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Abstract

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Hybrid Infrared and Visible Light Projection for Location Tracking

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ABSTRACT

Interactive projection systems typically require a dedicated location tracking technology for the purposes of cursor or controller input. Many research systems exploring projector-based augmented reality and augmented worktables require accurate registration of the projected imagery onto physical surfaces which is done either manually, using a camera, or other tracking device. In this paper, we describe the implementation of a prototype projector capable of displaying both infrared as well as visible light images. Using infrared patterns, we can discover the locations of light sensors in a manner that is invisible to a human observer while visible patterns provide application content. By unifying the location tracking and projection technology into a single device, we can greatly simplify the implementation and execution of interactive projection systems and inherently support multi-user stylus input on surfaces that may be non-planar and discontinuous.

Author Keywords

Infrared Projection, Projector-based Tracking, Augmented Reality, Simulated Displays, Physical Interaction

ACM Classification Keywords

H5.2 [Information interfaces and presentation]: User Interfaces. H5.1 [Multimedia Information Systems]: Augmented Reality.

INTRODUCTION

In modern computing environments, video projection has become a staple display technology for presenting dynamic content to viewers. While traditional uses of projectors such as business presentations and home theaters have become quite common, there exists a large body of research work in the field of HCI and computer graphics that has explored how projectors can dynamically transform surfaces in our environment to better suit the needs of our task. The Office of the Future [6] work from UNC is a key example of this type of exploratory work which unified many different research concepts into a single vision familiar to the HCI community. This vision included virtual portals, shared multi-user displays, and projector-based augmented reality. A few examples of research projects the combine projected light with awareness of the display surfaces include active display simulation [2] as shown in Figure 1, dynamically positioned information displays [4], shader lamps [7], and augmented worktables [8,9,10]. While far from a complete list, these projects demonstrate the significant value and richness of interaction a projector can add to normally static environments if given information about the objects and surfaces onto which content is being projected.

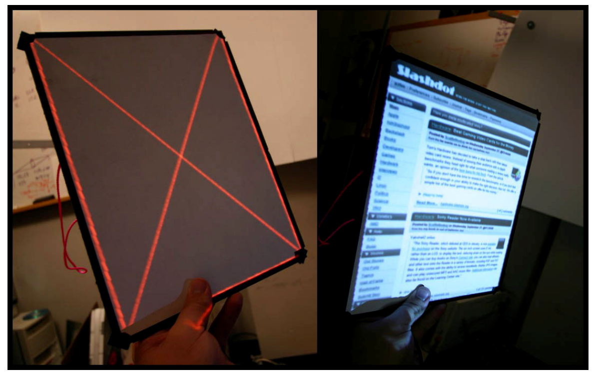

Figure 1. Tracking the location of a hand-held surface and then projecting content to simulate an active display.

However, one of the difficulties in implementing and executing these ideas that has limited their practicality and adoption is the issue of image alignment and location tracking. Many of these systems require accurate registration of the projected image onto physical surfaces for the illusions to be effective or calibration to an external location tracking technology. Often this alignment and calibration is done manually by skilled individuals adding significant overhead and maintenance costs. While self-calibrating projection systems have had success utilizing a camera [10], this approach generally displaces the calibration process to that between the camera and projector and is susceptible to the limitations of computer vision. In our previous work, we have demonstrated the benefits of using a projector-based method of location discovery accomplished by embedding light sensors at the points of interest and then projecting a series of patterns which uniquely identifies each pixel in the projector's screen space [2]. This technique endows a projector with inherent calibration-free object location discovery and tracking abilities that are robust against many of the issues that plague computer vision approaches. By unifying the location tracking and the projection technology into a single device, we can greatly simplify the implementation and the execution of applications that use projected light on physically aligned and tracked surfaces.

