Automatic exposure for panoramic systems in uncontrolled lighting conditions: a football stadium case study.

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ABSTRACT

One of the most common ways of capturing wide field-of-view scenes is by recording panoramic videos. Using an array of cameras with limited overlapping in the corresponding images, one can generate good panorama images. Using the panorama, several immersive display options can be explored. There is a two fold synchronization problem associated to such a system. One is the temporal synchronization, but this challenge can easily be handled by using a common triggering solution to control the shutters of the cameras. The other synchronization challenge is the automatic exposure synchronization which does not have a straight forward solution, especially in a wide area scenario where the light conditions are uncontrolled like in the case of an open, outdoor football stadium.

In this paper, we present the challenges and approaches for creating a completely automatic real-time panoramic capture system with a particular focus on the camera settings. One of the main challenges in building such a system is that there is not one common area of the pitch that is visible to all the cameras that can be used for metering the light in order to find appropriate camera parameters. One approach we tested is to use the green color of the field grass. Such an approach provided us with acceptable results only in limited light conditions.A second approach was devised where the overlapping areas between adjacent cameras are exploited, thus creating pairs of perfectly matched video streams. However, there still existed some disparity between different pairs. We finally developed an approach where the time between two temporal frames is exploited to communicate the exposures among the cameras where we achieve a perfectly synchronized array. An analysis of the system and some experimental results are presented in this paper. In summary, a pilot-camera approach running in auto-exposure mode and then distributing the used exposure values to the other cameras seems to give best visual results.

Keywords: Automatic exposure, Panoramic video systems, Real-time, Football

1. INTRODUCTION

Capturing panoramic textures has become a popular research area. Using multiple cameras instead of one wide-angle camera provides a higher resolution for large field-of-view textures where such panoramic images or frames again can be used in several different ways. For example, Mavlankar *et al.*[1] used a perspective panorama video as an intermediate representation and crop out regions of interest for an immersive presentation. Carr *et al.*[2] demonstrated a similar system, but using a robotic camera to follow the players in the game aesthetically. More traditional uses include image viewers[3] that can provide detailed presence.

In this respect, several researchers have focused on stitching multiple images together to produce one seamless panorama. However, often they are more focused on aligning the images properly than controlling the capture mechanism. The stitching and alignment tutorial by Szeliski[4] provides an overview of the state-of-the art approaches in stitching. For example, Agarwala *et al.*[5] introduced an interesting approach for stitching panoramic video textures from a single panning video camera and automatic alignment. One later example is given by Brown *et al.*[6] who proposed a fully automatic approach for aligning and stitching panoramic images using SIFT features. All these approaches employ computationally expensive global optimization schemes to estimate and achieve the perfect alignment in any sort of camera movements. But, when the motivation of the system is to record a panoramic video, it is more convenient to have a rigid camera array. In such a configuration, the cameras can be manually calibrated well in advance, eliminating the need for such complicated algorithms. Moreover, when

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a real-time constraint is present, one cannot afford to use the computing resources to align every single frame of the panoramic video.

One of the major things that contribute to the visual quality of a panorama is the color difference between multiple images. Such differences can stem from several factors like inter-camera differences and the amount of light in each image. The ideal case would be to use the same physical camera and the same exposure settings through out the panorama capture. However, when capturing panoramic videos, it is only possible to use the same physical camera if one uses a reflective sphere, but this approach can result in reduced resolution. When an array of multiple cameras produces images that are not captured using similar exposure parameters, there will be visual differences between adjacent camera images. Often this is overcome by color correction approaches, which handle the images post-recording. Xu *et al.*[7] provide a good performance evaluation of several color correction approaches. Xiong *et al.*[8] proposed an elegant color correction approach which applies a color transform that is optimized over all the images to minimize drastic changes per image. Ibrahim *et al.*[9] provide an interesting approach for selecting the reference for color correction.

Nevertheless, even though color correction approaches can provide good results in panorama images, they can introduce artifacts like flicker and unnatural colors when it comes to the stitched videos. This problem can be handled even before the recording of the videos in a constrained space like a sports stadium. In this paper, we therefore propose a novel approach to record panorama videos that do not require any additional color correction step. We developed and implemented several approaches using industrial cameras to record videos of a football stadium. The best results come from an approach where the time between two temporal frames is exploited to communicate the exposure setting from a pilot camera among all the other cameras. An in-depth analysis of our system and the experimental results are presented in this paper.

