recognized by differencing. If a uniform area is moved though, chances are, that the new position overlaps with the old one, so that the difference in these parts equals zero. As a consequence, truly changing areas can be

(a) Mesh-based method. (b) Mesh-based method combined with mosaic approach.

Figure 16. Result of moving object detection. Yellow: motion candidates, white rectangles: areas found to contain moving objects.

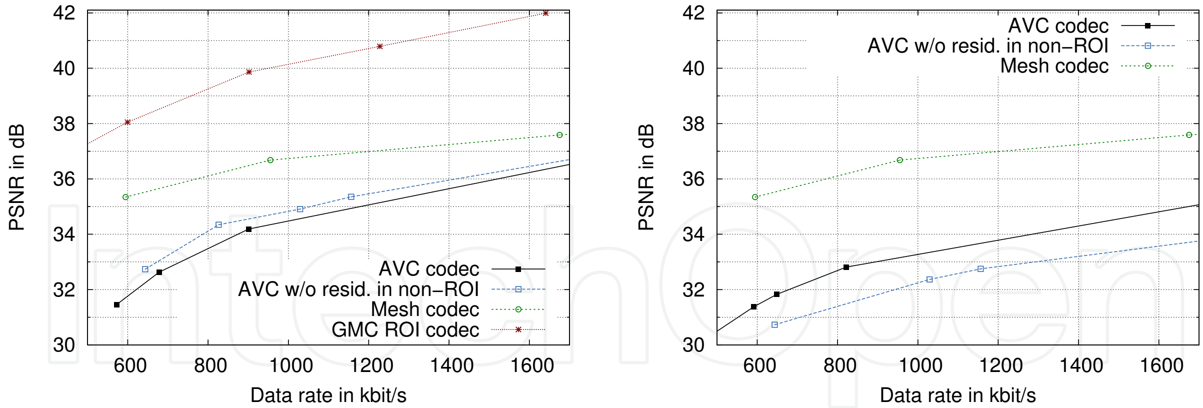
rather small, so that a filter threshold to get rid of false motion has to be quite low to not loose them. If more candidates in valid regions would be available, this threshold could be raised so that falsely detected moving regions could be discarded while the real moving objects are kept. By combining the mosaicking technique described in Section 4.2.1 with the mesh-based approach, this can be achieved. First a motion compensated reference picture from the preceding N frames is created by tracking the features and mapping them into the coordinate system of the current frame. With temporal distance as a weighting factor for the pixel values, the emerging image has the perspective of the current frame, only created from the previous frames. Moving object areas, which were already identified via differencing for preceding images or the aforementioned clustering step, are skipped during the mapping process, so that those areas are removed from the resulting reference image. If now the difference between the reference picture and the current image is calculated, the number of motion candidates increases, so that a higher noise filtering threshold can be used. This in turn leads to less misclassified regions and therefore less data that has to be transmitted. The result can be seen in Figure 16(b).

An option yet to be explored for coding purposes is the usage of a full 3D model instead of the comparatively simple mesh just described. To get the mesh as it is to the decoder side, a transmission of such a model would be necessary anyway, so its advantages could as well be used. 3D reconstruction from image sequences via depth estimation as described in [35] for example could be an alternative way to get such a model. Otherwise the mesh would be used as a base and turned into a 3D model by mapping texture from the video sequence onto it. Eventhough computationally expensive, the availability of such a model could provide several advantages, such as a better recognition of moving objects and a better understanding of the area for the following processing steps in a more elaborate system, wherein the coding and transmission of image sequences is only one step.

5. Results

In this section improvements in terms of coding efficiency for aerial video sequences employing the methods introduced in Section 4 will be evaluated.