Our previous implementations of this technique used an off-the-shelf projector which encoded pixel locations using visible light patterns. This resulted in tracking patterns that could be seen by human observers and also consumed a portion of the projection area reducing the number of pixels available for application content. While we our previous work [2] as well as [1] has had success in reducing the perceptability of the tracking patterns using high-frequency visible light patterns, our long term goal was to create a projector capable of projecting both visible images for application content and invisible infrared images for location discovery and tracking. This would allow the location tracking to occur without the user's awareness and would not interfere with application content. In this paper, we describe a proof-of-concept implementation of such a device.

ANATOMY OF A PROJECTOR

With a few exceptions, most modern projectors have three major components: a bright light source, a device to modulate the light to create an image, and optics to scale the resulting image onto a screen. A typical consumer Digital Light Processing (DLP) projector uses a high-wattage Xenon gas bulb to provide a bright white light source which is then focused onto a Digital Micro-mirror Device (DMD) for modulation. A DMD is a very high-density array of computer controllable microscopic mirrors that can either reflect light away from, or toward, the projection lens to create black and white pixels respectively. Each mirror corresponds to a single pixel in the projected image. To create grey pixels, each mirror rapidly moves back and forth as much as 50,000 times per second. The human visual perception system then interprets these high-frequency flashes as varying levels of gray. To create color, a rotating color wheel is placed in front of the light source to rapidly cycle between red, green, and blue light allowing the DMD to simulate a wide range of colors to human observers.

Recently, due reasons of cost, size, power, and life-span commercial manufacturers have begun using high-output light emitting diode (LED) arrays as an alternative source of light. A number of rear-projection televisions available today use LED-based lighting. Another advantage of LED illumination is that can be manufactured to emit red, green, and blue light as well as non-visible infrared (IR). Color images are created by electronically turning each group of LEDs on and off rapidly in synchrony with the DMD. In this same manner, we can use an LED light source to project both visible light and infrared images using a single projector as shown in Figure 2.

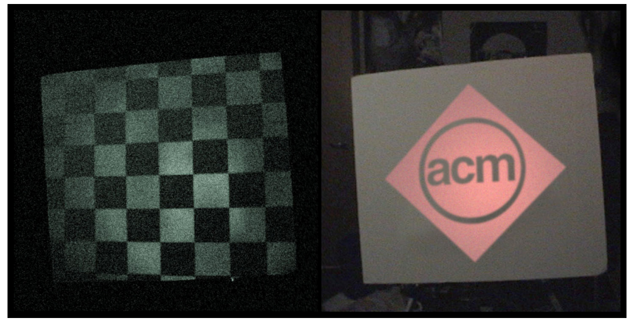

Figure 2. Two views of our projector output: a test pattern seen in infrared (left) and a visible light image (right)

CREATING OUR PROTOTYPE

Our light source is a small array composed of 24 high-output visible-light red LEDs and 24 high-output near infrared LEDs shown in Figure 3. Because our goal was to create a proof-of-concept device, we did not target color support in this implementation. However, a commercial manufacturer could trivially add a fourth IR color group to the RGB color arrays used in their existing design. A microcontroller is used to rapidly switch each group of LEDs on and off. A culminating lens is placed directly in front of the LED array to focus the light onto the DMD.

To spatially modulate our light source, we used a DMD with a 1024 by 768 array of mirrors. This is part of the DMD Discovery 1100 Kit from Tyrex Services that allows us to send binary images from a PC via a USB 2.0 connection to the mirror array. Due to the limitations of the development kit, we can only send 180 binary images per second. While this is far below the capabilities of the DMD itself of 50K binary images per second, it allows us to explore the principle of the approach.

The projection lens and component housing used in our prototype were taken from an InFocus X1 DLP projector. This simplified our implementation as it allowed us to reuse the mountings and lens system from a commercial projector providing the necessary physical relationship between each component to ensure proper optical alignment. A view of the components inside our prototype is shown in Figure 4.

INVISIBLE LOCATION DISCOVERY

Once we have a functioning projector prototype capable of emitting both visible and infrared images, we can use a series of Gray-coded binary patterns to discover the locations of sensors placed in the projection area as described in our previous work [2], but now without the user's awareness. These patterns uniquely identify each pixel in the projector's screen space allowing a light sensor to determine its pixel location by observing the pattern of light it receives.