The rest of the paper is organized as follows: Section 2 provides a brief description of the real-world scenario that we explored and some of the challenges involved. A detailed description of the panorama capture system and various approaches for controlling the exposure are presented in section 3, and some preliminary results are shown in section 4. In section 5, we provide some discussions and conclude the paper in section 6.

2. SCENARIO

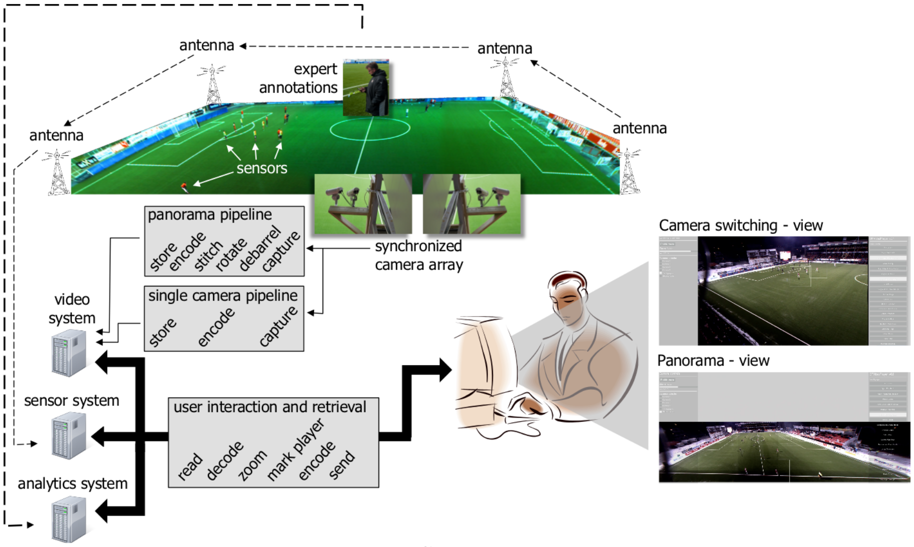
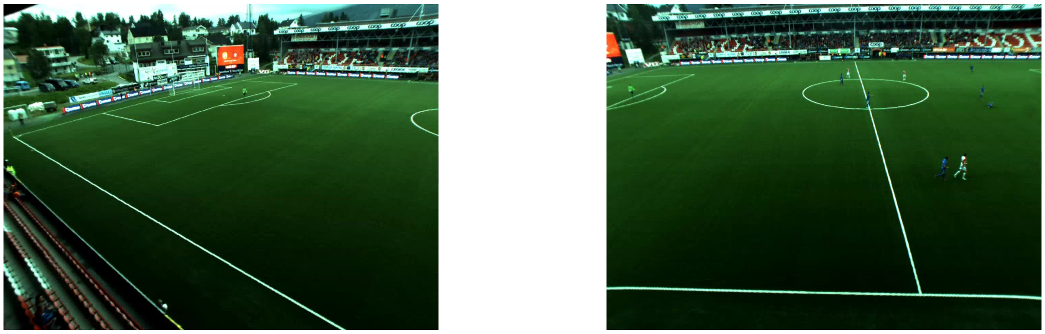


Figure 1: System overview

We have a prototype system[10–12] for capturing panorama videos that is used to display events and videos in an immersive fashion in a football (soccer) analysis scenario. In addition to a sensor subsystem and an event annotation subsystem, we have a panorama video subsystem that consists of four cameras (recently upgraded to five). The whole system is installed at Alfheim stadium in Tromsø, North of Norway. Figure 1 shows an overview of the entire system.

The video subsystem performs two major tasks: Video capture and panorama stitching. The real-time stitching pipeline is described in detail by Tennøe *et al.*[13] The video capture system is responsible for the synchronization of frames, driving the cameras and tranfering of video data from the cameras to the processing system. We use industrial cameras (*acA 1300-30gc*) manufactured by Basler supporting a frame rate upto 30 frames per second and a resolution of 1280 × 960. The lenses are of 3.5mm and are manufactured by Kowa. Moreover, the cameras are controlled by individual threads which also collect the video data from the cameras, and the time (shutter) synchronization is achieved by building a custom trigger box*. Furthermore, the cameras are placed on one side of the football stadium at an elevation of 10 m from the field. The cameras cover the entire field with sufficient overlap between adjacent cameras, i.e., figure 2 shows the four views captured from the four cameras. It can be observed that there is significant overlap between the cameras that can be used for stitching.



