Computer Graphics for Scanned Laser Displays

By Patrick Murphy and William R. Benner, Jr.

Projected laser displays, such as those for laser light shows, often use computer-drawn graphics, which are scanned onto the screen. These vector drawings have restrictions imposed by the laser projection equipment. Conventional vector graphics programs such as AutoCAD™ do not work well for laser display use. This necessitates laser-specific computer software. Current laser-scanning techniques are introduced in this article, which emphasizes the limitations of scanner technology and suggests remedies. Considerations for the design of laser graphics software are then set forth, and current laser systems are discussed, with an in-depth example using software developed by the authors. Future directions for laser display, scanning technology, and software are also reviewed.

Projected laser displays are by now commonplace. They are seen in applications such as planetarium shows, amusement parks, discos and nightclubs, and special events. There are four main elements used in laser displays:

• Beam effects. Still or moving beams are seen in midair, usually in combination with smoke.

• Interference effects, or lumia. The laser beam passes through a distorting medium such as textured glass, producing soft, gauze-like effects.

• Abstract graphics. The beam bounces off moving mirrors. The simplest system uses mirrors attached to loudspeakers for direct music visualization. More advanced systems use mirrors on galvanometer scanners, driven by oscillators to create abstract Lissajous (spirograph) patterns.

• Representational graphics. Mirrors on scanners are moved under computer control to create drawings, logos, text, and other random-scan vector images. Because they are vector, the graphics are cartoon-like outlines or simple wireframes, with no area fill.

Because this article is primarily concerned with representational graphics, the term "graphics," as used throughout, refers to this most complex type of laser-projected display.

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The requirements for a laser graphics display are conceptually simple: a laser producing visible light, a projector that scans the laser beam in horizontal and vertical directions, and a computer or similar system to drive the laser scanners:

• The laser. Display lasers usually are filled with a gas containing helium, neon, argon, or krypton in various amounts. These are available in a variety of beam colors and output powers. For the purposes of this article, the laser is merely a light source enabling graphics to be viewed.

• The projector. This contains scanners and the color system — everything except the laser and signal source. Typically, a multicolor beam (e.g., containing red, green, and blue wavelengths) goes through a color-selection device. The resulting beam passes through a shutter, used for safety and aesthetic reasons in case the color device cannot fully extinguish the light. The beam finally is moved horizontally and vertically using X-Y scanners. Figures 1-6 show different types of color laser projectors.

• X-Y scanners. Laser projectors are based around a pair of galvanometer scanners. A tiny mirror, typically 5x8 mm, is attached to each scanner's shaft. The scanners are positioned so the laser's beam first strikes one mirror, which scans horizontally, then strikes the other mirror, which scans vertically, and finally travels to the display screen. This combination of X and Y scanning makes possible random-scan vector drawings.

Until recently X-Y scanner technology has been surprisingly uniform throughout the professional laser display industry. Most graphics systems use closed-loop moving-iron scanners from General Scanning Inc., usually model G-120. Some low-cost systems use open-loop scanners from the same company, usually model G-124. Although many laser show companies wanted improved scanner technology, the ubiquitous GSI products had a beneficial effect: they were one of the few *de facto* standards in the laser industry.

Recently, scanners and scanner amplifiers from Cambridge Technology Inc. have become available. These appear to give a performance improvement of 1.5 to 3 times that of G-120 scanners, depending on which scanner amplifier is used with the G-120. An industry group is attempting to define speed standards; one for older G-120 type technology and another for faster scanners such as those from Cambridge.

• Scanner amplifiers. These condition and amplify the drive signal for the scanners. The better they do this, the better the resulting graphics.

Closed-loop amps use a feedback technique to tightly control corresponding closed-loop scanners. Open-loop amps have no direct feedback link to open-loop scanners. Techniques sensing back-EMF (electromotive force), caused by the scanner's resistance to movement, can synthesize feedback and partially compensate for this deficiency.