The light sensors we use are Vishay 56KHz IR receivers. These are low-cost receivers frequently used in remote controls. One benefit of using a modulated IR light is that it reduces interference from ambient IR sources and increases the effective range.

Due to the nature of wireless communication, the receivers have a built-in automatic gain control (AGC) which governs how much the incoming signal should be amplified before it is interpreted as digital information. This important feature allows the receiver to continue working properly in the presence of ambient noise and varying signal strength. However, the AGC can accidentally interpret long uninterrupted transmissions of the target signal as background noise resulting in de-amplification of the data stream until the signal is entirely lost. To mitigate this behavior, we modulate the 56 KHz carrier wave during the tracking period with an alternating data pattern of "01010101…" at 2 KHz. This prevents the ACG from accommodating and ensures our IR signal will be detected by the receiver. To spatially modulate the amount of IR light each pixel location receives, we use our DMD. The projector can operate in an open-loop mode broadcasting location data without the need for feedback from the sensors. It is worth noting that the DMD is not a perfect modulator. A small amount of IR light still escapes even when the mirrors are set to reflect light away from the lens. This is caused by back-scattered light within the projector housing and other limitations of the DMD development kit. We observed that the ACG within the IR receivers would periodically detect this signal leak causing the sensors to misinterpret the location data resulting in tracking instability. We are currently working on IR receivers with a software controllable gain to eliminate the artifacts resulting from erratic AGC behavior.

On the sensor side, we use a PIC microcontroller to look for the presence of the 2 KHz data signal to determine location. Using a series of 20 gray coded binary images, we can resolve the location of the IR receiver to the nearest pixel in a 1024x768 area. The DMD kit we are using is capable of rendering 180 binary images per second allowing up to 6 location samples per second. Our actual performance is slightly less due to synchronization overhead. As mentioned before, a production DMD unit with dedicated high-speed memory buffers is capable of rendering more than 50K binary images per second which could yield over 2500 location updates per second. In practice, manufactures would want to use the majority of the DMD duty cycle to create visible light images rather than perform location tracking. However, it would be possible to achieve 60Hz tracking using less than 2.5% of the DMD duty cycle. Location discovery could be performed in just 400 microseconds between each visible frame providing seamless real-time input interaction with the projected content with negligible impact on the visual quality of the image.

Figure 3. Light source of 24 red (clear) and 24 infrared (dark) high-output light emitting diodes.

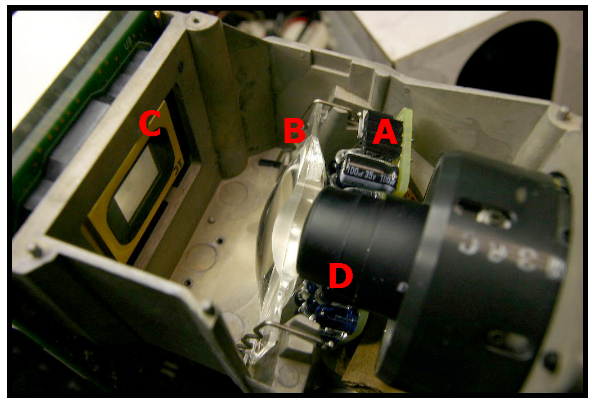

Figure 4. Inside our projector: A) LED light source B) culminating lens C) DMD device and D) projection lens.

Our prototype device successfully demonstrates that a single projector can be used to discover the locations of sensors placed in the projection area using non-visible infrared light as well as project visible application content. By unifying the location tracking and projection technology into a single device we can greatly simplify the implementation and execution of many interactive projected applications. By performing the location discovery process using non-visible light, we can track objects without the user's knowledge, preserve 100% of the projection area for application content, and search the entire projection area for sensors eliminating the issues related to incremental tracking discussed in [2]. Since our prototype is limited in frame rate, we can simulate the output of a commercially manufactured system by coupling it with another projector to assist in displaying visible application content for the purposes of demonstration. This coupling can be done with either a half-silvered mirror to align the two projection frustums or using existing software techniques.

