CONTINUOUS SYSTEM CALIBRATION USING NON-VISIBLE LIGHT

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ABSTRACT
With the growing adoption of automatic systems for aligning the geometry of large multi-projector displays in venues such as flight or ship bridge simulators, it has become possible for even the most complicated visual systems to be realigned regularly to maintain seamless geometric alignment. Despite this ability, for the most part, these alignment systems still require that the system be taken off-line in order to project alignment patterns and recalibrate the system.

This paper presents a method for both calibrating projection systems without interrupting the visible video feed of the image generator as well as continuously monitoring the geometry of the system and automatically triggering realignment when required using new projection technology which allows the simultaneous projection of both visible and non-visible (infrared) light.

INTRODUCTION
For a number of years the projection industry has used multiple overlapping projection systems to achieve arbitrarily large and irregularly shaped displays in immersive environments, and large venues such as amphitheaters. In recent years, a number of companies including Christie have developed machine vision systems which will automatically perform this geometric alignment more quickly and more accurately than manually aligning the projectors. Although these systems run quickly compared to manual adjustment, they still require the system to be taken off-line in order to project the patterns required for the automatic calibration system to re-align the image.

Very recently, projection systems have been introduced which will project not only visible light, but non-visible light (for example: near-infrared). These projectors are primarily designed for simulator environments. By combining the ability to drive visible and infrared image pipelines, the system is able to independently control a display which is visible to the human eye, and one which is visible only through sensing equipment such as night vision goggles.

Discussed in this paper is a method for using such a projection system to both perform continuous display monitoring and automatic correction without interruption of the primary display. By using both the visible and non-visible channels of the system simultaneously, we are able to both determine when a system has come out of alignment and recalculate appropriate warp and blend information using non-visible light patterns while continuing to display visible images to the user uninterrupted.

This method would be of particular use in high traffic environments, where shutting down the system for recalibration can cause problems, such as in theme parks, simulators, command and control centers, etc.
For the purposes of our experiment, detection of non-visible patterns is accomplished with commercial off-the-shelf camera equipment with visible light filtering to extract calibration patterns. The projection system is based on the Christie Matrix StIM and calibration is performed using a modified version of Christie’s Autocal software.

BACKGROUND

Since the introduction of automatic calibration systems over the past 10 years, great strides have been made in improving the automatic calibration of multi-projector geometry and blending, but for the most part, any practical commercial applications of these systems has acted on the display statically (i.e. calibration as a one-time, or periodic process).

Conversely, although less progress has been made on color matching using these automated systems (“good enough” matching often being the achievable goal to date), through the latest generation of projection systems used in simulation and control room applications, arrays of projectors are able to continuously monitor and correct color across a projector array using internal sensing and inter-projector communication.

Although this method cannot account for eye point, screen effects or other environmental issues, for most displays, this internal matching produces uniform color and brightness across the display for the lifetime of the system.

Comparable functionality for geometric alignment is a much more difficult problem. Since, by its nature the process is external to the projector; there is no choice but to use external sensing. Projected displays are, of course, dynamic and thus extracting useful fiducials can prove a problem without interrupting the video feed to produce markers such as those used in the static process. In some cases, features such as projection edges can be extracted and used, but again, in many real world applications, projector overlaps, screen edges or borders can eliminate the ability to use even this information.

With the introduction of projectors to the market which can project both visible and infrared imagery, an interesting new approach can be taken to the problem. By using the infrared channel for calibration (when not required for IR imagery) we have the ability to project a complete set of projector markers on the screen without interrupting the visual display. Providing we can accurately separate the visible and non-visible channels, this leads to the possibility of not only correcting geometry on the fly, but continuously projecting markers to determine when and if recalibration is required.

IMAGE CAPTURE

For the purposes of this experiment, a single Dalsa Genie C1024 camera was used. Although this camera is not designed for capture beyond the visible spectrum (see Figure 2 for the responsivity curve), the response to the wavelength of the IR LED was sufficient to capture images of the IR display providing the visible light was removed.

Filtering of the visible light was accomplished using a LP830 filter from Midwest Optical Systems. This filter is not ideally suited to the IR wavelength being captured and some attenuation of the IR signal was seen, however the visible light is completely removed for all practical purposes, so by using long exposure times and an open aperture, we are able to capture and isolate the infrared portion of the display for calibration.

![Figure 2: Responsivity of Dalsa Genie C1024](image)
The camera and lens were pre-calibrated to determine intrinsic camera/lens parameters to remove lens distortion from calibration calculations. During the experiment, extrinsic parameters of the camera (position and orientation) were calculated using fiducials on the screen. In general, these fiducials may be extracted from screen edges, specified manually by the user, or by using camera-visible points. In this case, a series of LEDs around the screen border are used to automatically calibrate the extrinsic parameters of the camera.