(a) Camera 1

(b) Camera2

(c) Camera 3

(d) Camera 4

Figure 2: Views from each camera for a perfectly synchronized exposure

There are several challenges in designing and implementing such a panorama video system. In the context of the camera setting challenges addressed in this paper, the main problem is that its an outdoor stadium where the light is not controlled. Furthermore, the cameras are looking at the entire field, but there is no place on the entire field that can be used for metering for all the cameras. One general assumption that can be made is that the green grass can be used for metering. However, grass has a directional reflectivity which means that the light seen from different angles can vary quite a bit. The lighting also changes during the game due to frequently changing weather conditions and movement of the sun. Thus, configuring the cameras with the appropriate settings is a big challenge.

In the current scenario using several cameras to generate a panorama video, the aperture must be kept constant to avoid changing depth of field. This means that the only parameters that one can (or should) control are the exposure time and the gain. However,we do not have full freedom in controlling both these parameters. The electric gain introduces noise in the system, so the highest image quality is achieved when the gain is as low as possible. The exposure time has an upper limit both because it can cause motion blur during the game

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*Hardware design and software open sourced at `https://bitbucket.org/mpg_code/micro-trigger-box` and also because there is a hard limit set by the frame rate. So a priority based estimation must be used which changes the exposure time until it reaches the threshold and then modify the gain if the exposure needs more compensation.

Furthermore, due to the difficult lighting conditions, it is not sufficient to set the exposure parameters before the game manually. You cannot select a small patch on the grass for metering because players can pass through it and affect the measurement. To address this challenge, we next present and evaluate three approaches for automatically synchronizing the exposure to the cameras.

3. AUTOMATIC EXPOSURE APPROACHES

A main challenge in a video system generating panorama video from a camera array is to handle an array-wide automatic camera exposure. In this respect, we use the internal metering mechanism to estimate the exposure parameters. The region of interest that is considered for metering can be modified for each camera. We make use of this functionality in the three exposure setting approaches described here.

3.1 Independent metering

This is the most trivial approach for an automatic exposure system. In this approach, we use the fact that the football field provides a nice surface for metering. Since our target space is confined to a football stadium, we can use the green surface of the football field to evaluate the exposure parameters. Initially, a manual selection of metering region is selected per camera, and the cameras are driven to make an automatic exposure. The internal mechanism decides on a specific exposure value and gain to achieve a pre-defined gray value for the average of all the pixels from the metering region. An upper limit can be imposed on the exposure time to force the camera to use a higher gain in case of low light, instead of increasing the exposure time.

3.2 Pairs metering

This approach can be considered as a special case of the Independent metering presented above. In this approach, we exploit the fact that the adjacent cameras have an overlapping region. Therefore, camera pairs are formed which have defined regions of interest that points to the same physical space on the field. The selection of the region of interests are performed manually to minimize the effect from the players or other elements on the field. Then the cameras are run independently to perform automatic exposure but metering based on the selected patches that are overlapped. Since the camera pairs are physically close to each other, the directional reflections will have minimum effect on the exposure. But the first camera pair and the second pair are at a distance of 4m from each other.

3.3 Pilot camera approach

In this approach, there is a pilot camera which functions in auto-exposure mode where the pilot camera's exposure parameters are transfered to the other cameras. Here, let the m cameras be named C_j where $j \in [1, m]$, and C_p be the pilot camera. Let e_j and g_j be the exposure time and gain of camera C_j.

Then, given e_p and g_p from the pilot camera which operates in auto exposure mode, we need to compute e_j and g_j for the rest of the cameras. Furthermore, let T_j be the transformation function from the pilot camera to camera C_j. Then,

$$(e_j, g_j) = T_j(e_p, g_p). \tag{1}$$

The transformation function depends on the relation of camera C_j to the camera C_p. In an ideal situation where the cameras are all identical and have exactly the same settings for aperture and focal length, T_j will be identity function. However, this is not the general case because physically different cameras do not have identical spectral response curves thus leading to difference in exposures. Other factors that can cause differences are the imperfections in adjustment of the aperture size. Generally, the cameras need a prior calibration step to estimate the corresponding transformation functions.

