A MODULAR HIGH-RESOLUTION MULTI-PROJECTION SYSTEM

Christian Weissig, Ingo Feldmann, Joachim Schüssler, Ulrich Höfker, Peter Eisert, Peter Kauff

Fraunhofer-Institute for Telecommunications
Heinrich-Hertz-Institute
Einsteinufer 37, 10587 Berlin

ABSTRACT

This paper presents a new scalable and modular high-resolution multi-projection system, which is able to support any projector type and configuration. The projected images are blended at the image borders and can be adapted photometrically and geometrically to arbitrary screen geometries. To satisfy the requirements of high quality real-time video processing a special hardware, the so-called CineCard, was developed. It solves the problem of high-resolution video synchronization, decoding, photometric screen adaptation and blending by using dedicated hardware. It works as a PCI plug-in card for conventional PCs and is able to control up to four separate projectors. Multiple CineCards can be synchronized externally. Thus, the system is scalable in terms of number of projectors and is able to serve a given multi-projection configuration by a limited number of PC's.

1. INRTODUCTION

Being present at a live event is undeniably one of the most exciting ways to experience entertainment. It is therefore the mission of immersive media to bring this experience to those users who are not able to participate. The ability to evoke a state of 'being there' or 'being immersed' will therefore not remain the domain of flight simulators, CAVE systems, VR applications, theme parks or IMAX theatres. It will migrate towards telecommunication and will enhance quality of business, entertainment and daily life in general.

High-resolution multi-projection systems, which are able to reproduce large-scale events in life size and with highest amount of realism, represent main key components for the successful introduction of immersive media. Even the next generation of digital high-end projectors will not be able to meet all requirements of immersive video applications such as dome projections, large projection walls or 360° cylinder projections. Therefore a couple of -multi-projection systems have been proposed for this purpose in the past [1, 2, 3]. Most of them use a

Figure 1: High-Resolution cylindrical multi-projection system, **left:** Panorama projection on a cylindrical shaped screen**, right:** Projector array

cluster of synchronized PC's where each PC serves one projector only. Obviously, such an approach results in a tremendous number of PC's with all unavoidable disadvantages like an increased failure probability, a high amount of system complexity or high costs for installation, adjustment, and maintenance. To overcome these drawbacks, the Fraunhofer Heinrich-Hertz-Institute (FhG/HHI) has developed a PCI board that supports a wide range of immersive multi-projection applications with with highest video quality in a modular and flexible PC architecture. Due to this technique it becomes feasible to drive up to six HD projectors by one PC and an almost unlimited number of projectors in any arbitrary configuration by a cluster of a few synchronized PC's. Fig. 1 shows an example for the application of the proposed system at a cylindrical multi-projection screen.

2. SYSTEM OVERVIEW

The main idea of immersive multi-projection is to stitch a given number of video frames to one image of ultra-high definition that can be presented either at a large planar screen (projection wall) or at screens with a curved surface (360° panoramas or spherical domes). To avoid visible art … vel

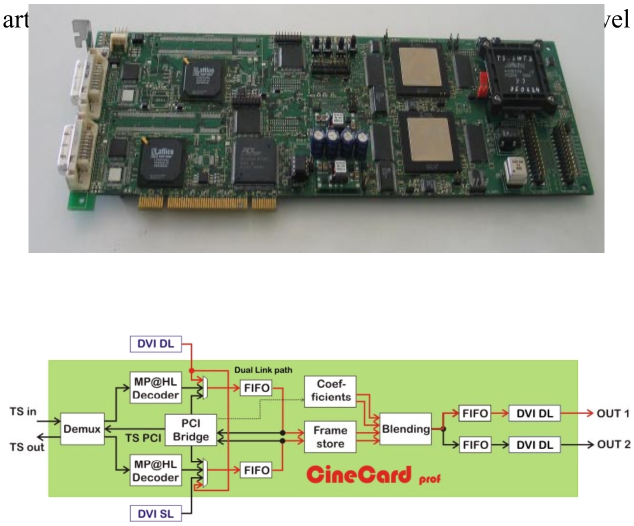

Figure 2: Developed *CineCard* hardware, **top:** PCI plugin-board, **bottom:** system design

adjustments and geometric calibration have to provide seamless transitions between the single video frames. Furthermore, to achieve an appropriate motion portrayal, all video frames have to be well-synchronized. Finally, efficient video compression techniques are required to handle the extremely large amount of video data.

