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The physics of the data projector

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Abstract

Data projectors have become a common sight in school classrooms, often in conjunction with an interactive whiteboard. Long periods of continuous use coupled with the transfer of a large amount of thermal energy from the projector's bulb means that they frequently break down, often in such a manner that they become uneconomic to repair. In this article, the operation of a data projector is discussed and the potential of a disassembled data projector for teaching light, colour and digital photography is examined. For the purposes of this article the term 'data projector' will refer to 3LCD projectors, the type most commonly found in classrooms; digital light processing projectors are discussed briefly at the end of the article.

Disassembling a data projector

Disassembling a data projector is very simple: the keep-taking-out-screws-until-bits-come-loose method was found to be extremely successful. A newly disassembled data projector is shown in figure 2.

How does a data projector work?

The optical assembly of a data projector has six main components as shown in figure 3.

Light source

The projector's light source is a high power (100–300 W) metal halide high intensity discharge (HID) lamp that usually costs between £100 and £400; a typical bulb can be seen in figure 4. Light is produced by passing a current through an arc tube containing a mixture of mercury, argon and metal halides; the arc tubes typically operate at around 550 kPa and 1000 °C. HID lamps are used as they can produce very clean white light and are substantially more efficient than incandescent bulbs. Care must be taken when using metal halide lamps as unshielded lamps produce a large amount of ultraviolet radiation; damaged lamps have caused photokeratitis (a burn of the cornea) and severe sunburn [1].

Diffuser

Light from the HID lamp is diffused by two diffusers. The first diffuser also incorporates a low-pass filter that reflects the short-wavelength purple/violet component backward and prevents it from entering the optical assembly. This reflected light can be seen in figure 5.

Dichroic filters

The white light from the HID lamp is first split into red, green and blue components by two dichroic filters. A dichroic filter is one that transmits a very narrow range of wavelengths and reflects all others, typically named for the colour that they reflect (a red filter therefore reflects red light and transmits all other colours). These filters, created by vacuum-depositing thin layers of a dielectric onto a glass substrate with low thermal expansion properties, can therefore be used to split a beam of white light into red, green and blue components.

The white light is first incident on a blue dichroic filter, splitting it into blue and yellow beams; this yellow beam is then incident on a

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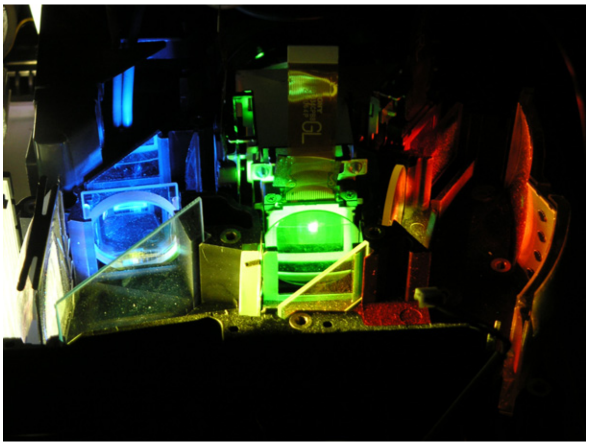

Figure 1. The inside of a data projector shown in use.

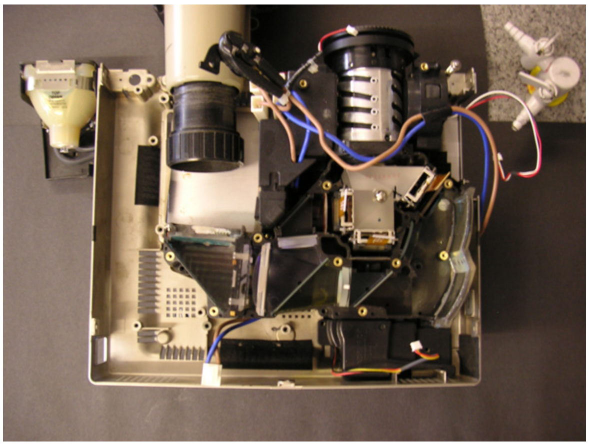

Figure 2. The interior of a data projector shown from above. The interface, processing and most of the cooling parts have been removed and the bulb (shown to the left) has been replaced by a slide projector.

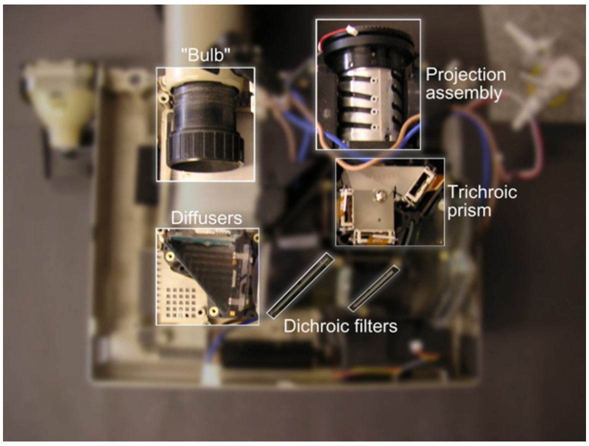

Figure 3. Data projector with main components highlighted.