The general processing flow is presented in figure 3. There are two types of threads that are running concurrently, i.e., one is for controlling and communicating with the pilot camera, and the other type is for the rest of

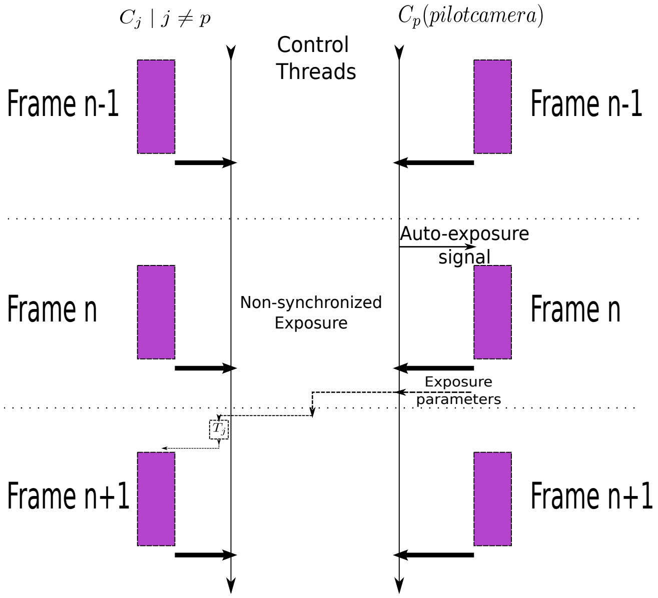

Figure 3: Pilot camera approach

the cameras. All these threads have a synchronization barrier at the end of every frame. Periodically, the pilot camera thread sends a trigger to the pilot camera to make an auto-exposure signal and lock the exposure until the next trigger. In figure 3, this can be seen before acquisition of frame n. After the exposure, the exposure parameters e_p and g_p are transferred back to the controlling machine. These parameters are communicated to other threads which in turn transfer these individually to the other cameras applying the appropriate transformation.

It can be observed that the frames n of the other cameras are not synchronized in exposure with the pilot camera, but we have observed empirically that the light conditions change slowly over the period of the exposure updating trigger. One more important detail is that the frame rate sets a hard upper bound on the execution time and thus on exposure time too. The formulation of transformation function cannot guarantee this because one of the transformations can demand a higher exposure time than the upper limit. Especially, when the cameras have lower response to light than the pilot camera. This problem can be handled in two ways. One way is to embed this property into the transformation function by placing an upper bound. The other way is to handle it in the driver before setting the camera parameters. We found that the driver solution is safer and more robust to further changes in the algorithm.

4. EXPERIMENTS

We will show stitched panorama to demonstrate the visual effect easily. The panorama images presented here for each approach are to emphasize the different lighting conditions. The first sections present images recorded during different lighting conditions that emphasize the differences in the approaches. Section4.4 shows the result using the three approaches from the same match in the same lighting condition for a fair comparison.

4.1 Independent metering

Figure 4: Panorama generated using Independent metering approach in a snow condition.

Figure 4 shows one of the light conditions, where there is snow around the football field. The metering system has to compensate for this and make good choice of exposure values. The influence of snow can be observed in the independent metering approach. But the problem is that the exposures are different in each of the cameras, even though each of the images are well exposed, they are not synchronized.

4.2 Pairs metering

Figure 5: Panorama generated using Pairs metering approach under a partially cloudy sky.

In this approach a clear difference can be seen at the center of the field. But the left two and the right two parts of the panorama are perfectly seamless. Figure 5 shows one of the possible light conditions. It is when the sky is partially cloudy.

4.3 Pilot camera approach

Figure 6: Panorama generated using the pilot camera approach under an overcast sky.

Figure 6 shows another lighting condition where there is an overcast sky. But it can be observed from the figure that the exposure in the whole of the panorama is perfectly synchronized. There is no specific color-correction applied when stitching the panorama.

4.4 Comparison

In this section we present frames using the three approaches during similar time period for comparison. This is also one of the hardest light conditions to handle, when there is direct sun on the stadium and the stands cast a shadow. In such a case, the camera's dynamic range is insufficient to capture variation in the light and dark areas. It can be observed that the first and second approach provide rather similar result where as the third approach provides a seamless result. This similarity between the first two approaches has been observed in different light conditions as well.