For this purpose FhG/HHI has developed a modular and PC-based concept for immersive multi-projection systems (see fig. 2). The core of this system approach is a PCI board that is able to serve either four XGA or two HDTV (SXGA, SGA+) projectors at once. This CineCard contains dedicated hardware for real-time processing of required colormetric corrections, mainly alpha blending and black level adjustment. Input streams are allowed to be compressed or uncompressed. Uncompressed videos are grabbed from a Dual-Link DVI connector (either two SXGA streams with 8 bit/pixel or one stream with XGA resolution but 16 bits/pixel), whereas compressed videos are taken from a MPEG-2 transport stream (either loaded from local disk via PCI bus or streamed from a LVDS SPI input). In the later case the transport stream is de-multiplexed and the resulting MPEG-2 elementary streams are decompressed using two onboard MP@ML decoders.

Projector arrays of arbitrary size and configuration can be achieved by cascading an unlimited number of CineCards. In this case precise synchronization of the several video streams is achieved by a patented recovery of sync data from the MPEG-2 transport layer. Horizontal and vertical blending functions as well as pixel-selective colorimetric processing allows to extend the projector array in each direction as well as to serve screens of almost any kind of

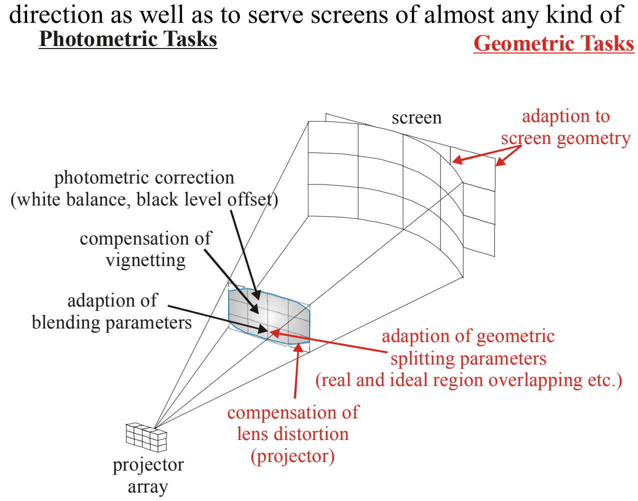

Figure 3: Photometric and geometric calibration tasks for the proposed multi-projection system

curved surface. An onboard warping chip and an automatic camera-based calibration tool is under development for this purpose.

3. SYSTEM CALIBRATION

In general, there are two major calibration tasks for the proposed multi-projection systems: the geometrical and photometrical system calibration.

As illustrated in fig. 3, the photometric calibration can be splitted into three parts, the compensation of the photometric deviations between the projectors (white balance, black level), the compensation of projector lens vignetting effects and the adaptation of border blending parameters (gamma correction).

The geometrical calibration again consists of three tasks. Firstly, according to the number of projectors the original image needs to be split into overlapping sub-images. Secondly, these sub-images need to be adapted to the existing screen geometry. Finally, the deviations caused by the projectors lens distortion or by curved screens need to be compensated.

3.1. Photometric Calibration

In practice, the photometric properties of usual DLP projectors vary drastically. A simple hardware based adjustment of projector contrast and brightness is in many cases not sufficient for high-quality projections. But it can at least be used as a first rough system calibration step.

