Hybrid Infrared and Visible Light Projection for Location Tracking

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ABSTRACT

A number of projects within the computer graphics, computer vision, and human-computer interaction communities have recognized the value of using projected structured light patterns for the purposes of doing range finding, location dependent data delivery, projector adaptation, or object discovery and tracking. However, most of the work exploring these concepts has relied on visible structured light patterns resulting in a caustic visual experience. In this work, we present the first design and implementation of a high-resolution, scalable, general purpose invisible near-infrared projector that can be manufactured in a practical manner. This approach is compatible with simultaneous visible light projection and integrates well with future Digital Light Processing (DLP) projector designs – the most common type of projectors today. By unifying both the visible and non-visible pattern projection into a single device, we can greatly simply the implementation and execution of interactive projection systems. Additionally, we can inherently provide location discovery and tracking capabilities that are unattainable using other approaches.

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 human-computer interaction, computer vision, and computer graphics that have explored how projectors can provide sophisticated capabilities such as 3D scanning [2], office augmentation [7], display simulation [3], contextually located displays [5], appearance augmentation [8], and augmented worktables [9,10,11]. While far from a complete list, these projects demonstrate the significant value projectors provide as a data acquisition device or interactive tool rather than simply providing a large passive display.

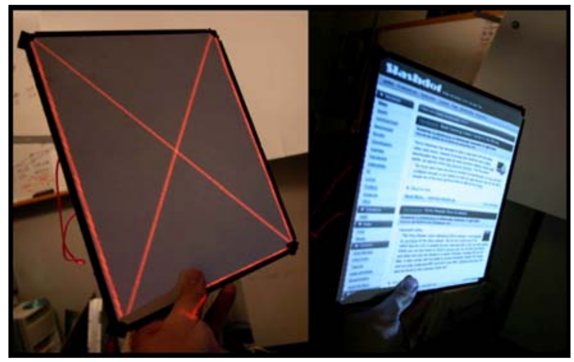

Figure 1. Tracking the location of a hand-held surface and then projecting content to simulate an active display.

However, these systems have two major drawbacks that severely limit their use and adoption both inside and outside the research community. Firstly, the interactive systems require an external tracking technology for detecting input which can add significant cost and configuration complexity such that installation would require the skill set of an expert developer. Secondly, the applications that use the projector to create structured light have relied on high-contrast visible light patterns that ease the problem of optical segmentation but result in a highly caustic visual experience for human observers. In this work, we present a solution which addresses both of these problems with a single device. In Figure 1, we show an application of using our device where a hand-held surface is being tracked and projected onto without the need for an external tracking technology through the use of invisible structured light patterns. This is accomplished by creating a hybrid projector capable of presenting both invisible infrared and visible light images in a high-speed time multiplexed manner. Infrared sensors located in the surface detect the structured light patterns and report their locations back to the host computer. By using a single device

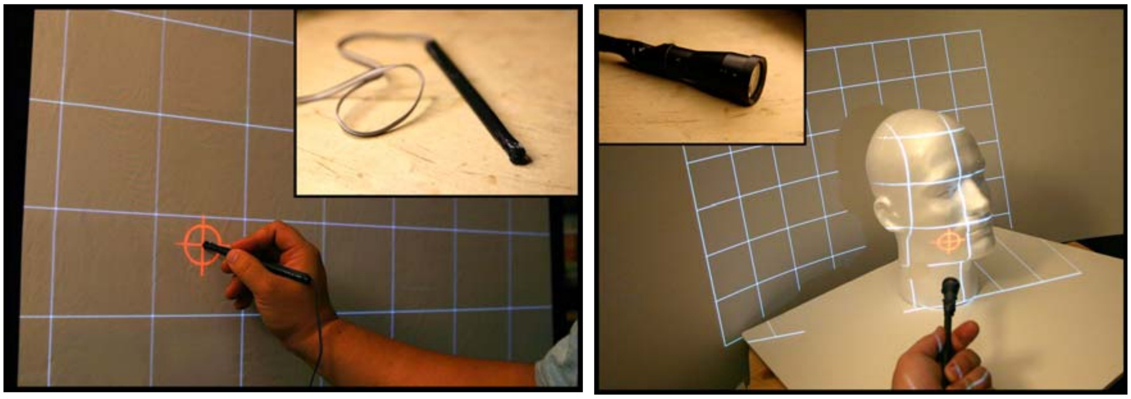

Figure 2. Inherent tracking capabilities provided by a hybrid infrared-visible light projector: *Left* – calibration-free multiuser stylus tracking. *Right* – pointer tracking on non-planar and discontinuous surfaces of unknown geometry.

to perform both tasks, we not only simplify the implementation of many applications we also inherently support a number of input capabilities that are unique to this approach shown in Figure 2. This hybrid projector provides inherent calibration-free tracking of one or more input styli simultaneously. Each of these "light pens" contains an infrared sensor in the tip providing both location and identity without ambiguity even if a large number of pens are used. Additionally, the calibration-free nature of our approach allows the tracking of pointers on projected displays even on non-planar discontinuous surfaces of unknown geometry. This is difficult or impossible using alternative tracking technologies.