There are many different sources for scanner amps — almost one for each laser show company. Unlike the situation with lasers and scanners, a display system designer can significantly improve system performance by his or her choice of scanner amplifiers.

• Blanking. One important function of a projector is to blank the beam, or turn it on and off. This allows discontinuous graphics to be drawn — traces connecting different parts of the image cannot be seen. Blanking control is usually handled as a subset of intensity and/or color control. For example, all colors go to zero when blanked points are being output.

• Intensity and color. Many different ways have been developed to control intensity and color in a laser projector. The most common today are scanner based, where a scanner moves or chops a beam, and acousto-optic modulator (AOM) based, where a special crystal optically diffracts a beam based on a driver signal.

The intensity and color subsystem is probably the key area distinguishing different projectors. The talent of a display system designer is most rigorously tested here.

Unfortunately, the many methods of controlling intensity and color make it difficult for the laser graphics software designer. In the past, software was designed to support one or a few types of devices. Recently, more systems have developed "universal" outputs that can run any type of intensity and color devices.

• Other projector components. There may be many other devices in the projector, such as solonoid-activated mirror positions for creating beam and lumia effects. These do not require sophisticated computer controls and therefore will not be further discussed here.

• Laser graphics drivers. Representational graphics are almost always digitally created. A computer outputs a series of voltages designed to control the X and Y scanners and the intensity/color devices. These voltages can directly drive the laser projector, or can be encoded on tape using frequency modulation or pulse-code modulation techniques for later playback. (The voltages cannot be recorded using standard tape recorders as they often contain unrecordable direct current [offset] voltages.)

The preceding has been a necessarily brief overview of laser display systems. Two more detailed discussions of this technology are a 1982 paper by Ken Deaton[1] and a 1991 article by Ivan Dryer.[2]

Vector Images for Lasers

Any description of laser graphics has to take into account the special requirements of these vector images. These include the differences between laser vector graphics and raster graphics, and the limitations of laser-projected vectors. (Strictly speaking, "vector" implies polar coordinates such as those seen on a vectorscope used to monitor television signals. The term "vector" will be used here in the broader sense of specifying only endpoints of a line — whether in polar or Cartesian coordinates — as opposed to specifying every pixel in a line to be drawn, e.g., raster.)

Laser Graphics vs. Raster Graphics

Laser displays are almost always done using vector computer graphics. The primary reason is that vector graphics provide brighter images than raster graphics, for any given laser source. Although display lasers are extremely bright, their light is concentrated in one small area — total optical power ranges from 0.02 to just 20 W. Instead of enlarging 20 W of light to fill a screen, and then only turning on desired parts (pixels), the vector technique allows maximum brightness, as only the drawing itself is imaged.

Unfortunately, laser beams are difficult to steer. Unlike electron beams in cathode ray tubes (CRTs), laser beams are made of uncharged photons. They do not respond to magnetic fields, so brute-force methods are necessary. As described earlier, galvanometer scanners with tiny mirrors are almost universally used for X-Y deflection.

This introduces the problem of controlling these moving mirrors. The scanner shaft and mirror have enough mass to possess significant inertia. This limits random-access vector drawing to a useful bandwidth of less than 2,000 Hz.

It should be noted that raster laser projectors have been successfully operated, generally using rotating polygonal mirrors for high-speed horizontal scanning and fixed-frequency galvanometer scanners for medium-speed vertical scanning. Once such a device is constructed, the input to it is essentially the same as to a projection CRT, and thus need not be further discussed here.

Laser Display Advantages

Much of this paper is devoted to limitations of laser display. In fairness, we should mention four significant advantages that make laser displays a viable and desirable medium. First, they can project very large images. This is used in shows that scan onto such "screens" as Stone Mountain in Georgia, Grand Coulee Dam in Washington State, and Niagara Falls. Second, the pure, highly saturated colors of laser light glow with an eerie shimmering. This "laser speckle" is due to optical effects of the laser's coherent light that actually occur on the retina, making the light literally eye-catching. Third, the contrast ratio is extremely high (over 100:1) — images seem to float when seen in a dark environment such as a planetarium dome. Fourth, nongraphics effects such as large Lissajous patterns, wispy lumia, and city-spanning laser beams are difficult to achieve with other media or techniques.