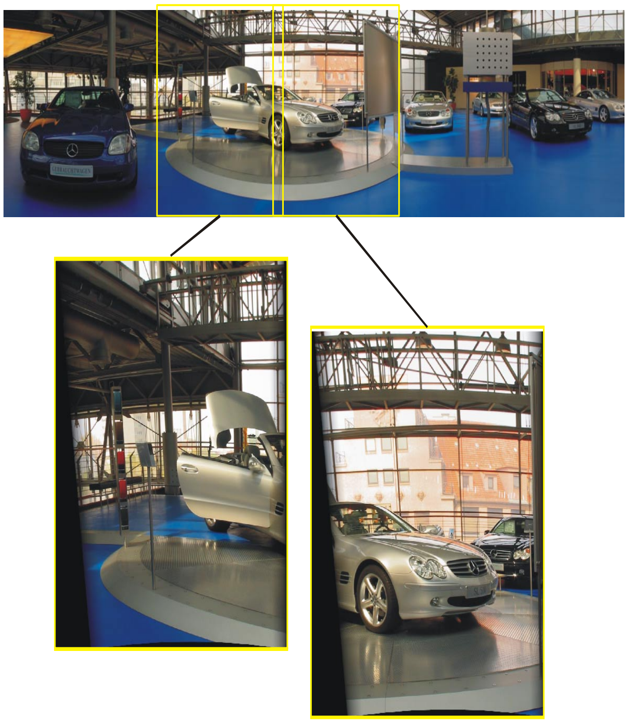

Figure 4: Example of photometric and geometric image pre-processing.

In a second step, an electronical image adaptation is required. As mentioned before, for the proposed CineCard system an integrated multiplicative (white balance) and additive (black level) correction unit was developed which works at pixel resolution. In this way, it is possible to compensate uniform as well as non-uniform color distributions which may be caused by the projector lens vignetting or non-central projection positions (as shown in fig. 1).

Another problem is the non-linear optical intensity characteristics of conventional DLP projectors. In practice it is usually modeled by an exponential function, the so called *gamma-function*. For an optimal blending performance at the borders of the projected sub-images it is necessary to determine and correct the exact colorimetric intensity distributions for each of the color channels of all projectors.

To handle this problem, the developed CineCard system contains a special gamma-correction unit which compensates the effects of non-linear intensity distributions of the projectors.

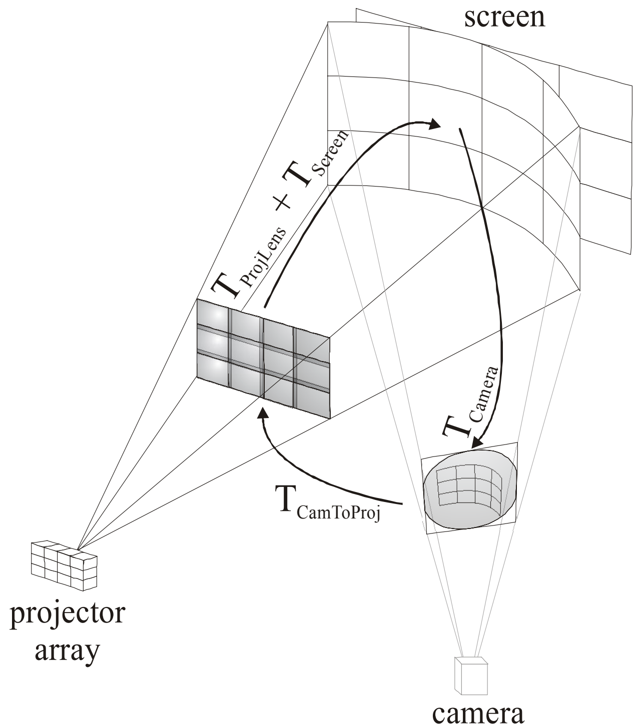

Figure 5: Automatic camera-based system calibration.

3.2. Geometric Calibration

The task of geometric calibration is the adaptation of all sub-images to the screen geometry. In general, the process of image projection transforms the original image to an arbitrary shaped object on the screen. This transformation depends on the shape of the screen, the position and orientation of the projector and the projector's parameters (lens distortion etc.). For example, for flat screens this transformation causes the so called *keystone* effect.

In order to stitch together the sub-images on the screen this image transformation needs to be compensated. Especially in the overlapping regions the projected images need to fit exactly their theoretical constraints on size and image position to avoid artifacts such as blurred blending areas etc. For these areas the geometric projection error needs to be less than the projected image pixel size on the screen to achieve high-quality and high-resolution multi-projection images.