In Figure 4 we see an image capture of a projected test pattern with the visible light filter applied to the left half of the image. Although it is clear that the camera is far more sensitive to the visible light, we can clearly differentiate the IR only portion of the image as well.

**PROJECTION SYSTEM**

The projection system used for the experiment is the Matrix StIM designed by Christie Digital Systems specifically for the simulation market. The light source of the Matrix StIM is an array of 4 high power LEDs (red, green, blue and infrared). The infrared LED runs at a wavelength of approximately 840 nm for direct stimulation of night vision equipment. Using the StIM with dual image processing functionality, we are able to independently control displays feeding to the infrared LED and the other three visible LEDs.
For the purposes of the experiment, the StIMs can be run in standard interleaved mode where the IR video stream and visible video stream are both run at 60 Hz and are directly combined into a 120 Hz output signal. This method is more than adequate to demonstrate the concept of IR alignment and has the added benefit of introducing smear reduction to the output video by introducing the non-visible gap between each visible frame. There is the drawback of reduced brightness in this case though. Ideally, in a future product, there would be the option of specifying the visible to IR ratio providing the user with different brightness and smear reduction options. The calibration system itself should be very flexible regarding this mix as it can simply operate on longer exposure times providing the visible light is effectively filtered from the camera.

**CALIBRATION**

Using the Matrix StIM, we are able to simultaneously control independent signals which run to the visible and infrared LED channels. Figure 9 shows an example of simultaneous visible and IR images captured with the camera unfiltered to display both channels.

With the visible light filter applied to the camera, only the IR test pattern can be viewed through the camera (see Figure 10).

Once the test patterns are successfully isolated from the visible image, the calibration process can be run. Although this method would work with most any automatic calibration system with similar requirements, in this case, Christie’s automatic system Autocal is used to perform the calibration. This process requires a series of test pattern points similar to those seen in Figure 10 to be displayed in a series of images.
These images, in turn, have a threshold applied to them to isolate marker points (Figure 11) which allows the system to locate and index each point to perform the geometry correction and blending calculations. Once these calculations are complete, the data is loaded into the projector and the image can be restored to alignment without interrupting the visible video feed.

CONCLUSIONS

With commercial off the shelf machine vision hardware and with the help of the new IR capable simulation projectors we are able to produce a prototype calibration system which allows for visible images to be simultaneously displayed with non-visible test patterns which were used to automatically recalibrate the geometry using the currently available version of Christie’s Autocal software.

Results from the calibration were identical to those generated by visible test patterns to within the error of the system (sub-pixel).

Future development should allow for both Autocal and other automatic alignment systems to be modified to use this basic method to both monitor and correct geometry using infrared projection in a real world commercial application.

FUTURE DEVELOPMENT

Although the experiment proves that monitoring and correction of geometry using non-visible projection is achievable with current technology, much more work can be done to make this ability more functional in real world situations.

The camera selected was one used for standard auto-calibration installations. In a laboratory setting, lighting conditions were easily controlled to allow for the calibration. A camera more sensitive to the near IR range, as well as a filter selection which does not attenuate the projector’s IR display will make the system more robust for real applications of the system.

For more flexibility in final image quality, further development of interleaving methods would be beneficial. By taking advantage of technologies such as Accuframe smear reduction, infrared test patterns can be applied in dark intervals without further affecting the brightness of the visible image.

Finally, after implementation of a brute-force monitoring system, system responsiveness could likely be improved with the implementation of a more elegant method of determining when a recalibration is required.

AUTHOR BIOGRAPHIES

Kevin Wright graduated with a bachelor’s degree in Systems Design Engineering from the University of Waterloo in 1996. Since graduating, Kevin has been involved in the design and development of engineering and visualization software including mesh generation and visualization tools for computational fluid dynamics and more recently, software tools for advanced projection systems. Currently, Kevin is a Senior Program Manager with Christie Digital Systems working on both projection and computing systems for Simulation and Visualization environments including Christie’s automatic projection alignment system, Autocal.

Robert Flatt received his B.Math - Computer Science degree from the University of Waterloo, Waterloo, Ontario, Canada in 2004. Rob’s experience includes research and development of embedded systems, visualization software, transcoding solutions, and projection systems. Currently, Rob is a Software Developer at Christie Digital Systems, working on software solutions for various advanced projection systems (including an automatic calibration system for multi-projector displays).

Stuart Nicholson
REFERENCES