Figure 7: Generated panorama recorded using Independent metering approach

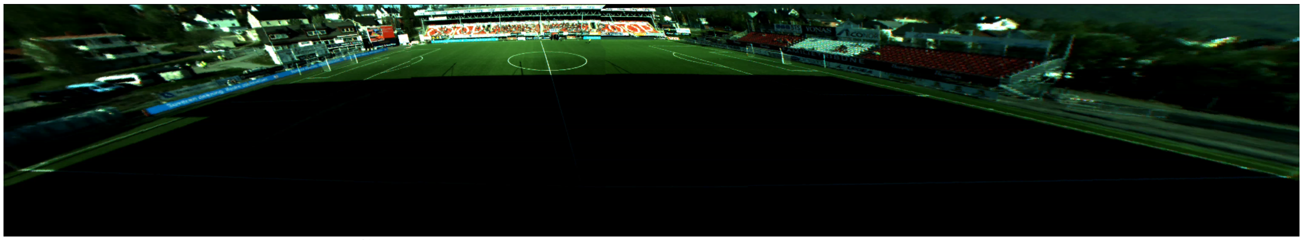

Figure 8: Generated panorama recorded using Pairs metering approach

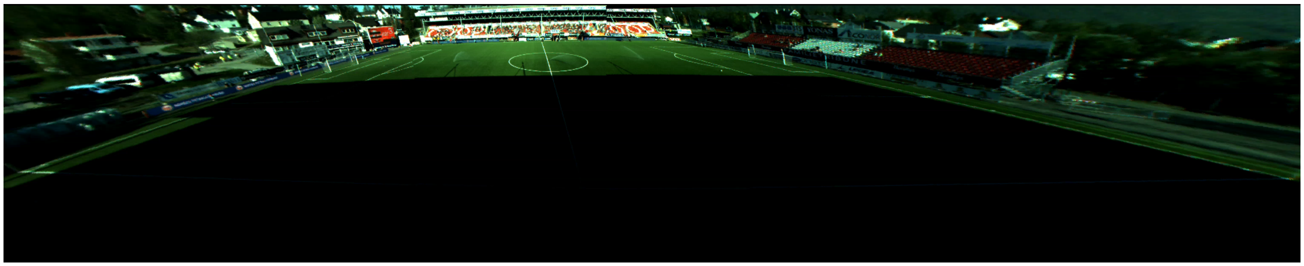

Figure 9: Generated panorama recorded using Pilot camera approach

5. DISCUSSION

The approaches perform varyingly depending on the lighting conditions. In several situations the first two approaches provide similar results owing to the large overlap between adjacent pairs. The third approach always provides seamless panoramic video. But all three approaches fail to provide a visually pleasing output in the case of high contrast. This is more of a lack in the dynamic range of the cameras than the shortcoming of the approach itself.

Figure 10: Artifacts observed due to color correction occassionally

We initially employed a color correction component in our stitching pipeline. As mentioned earlier, applying color correction to every frame that is estimated according to the current frames introduces unwanted artifacts. Figure 10 shows one such effect. Here it can be seen that the color correction is trying to achieve a seamless field but instead introduces an unnatural green in the whole of the right part of the panorama. This can be avoided using only correction in the luminance component, but this cannot provide a seamless scene in the target areas[on the field].

The system can be easily extended to accommodate other interesting functionalities like capturing of high dynamic range videos by making multiple exposures. The pilot camera approach can be configured such that two kinds of exposures are performed every alternating frame. One exposure to capture the details in the highlights region and the other to capture the details in shadow region. Then the video can be formed by fusing these two exposures appropriately.

6. CONCLUSION

In this paper, we present an elegant approach for controlling the exposure of a multi-camera array such that we get a uniform exposure across the captured panorama. This approach can be scaled to several cameras. We also presented results from the experiments performed from a real setup in a football stadium. An outdoor stadium provided us with plenty of challenges, where the light is essentially uncontrolled. We also discuss the applications of panorama to show the motivation for an automated exposure control system.

Later, we provided some examples on how this system can be extended to handle more challenging conditions. The limited dynamic range of the camera need not effect the overall dynamic range of the captured panorama. There are several methods that exist for doing this for an individual camera or one static panoramic image. We provide a way to extend it to panoramic videos.

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