Therefore, the coding efficiency of the AVC implementation *x264* [36] is compared to an encoder optimization which suppresses all residual data for non-ROI blocks, first. This

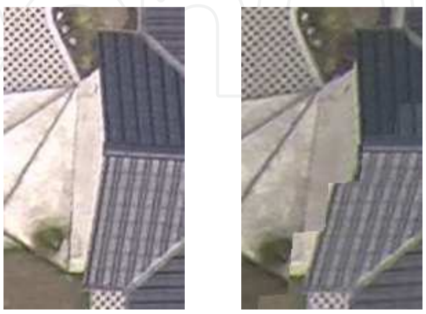


(a) RD plot for AVC-based systems, only for **ROI areas**. Mesh-based coder for comparison.

(b) RD plot for comparison of mesh coding system with AVC for the **entire frame**.

Figure 17. *Rate-distortion* (RD) diagrams for ROI-based coding systems and mesh coding system, each compared with AVC for very low bit rates.

(a) Reconstructed image from the mosaic.



(b) Detail of the original image.

(c) Detail of the GMC-based reconstr. image.

Figure 18. Mapping errors due to perspective distortions in the GMC-based coding system.

is expected to provide improved ROI quality at cost of non-ROI quality (Section 3.2). Additionally, the GMC-based approach is included in the comparison, which encodes all non-ROI in skip mode. Thus, apart from signalization, the entire data rate can be used to encode the ROIs (Section 4.2). Both encoders are controlled by the external *ROI Coding Control* (cf. Figure 7).

Bitstreams were created and decoded either with a standard video player or, for the GMC-based implementation, with a special *ROI decoder* (cf. Section 4.2.1). For quality comparison, the widely used image difference measure *Peak-Signal-to-Noise Ratio* (PSNR) can not be used for entire frames, because the output of the GMC-based ROI decoder is not pel-wise the same as the input – especially at object borders. To overcome this issue and to give a realistic performance analysis, only the PSNR of those macroblocks containing a ROI is considered for different coding systems (Figure 17(a)). Mapping errors caused by the projective transform of non-planar frames into a mosaic occur. Thus, any object not matching the planarity assumption causes shifted edges as depicted in Figure 18. The GMC-based approach however, was designed to buy a reduction of data rate for the price of such errors which are considered to be not as grave as they do only occur in small partitions of the frame. This can be seen in Figure 18(a).

For ROI, the encoder without residual coding performs slightly better for very low bit rates ($\leq$1500 kbit/s) than the (unmodified) AVC coder, as was expected. Since the residual isn't coded anymore, block artifacts become larger. They also serve as a base for motion vector derivation, which leads to an inhomogeneous motion vector field that is expensive to code with the AVC differential encoding. Thus, only little additional gain can be gathered by discarding residual data for non-ROI. The GMC-based approach outperforms both opponents by far in terms of PSNR at any bit rate, since significantly more bits are available to encode a very small image area (compared to the entire frame).

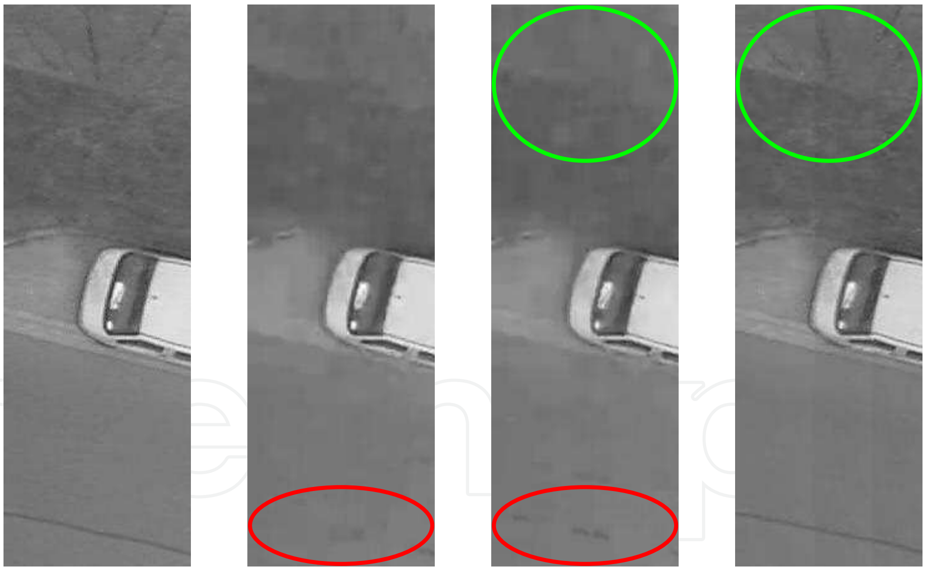
Informal subjective tests support these findings and demonstrate the achievable quality. The resulting image quality after ROI coding and decoding is shown once for a magnification of non-ROI (Figure 19) and once for ROI areas (Figure 20), respectively. For this comparison all coders were operated with the same parameters, except for the *Quality Parameter* (QP), which was adjusted for each coder to match an overall bit rate of about 1000 kbit/s.