Laser Display Limitations

One branch of computer graphics uses oscilloscope-type CRTs for displaying vector graphics, in applications such as computer-aided design (CAD), flight simulation, and arcade video games (two well-known examples are Atari's *Asteroids* and *Battlezone* games from the early 1980s). In a CRT-based system, the computer simply specifies the vector endpoints. Hardware circuits manage the stroke, evening out the vector drawing speed. This is not usually done with laser projectors.

Laser vectors cannot be stroked nearly as fast as CRT vectors. For example, laser graphics must dwell around 300 msec at corners and at stroke endpoints, to avoid overshoot and ringing. The dwell time is usually added not in the projector hardware, but by adding extra points into the image.[3] In other words, the software manages the stroke, attempting to achieve constant velocity.

A typical line might have 22 points: at the line start location there will be 5 blanked, then 3 visible "anchor" points; 6 points along the line, and at the end location another 3 visible and 5 blanked. With high-performance scanner amps, the same line could be improved to about 13 points.

This means that a large number of points are used simply for velocity compensation. Compounding this problem, the laser-projected image fades faster than the same image drawn on a CRT. This is because the laser cannot rely on phosphor persistence — only on the eye's natural persistence of vision. Only about 700 discrete points can be drawn before the image begins to flicker objectionably. ("Objectionable" is a relative term; in the authors' experience, many laser artists are less bothered by flicker than are audience members.)

The result is that lasers cannot do detailed AutoCAD-style vector drawings. The number of vectors in a low-flicker image is on the order of 50 or less. This is why 2-D laser light show drawings tend to be cartoon-like outlines, and 3-D objects are almost always wireframes.

Because of these laser display limitations, common computer graphics programs such as AutoCAD are not well suited for laser drawing tasks. One major laser display company tried using a commercial computer-aided design (CAD) program for creating 3-D objects. They then converted the data for laser use. The main problem found was in vector sorting. For complex objects, vectors were drawn in a haphazard order, which significantly slowed the effective scan speed. This and other problems were intractable enough that the company is considering moving back to laser-specific drawing software in its next-generation design.[4]

Advances in Display Laser Technology

These limitations have bedeviled laser system designers ever since the scanning technique was developed in the mid-1970s by Ivan Dryer of Laser Images Inc. for the first Laserium™ shows. To achieve higher graphics performance, Dryer and others gradually moved away from open-loop scanners to the more expensive but more controllable closed-loop technology. Today, nearly all professional graphics projectors use closed-loop scanners.

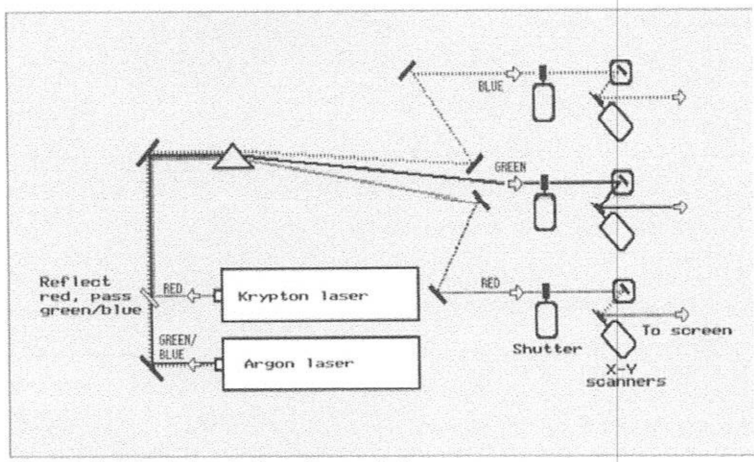

Figure 2. Multiple single-color beam laser projector.