In practice, it is difficult to adapt the screen shape to its mathematical model. In our tests we have noticed, that even in case of flat screens often slight surface deviations of the screen shape exist which decrease the accuracy of the projection. Furthermore, geometric projection

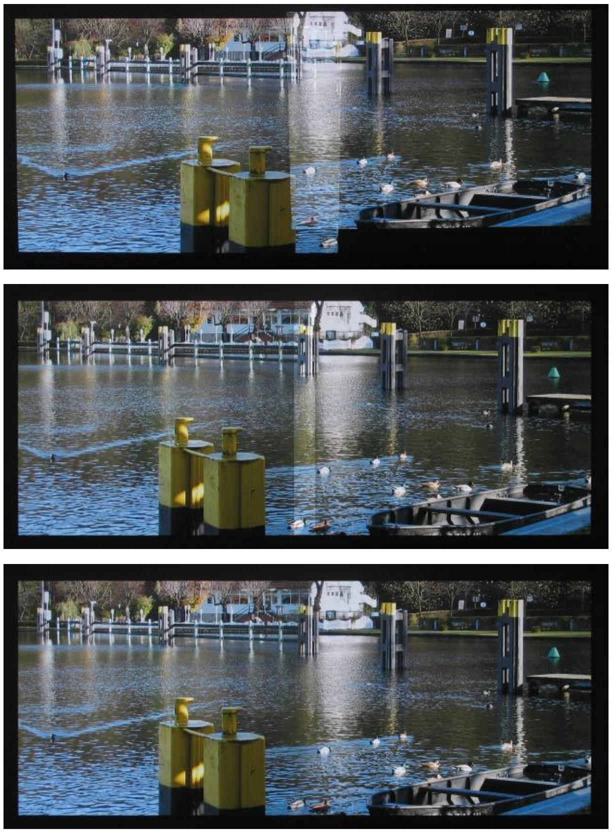

Figure 6: Results for camera-based automatic system calibration, **top:** Initial state, **middle:** result of geometric calibration, **bottom:** result after photometric calibration

deviations, such as projector lens distortion etc. need to be considered.

To solve this problem, we use a three step approach. First, we determine the projectors lens distortion in an offline process. As this value does not change it may be considered as a fixed projector calibration parameter. Secondly, we determine a rough mathematical model of the screen shape. This model is locally corrected in a third refinement step.

Fig. 4 shows the result of the geometric image preprocessing for the example of the cylindrical multi-projection system illustrated in fig. 1. The original panorama image in fig. 4 (top) was split into overlapping sub-images according to the number of projectors. To compensate the deviations caused by the projection to the cylindrical screen surface all sub-images are geometrically corrected in a preceding transformation step which is exactly inverse to the projective image transformation to the screen surface. The resulting images (fig. 4 bottom left, right) appear on the screen surface without any geometrical distortions (see fig. 1, left).

3.3. Automatic Camera-Based Calibration

To simplify the overall calibration process we have developed an automatic approach which is based on a fully calibrated digital camera system (see fig. 5). This calibration is obtained by the analysis of a special pattern projected onto the screen surface. Based on the geometric transformation parameter the photometric projection parameter can be determined in pixel resolution for each of the projectors separately.

So far, the proposed automatic system was developed and tested for flat screen shapes as illustrated in Fig. 6. The top image shows the initial projection of two sub-images onto a flat screen. The result of geometrical calibration is demonstrated in the middle image. Note, that the final screen size is adapted to the maximal available rectangular screen area covered by both projectors. Furthermore, due to the high precision of the geometrical image correction no blurring artifacts occur in the overlapping area. Finally, the bottom image shows the result of photometric image adaptation. Both, the non-linear projection characteristics of the projectors as well as the deviations of white-balance and black level between the projectors are compensated.

4. CONCLUSIONS

We have presented a scalable modular high-resolution multi-projection system. A special hardware plug-in card, the so called CineCard, was developed for this purpose. It handles the tasks of video decoding, synchronization and photometric image correction in real-time. Furthermore, we have demonstrated an approach for a fully automatic calibration of the system for the case of flat screen shapes. In our future work we plan to extend the automatic calibration approach to arbitrary screen shapes. Further, an additional warping chip will be developed which extends the functionality of the CineCard in order to perform a real-time geometric image adaptation.

5. REFERENCES

[1] A. Majumder, Intensity seamlessness in multiprojector multisurface displays. *Technical report*, University of North Carolina, Chapel Hill, 1999

[2] K. Li ans Y. Chen, Optical blending for multi-projector display wall system. *In IEEE Proc. 12th Laser and Electro-Optics Society*, volume 1, pages 281-282, 1999

[2] P. Lyon, Edge blending multiple projection displays on a dome surface to form continuous wide angle fields-of-view. *In Proceedings of 7th I/ITEC*, pages 203-209, 1985