Starting with the results of non-ROI (Figure 19), a magnified outtake of the original frame is shown as it was recorded by a camcorder mounted to a motorized glider in Figure 19(a). A magnified outtake of the coding result of the unmodified AVC coder is printed in Figure 19(b). The loss of details is obvious as can be seen e. g. in the tree and with the man holes on the right (light green/dark blue markers). Essentially, the modified AVC codec with disabled residual coding in non-ROIs delivers similar image degradations as the previous codec. But since no residual information was employed, additional block errors occur e. g. at the street light (Figure 19(c), red arrow). The *ROI controlled* GMC-based codec from Section 4.2) is able to provide the highest level of details for the entire frame (Figure 19(d)).

For ROI (Figure 20), the results look quite similar. Figure 20(a) again is the reference, representing the recorded quality. In contrast to the results for non-ROI, the standard AVC performs worst, because the available bitrate has to be spread over the entire frame (Figure 20(b)) leading to heavy loss of details (e. g. markers at the road, dark red ellipses), whereas the modified AVC codec (without residual coding for non-ROI) is able to preserve slightly more details at a relatively bad overall quality (Figure 20(c)). The *ROI controlled*

(a) Original. (b) AVC. (c) AVC w/o residual coding for non-ROI. (d) GMC-based ROI coding with *ROI Control*.

Figure 19. Quality visualization of **non-ROI areas** (outtakes) coded with 1000 kbit/s with different coders:
(a) Original
(b) AVC encoded and decoded
(c) Modified AVC: coding of non-ROI blocks without residual
(d) GMC-based ROI coding using *ROI Control* from Section 4.2



(a) Original. (b) AVC. (c) AVC w/o residual coding for non-ROI. (d) GMC-based ROI coding with *ROI Control*.

Figure 20. Quality visualization of **ROI areas**, here outtakes of *new area*, coded with 1000 kbit/s with different coders:
(a) Original
(b) AVC encoded and decoded
(c) Modified AVC: coding of non-ROI blocks without residual
(d) GMC-based ROI coding using *ROI Control* from Section 4.2

GMC	Mesh
One plane assumption	Multiple plane assumption
Mosaic creation of *planar* landscapes only	Mosaic containing 3D structures can be derived
Adapts to *global* motion	Adapts to *local* motion
Coarse MO-classification results	Refined classification results of MO
Very robust	Sensitive to unremoved outliers
Easy computation	More complex computation

Table 1. Differences between GMC-based and mesh-based approach.

GMC-based codec (Section 4.2) also performs best, since it is able to provide full spatial resolution over the entire frame (Figure 20(d), light green ellipses). For aerial video sequences in full HDTV resolution, with a GMC-based ROI coder, a bit rate of 0.8–2.5 Mbit/s at 1000 kbit/s (depending on the sequence) can be reached, which is much less than the bit rate needed for detail preserving regular AVC video coding.

In Section 4.4 mesh-based coding was presented as an alternative to the GMC approach. The main differences between those two are summarized in Table 1.