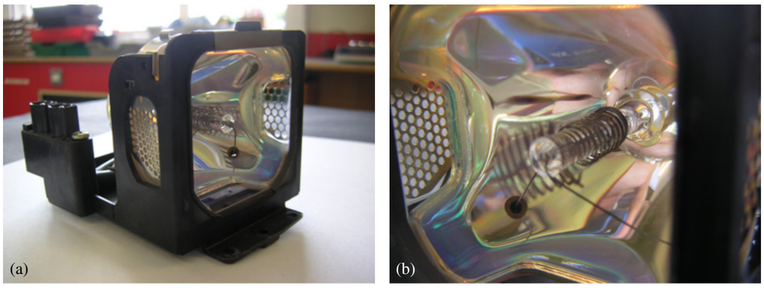

Figure 4. Two views of the projector's bulb. (a) A 150 W projector bulb. Note the two large airholes on either side of the bulb's arc tube. (b) A closeup of the bulb's arc tube showing the connecting wires.

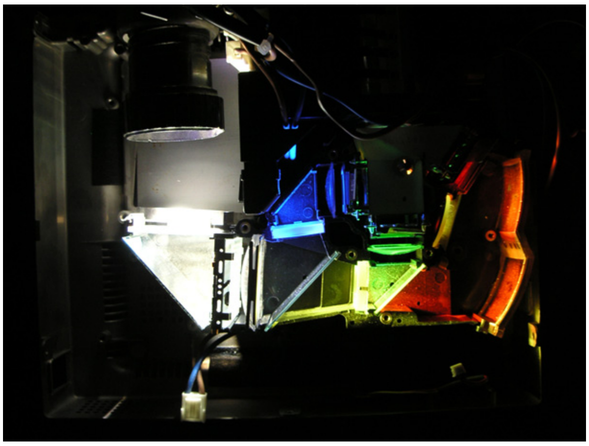

Figure 5. White light from the slide projector has been split into red, green and blue components by two dichroic filters. Purple light reflected by the first diffuser can be seen top left in the image.

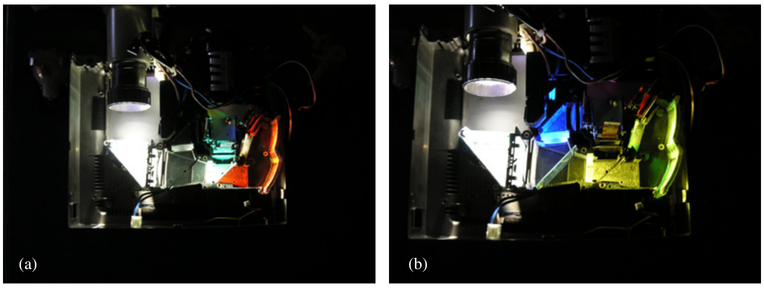

Figure 6. Projector with dichroic filters removed. (a) With blue dichroic filter removed light is split into cyan (blue + green) and red components. (b) With green dichroic filter removed light is split into blue and yellow (red + green) components.

green dichroic filter, splitting it into green and red beams (see figure 5). Each beam is then directed to an LCD screen which adds the image information before the beams are recombined by a trichroic prism. Use of dichroic filters means that the splitting is no longer accomplished through the use of polarizing filters as was the case in older projectors [2]. The composite nature of light can be investigated by removing one of the dichroic filters (see figure 6).

LCD imaging screens

The projector's image processor splits the source image into red, green and blue channels (see

Figure 7. An example of colour channels. Here figure 1 has been split into (left to right) red, green and blue channels.

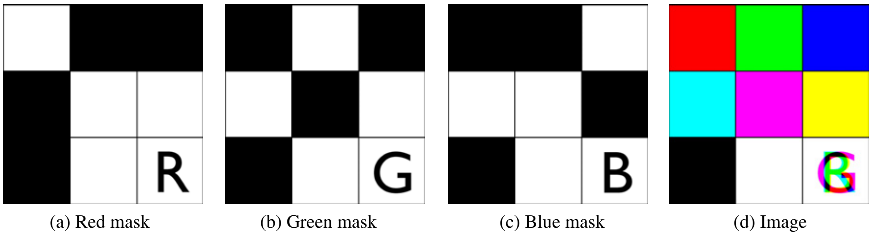

Figure 8. An example of red, green and blue masks and the resultant image.