APPLICATIONS

The simulated display shown in Figure 1 is accomplished by tracking four sensors, one placed in each corner, simultaneously and then warping application content to fit the defined quadrangle. This allow us to simulate an active display on a light-weight, low-cost surface. By adding a

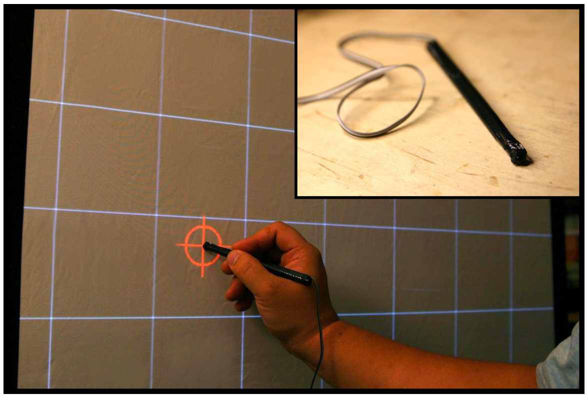

Figure 5. A stylus with a light sensor (insert) used to interact with a rear-projected display.

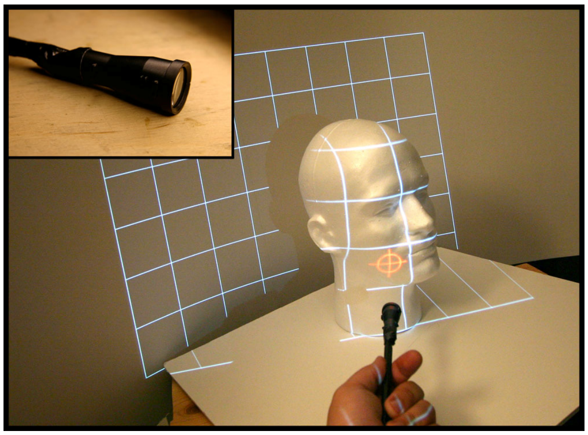

Figure 6. A stylus utilizing a focusing lens (insert) for distant pointing on non-planar and discontinuous surfaces.

touch sensitive film to the hand-held surface, we can simulate tablet-pc like interaction [2].

The continuous broadcast of location data also allows inherent support for multi-user stylus input on projected displays. In a rear-projected configuration, we can use a stylus containing a light sensor in the tip to interact with large displays, shown in Figure 5. This approach supports the simultaneous use of a large number of light pens without interference or pen ambiguity. This feature could be made available in LED illuminated DLP rear projected televisions with a relatively small design change. In front projected configurations, occlusion from the hand or stylus prohibits surface contact pointing, but a focusing lens would allow pointing from a short distance. The geometry of the screen does not need to be known and continues to work even when the surfaces are non-planar and discontinuous, Figure 6. This is difficult or impossible using alternative tracking technologies.

Long distance pointing technologies such the that used by PixArt Imaging Inc. in the Nintendo Wii Controller utilizes external IR LED emitters and a handheld IR camera for tracking [5]. The emitters must be placed in proximity to the display and is not sensitive to display size resulting in a relative pointing system. An IR capable projector can place multiple IR dots directly within the projected image without obscuring application content creating an absolute pointing system as well as support many spatially distributed IR dots or complex patterns allowing 3D recovery of the camera position and automatic screen identification in a multi-screen environment.

By embedding sensors into small objects, we can track interactive physical widgets on a table top surface similar to [8,9]. Multiple sensors in a single physical widget can be used to detect rotational orientation. and perform Shader Lamp techniques [7]. Further reaching applications include location dependent data delivery [3] and real-time range finding [1]. By projecting the patterns in IR light combined with an IR camera it is possible to capture depth data of a user's face or body in real-time without the user's awareness.

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