PREVIOUS APPROACHES

While high-contrast visible structured light patterns greatly ease the computer vision or optical segmentation problem needed for demodulating the encoded data, it has been well recognized that these flashing images produce a significant amount of visual strain on users. Some work, such as [1] and [3], presented methods of eliminating this strain by reducing the perceptibility of the structured light patterns. In [1], Cotting et al. suggested using high-speed projection combined with a synchronized high-speed camera to detect structured patterns encoded in an image as color distortions that are below human visual sensitivity. While effective in its goal, this approach remains quite costly and degrades the image quality for the sake of modulation. In [3], we presented an alternative method of using frequency modulated patterns that were above the sensitivity of the human eye having the appearance of solid gray squares but were distinguishable using a light sensor. While this approach was low in cost, the patterns still maintained a visible manifestation and consumed pixels that could not be used for application content.

In [4], Nii et al. created an infrared projector prototype using discrete light emitting diodes (LEDs). The projection lens focused directly onto the LED array creating a low resolution infrared (IR) projector where each LED corresponded to a single pixel. While this approach provides very high-data rates, it has severe limitations in terms of resolution scalability. It is very difficult to create small arrays containing more than a few hundred LEDs which is not comparable to typical modern projectors which may have anywhere between 786,000 and 2 million pixels. This approach is also incompatible with visible light projection.

Another difficulty in creating an IR capable projector comes in the form of the light source used in most modern projectors. Typically, a projector contains a high-pressure gas bulb that provides a wide spectrum white light source. The bulb itself generates a significant amount of IR energy, but mostly in the form of unmodulated, unstructured heat. As a result, the optical elements in projectors that shape and direct the light are typically designed to filter out this IR energy to prevent the heat from reaching the delicate image modulation element potentially damaging it. But, even if the optics were modified to allow the near IR frequencies that could be used for sensing to pass through, it is very difficult to reliably use unmodulated IR light energy for data transmission since it is highly susceptible to ambient interference.

As result of these difficulties, nearly all of the research work exploring applications of projected structured light has relied on visible light patterns. Many publications go on to suggest that perhaps an infrared capable projector could be created in the future recognizing the value it would provide in making these research techniques more usable. However, none of these publications actually describe building such a device.

We present the first design and implementation of a high-resolution, scalable, near-infrared projector. Our approach is fully compatible with simultaneous visible light projection and can be easily integrated in the next generation of Digital-Light Processing (DLP) projectors – the most common type of projector currently in use.

Figure 3. Two views of our projector output: a test pattern in infrared (left) and a visible light image (right)

Figure 4. Light source of 24 red (clear) and 24 infrared (dark) high-output light emitting diodes.

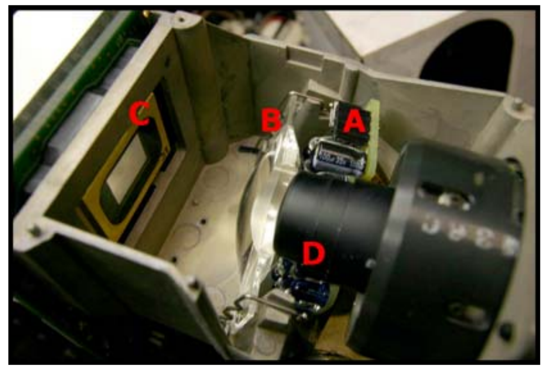

Figure 5. Inside our projector: A) LED light source B) culminating lens C) DMD device and D) projection lens.

OUR APPROACH

We elected to create a multi-color LED array illuminated DLP projector. Contained within a DLP projector is a Digital Micro-mirror Device (DMD) which is a high density array of microscopic actuated mirrors. Each mirror corresponds to a single pixel in the projected image and the brightness of that pixel corresponds to the duty cycle of the underlying mirror. A production DMD is capable of generating up to 50,000 binary images per second. This provides a method for presenting binary structured light patterns at a rapid rate. Our LED array contains a mixture of both visible light and infrared light LEDs. By electronically cycling between each color rapidly in synchrony with the DMD modulation, we can project distinct visible light and infrared images with a resolution of 1024x768 using a single device, shown in Figure 3. By using four color LED arrays (red, green, blue, and infrared), we can support full color visible light images as well as modulated IR light for ease of detection using low-cost IR sensors commonly used in television remote controls.