In the past half decade, there have been at least three major advances in laser display technology. The first is improved lasers, especially designed for the needs of laser projectors. The second is intra-image color via mixing of red, green, and blue beams in a manner analogous to RGB mixing in television. The third change has been increasing sophistication in computer graphics software applied specifically for laser vector drawings.

These changes had a synergistic effect on each other. New-generation mixed-gas lasers have made it possible to get a good balance of red, green, and blue light from a single laser. New-generation software was able to output red, green, and blue signals on a point-by-point basis. These helped speed the introduction of projectors capable of producing a full-color image. (Full-color is another relative term. Due to limitations in available laser wavelengths, most RGB systems' color gamut is weak in red and blue, resulting in a somewhat restricted choice of colors.)

The improvement in computer graphics for lasers, of course, was not limited to RGB capability. Features such as 3-D data bases and graphic user interfaces (GUIs) are now standard for laser computer graphics. But before looking at current systems, we will first examine elements unique to the design of laser graphics software.

Considerations for Laser Graphics Software

Background

A laser graphic is essentially a connect-the-dots drawing. A typical frame is made up of 300 to 1500 points. At minimum each point has an X and Y spatial coordinate and a color coordinate. In simple systems, the color is either draw (pen down) or blank (pen up). More advanced systems use lookup tables for the color, while the most advanced store the actual red, green, and blue values for each point. Systems using three-dimensional calculations include a Z spatial coordinate. Pangolin is developing a system which also adds an F, or focus coordinate, to control the beam size at each point.[5]

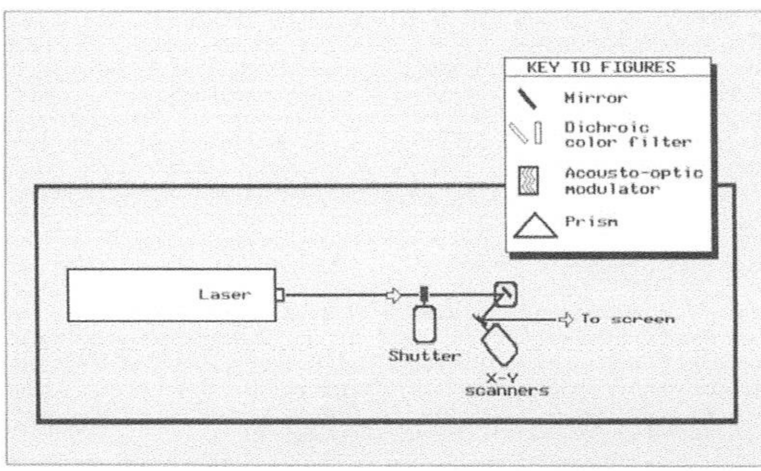

Figure 1. Single-color laser projector.

Spatial Resolution

Commonly, the X, Y, and Z coordinates are stored in resolutions of 8, 12, or 16 bits each. Given the natural smoothing action of the scanning technique (one of the few benefits of the scan mirrors' high inertia), the visible limit of resolution is approximately 10 bits. That is to say, the eye has difficulty perceiving any difference between frames and animations shown at 10 bits versus higher resolution.[6]

Eight-bit spatial resolution, while noticeable, is sufficient for low-cost applications, especially those where laser graphics are not the primary focus of attention (e.g., discos). In higher-resolution systems, the choice between 12 and 16 bits depends on the software design. For example, if image data is post-processed in the computer to produce digital rotations, translations, etc., then 16 bits may be preferred to avoid any possible computation rounding errors.

Intensity Control

Since most laser projectors use the same type of scanning devices, there is not much variability between systems in terms of how X, Y, and Z coordinates are handled. However, there are a number of different techniques for intensity and color control. In fact, intensity is often controlled separately from color, multiplying the possibilities. For "universal" laser graphics systems, the designer must provide for as many different devices and techniques as possible.