To make use of the mesh-based concept, motion vectors as well as residual data have to be transmitted from the encoder to the decoder. Seeing as the decoder already knows the preceding image when decoding the current one, a transmission of the feature points isn't necessary. Finding the mesh grid points at the decoder can be achieved by the same steps used at encoder-side, which were described in Section 4.1.

[37] showed, that for a QP of 30 nearly 20 % of the data rate of a video is needed for the coding of motion vectors. For mesh-based coding only a fourth of the data rate necessary for the transmission of motion information in AVC is needed. This is because only motion vectors for the grid points of the mesh have to be taken into account in contrast to sending motion vectors for every block. Another advantage is the omission of modes and the fact, that the signaling of how the image is divided for coding isn't necessary anymore. The residual is thought to be equally big for both methods.

In Figure 17(b) a comparison between mesh and AVC coding is performed. It has to be noted that in this plot the PSNR for the *entire frame* was used, in contrast to using the "quality" of ROIs only in Figure 17(a). It is obvious that the mesh is able to achieve a better overall PSNR at any bitrate when compared with the AVC coder. Though the bitrate of the GMC-based approach is still below this of the mesh for the same PSNR, the reconstructed mesh image doesn't show perspective distortions anymore. Overall, compared to AVC, a reduction of data by about 10 % when using the mesh-based approach seems realistic, taking into account the findings of [37].

6. Conclusion

In this chapter, an improvement of coding efficiency for standardized video coding is shown for user scenarios, in which a discrimination between *Regions of Interest* and background is reasonable. Aerial video sequences, as captured e. g. by an airplane or an *Unmanned Aerial*

Vehicle (UAV), were used as an example for cases, where smart usage of encoder control and optimization techniques can help to reduce data rate significantly.

Two properties of these video sequences were exploited: firstly, in common airborne video sequences most of the content of one frame was already present in one of the previous frames. But only the parts *not* previously known are regions of interest and are called *new area*. Secondly, a flat surface of the scene can often be assumed. Thus, a projective transform is sufficient to warp the background of the previous frame to the one of the current frame. To make use of both of those properties, AVC was extended by a *global motion compensation* to represent the background movement in the scene similar to *MPEG-4 sprite coding*.

This GMC-based approach, however, has two consequences: on the one hand noise remains frozen, on the other hand, moving objects contained in the recorded sequence are also frozen at the position of their first occurrence. To overcome this issue, a (difference-image-based) detector for *moving objects* is employed for this type of ROI. In the GMC-based coding scheme, only image parts containing new areas and/or moving objects are encoded, whereas remaining parts of the image are coded in skip mode. To enable appropriate reconstruction at decoder side, a special *ROI decoder* is necessary. The decoder basically creates a mosaic in a buffer, while the video sequence is generated by cutting single frames out of it. Finally, moving objects are pasted in the resulting video sequence. Additionally, a high-resolution mosaic is available to get an overview of the entire scene. At the cost of small perspective degradations in the decoded video, an overall subjectively very good quality can be reached, whereas a bitrate reduction from 8–15 Mbit/s to 0.8–2.5 Mbit/s can be realized.

For low flight heights or high structures on the ground (high buildings, trees etc.), many static background-elements are misclassified as moving objects because they violate the model-assumption of planarity. Hence, the data rate increases as more erroneous moving objects have to be transmitted.

To overcome this issue, employing a mesh can further improve the coding efficiency by creating small patches fitting local perspective distortions. In this approach, feature points are detected and a mesh is triangulated between them. Motion estimation is done for all of these patches and not just globally as it was done in GMC. Thus, perspective distortions can be avoided. Another bonus of the mesh-based approach is a lower misclassification rate of static objects as moving ones, which is quite helpful if those are considered to be ROIs. In the worst case, the coding efficiency for the GMC-based approach as well as for the mesh-based one is equal to this of AVC.

Summarizing, it can be noted that *Region of Interest* coding is able to reduce the data rate by 80–90 % without encumbering the surveillance task for particular application scenarios, as it is shown in this chapter using the example of aerial video coding based on landscape models.

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