LED illumination is currently in development by commercial manufacturers as their efficiency in Watts/lumens is approaching that of high-pressure gas bulbs. Consumer products with three color LED illumination are currently being showcased are expected to be on the market within the next year.

Location discovery is accomplished by projecting Gray-coded binary structured light patterns [3]. The binary patterns divide the projection area into progressively smaller regions uniquely encoding every pixel. By decoding the sequence of light detected by a light sensor placed in the projection area, we can resolve the location of the sensor to the nearest pixel. By repeatedly projecting these patterns, we can track the location of moving sensors and then project visible application content in response to their locations as in the hand-held projected display shown in Figure 1. Dedicating 100% of the duty cycle of a production DMD unit to structured light patterns would yield up to 2500 location samples per second. However, this is unnecessarily high for most interactive applications and precludes the ability to project visible application content. If we use a typical projector visible light refresh rate of 60Hz, it would be possible to obtain 60Hz input tracking by inserting a burst of invisible Gray-coded patterns between each visible frame using only 2.4% of the DMD duty having a minimal impact on the overall projector brightness. However, since the location data is inherently bound to the pixels in the visible image, this small trade off in brightness provides a significant gain in capability providing out-of-box calibration-free tracking of multiple input pens and pointing on non-planar discontinuous surfaces of unknown geometry, Figure 2. By embedding sensors into small objects, we can track interactive physical widgets on a table top [9,10]. Multiple sensors in a single object provide distance and rotation. Installing several sensors into planar and non-planar surfaces, we can simulate displays [3], augment 3D objects [8], and entire offices [7] .

Additionally, it enables practical use of structured light applications combined with computer vision in environments that would normally prohibit the use of visible patterns. IR projection also allow placement of IR patterns in inconvenient locations. For example, the distant pointing capabilities provided by the PixArt camera used in the Nintendo Wii require IR dots for tracking [6]. Normally, these IR dots are placed above or below the screen to prevent visually obstructing the application content, but an IR projector can place these dots in the optimal location in the middle of the screen and at the proper scale to preserve accurate pointer translation. Additionally, more complex patterns could be projected to provide both 3D discovery of the camera position as well as screen identification in a multi-display environment. An IR projector in combination with an IR camera would also provide the ability to perform high-speed 3D capture without the user's awareness [2].

PROOF OF CONCEPT PROTOTYPE

Since creating a DLP projector that performs as well as a commercial production unit involves a significant amount of manufacturing and engineering resources, our focus was to create a proof-of-concept prototype that was functionally identical to a production unit but was limited only in performance along certain metrics.

The light source we used in our prototype is a small array of 24 visible light red LEDs and 24 near-infrared LEDs shown in Figure 4. We did not have the manufacturing capability to create high-density four color arrays, but this is well within the means of a commercial manufacturer. Our DLP development kit from Tyrex Services, Inc. provided a 1024x768 resolution DMD connected to the PC via a USB 2.0 port for uploading images. Our DLP development kit was limited to only 180 binary images per second, but is functionally identical to a production unit capable of 50,000 images per second. While a higher-speed prototype is in development, we can simulate interactive tracking and color application content by coupling the IR projector prototype with a visible light projector. The light sensors we used are Vishay 56KHz IR receivers capable of a 4Kbits/s data rate. Both 455KHz IR receivers and +2MHz IrDRA receivers are available which provide much higher data rates if needed.

Due to the nature of wireless communication, IR receivers have a built-in automatic gain control (AGC) to tune out background noise and amplify the modulated input signal. Since our modulation rate, 180Hz, is much lower than the supported data rate, 4KHz, we run the risk of having the AGC "tuning out" our data accidentally interpreting it as background noise. To mitigate this, we transmit a 2KHz data pattern preventing the ACG from over accommodating. We then look for the absence or presence of this 2KHz signal which is modulated at 180Hz by our DMD. This demodulation is done by a PIC microcontroller. Twenty patterns are necessary to resolve every pixel in a 1024x768 area. As the resolution of the DMDs increase, the number of patterns increases only logarithmically [3].

A view of the components inside our prototype is shown in Figure 5. The optical path needed to be modified from a typical high-pressure gas bulb projector to accommodate the difference in light source geometry. The semi-parallel light from an LED array can be focused on the DMD using a culminating lens. The angle of incidence is determined by the reflection angle of the DMD mirrors. This was 12˚ for our prototype.

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 improve the usability of many interactive projected applications by eliminating the need for an external tracking technology, eliminating the need for calibration, and eliminating the high-contrast caustic patterns. It also provides inherent sensor tracking capabilities that are unique to this approach. It scales easily as the resolution capabilities of DMD technology increases. Additionally, this approach can be easily integrated into the upcoming generation of LED illuminated DLP projectors with only a minor change in light source design and projector firmware.

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