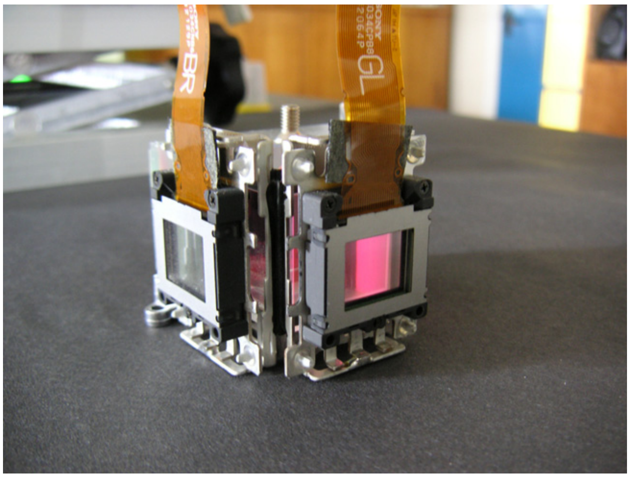

Figure 9. The blue and green LCDs and their data connectors are shown here bolted to a trichroic prism. In this photograph, white daylight entering through the 'output' face has been split into components and the red component can be seen reflecting from the interior interface of the first red–cyan dichroic prism.

figure 7) and each channel is then created in greyscale on an LCD screen by turning pixels on and off at varying rates. The LCDs act as masks through which each component is projected to form an image (see figure 8). Two of these LCDs and their data connectors can be seen in figure 9.

Trichroic prism

The trichroic prism essentially reverses the action of the two dichroic filters after the image data have been added to the components by the LCDs. The trichroic prism is created by combining two dichroic prisms: the first combines the blue and green components into a cyan component which is then combined in a second dichroic prism with the red component to produce the full-colour image (see figure 10(b)). The trichroic prism can be removed from the optical assembly and used to show that light can be split into three components; light shone through the 'output' face will show different intensities at each face of the prism depending on its colour.

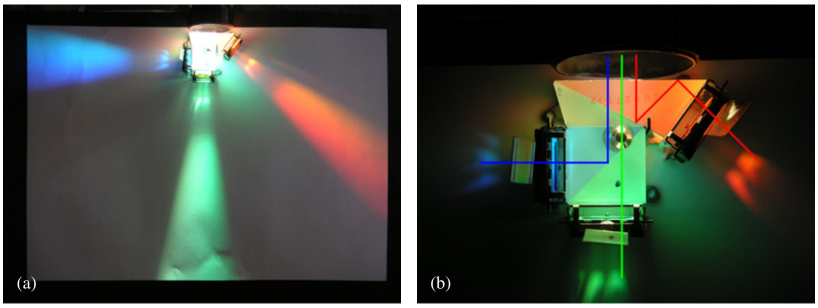

Figure 10. Trichroic prism. (a) The trichroic prism (removed from its housing) splits white light from a slide projector into red, green and blue components. (b) Close-up of trichroic prism with simplified beam paths indicated. The object in the centre of the prism is part of the mounting bracket and serves no optical purpose.

Focusing assembly

The focusing assembly takes the combined image from the trichroic prism and focuses it onto the screen. It usually incorporates some zoom functionality.

Teaching astrophotography

The trichroic prism from a disassembled data projector offers an interesting way to teach the difference between older 1CCD camera systems and newer 3CCD systems.

Older 1CCD systems used in digital cameras overlaid a Bayer filter [3] onto the CCD to produce colour images. Each four-pixel block of the filter is coloured with two green pixels and one red and one blue pixel in order to replicate the eye's greater sensitivity to green light. The use of a Bayer filter causes the colour resolution to be lower than the luminosity resolution. Large telescopes work around this by using a 1CCD sensor which takes three shots through red, green and blue filters to produce colour images but this method is unsuitable for imaging moving objects. Newer 3CCD camera systems use a trichroic prism to split light into three components which are recorded by three separate CCDs, thus ensuring that the image's colour resolution and luminosity resolution are the same.

DLP projectors

In a digital light processing (DLP) projector the LCD is replaced by an array of 'micromirrors' called a digital mirror device (DMD). The DMD is composed of hundreds of thousands of square aluminium mirrors less than 20 μm across, which rotate through 10° or more in both planes to direct coloured light either onto the screen or onto a heatsink. Each mirror acts as a pixel and therefore different shades are created by altering the frequency at which it tilts back and forth. More expensive DLP projectors use a three-DMD system similar to the 3LCD system. DLP projectors have the advantage of a sealed light path and therefore do not require a filter.

Further information

More information, including high resolution copies of the images used in this paper, is available from http://wordpress.mrreid.org/the-physics-of-the-data-projector/ or http://snipurl.com/2mvnx. The equipment used in the creation of this paper can be borrowed on a short-term basis; please contact the author for details.

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Alastair Reid graduated from King's College London in 2002 and teaches Physics and Science in Surrey, UK.