Here is an example. For intensity control, a projector will have either:

• No intensity device. The beam is always on. It is possible to draw many graphics with few or no visible traces between graphic elements, so this is an option in low-cost systems.

• Digital intensity device. The beam is either on or off. Usually implemented with devices driven by transistor-transistor logic (TTL) level signals.

• Analog intensity device. The beam can be faded in intensity. Usually implemented with devices driven by signals between 0 and 5 V.

The computer graphics system should handle all three possibilities. For example, Pangolin's system provides both a TTL-level digital output and a 0 to 5-V analog output. For systems with no intensity, the computer palette is adjusted so normally invisible blanked lines are drawn in a visible color. These accommodations are easy to implement.

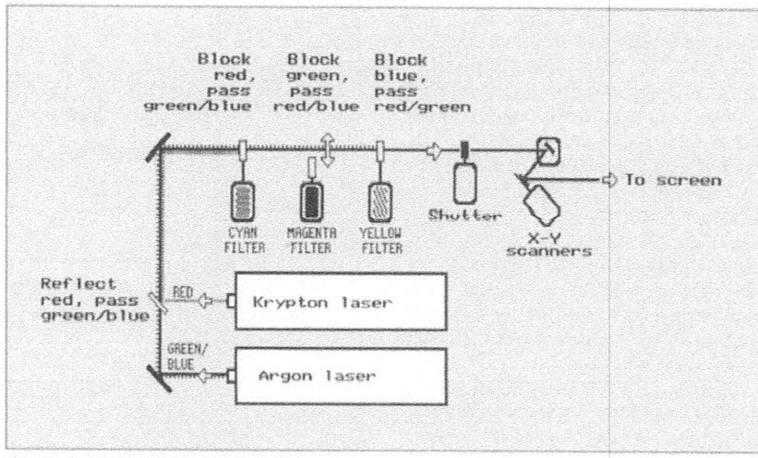

Figure 3. Digital color laser projector.

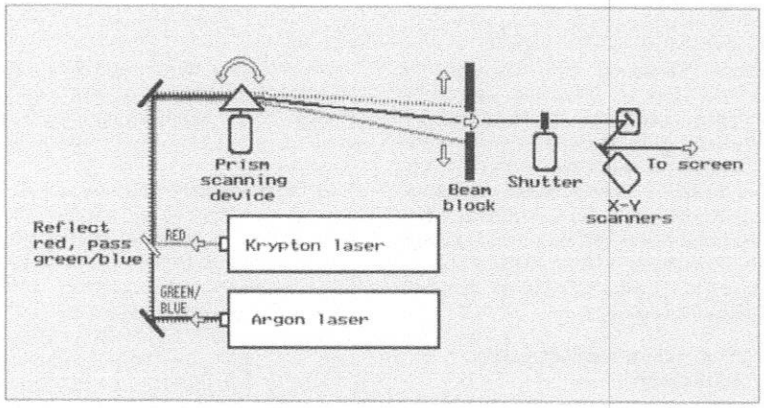

Figure 4. Single-channel analog "prism" color laser projector.

However, to truly complicate matters, intensity devices vary in speed. If an acousto-optic modulator is used, it operates much faster than the associated X-Y scanners. This means that a command to turn the beam off at a certain point will take effect before the beam reaches that location. Few systems have hardware compensation for this time difference, so the adjustment is usually done via software.[7]

If a graphics system is designed for a specific projector, the desired lag or lead time can be hard-coded into the software. However, systems designed to work with any projector must have variable lag/lead times. This is usually expressed as a point offset, meaning when the command to move to a certain point is given, the intensity is picked up from previous or subsequent points.

Color Control

The previous discussion concentrated on intensity devices. These devices are also used in color laser projectors. Now the designer's job is further complicated because there may be a single color signal sweeping across the visual spectrum, or three color signals, one each for red, green, and blue. (One company even markets a projector requiring two color signals, red and green/blue.)

Most color projectors use the color device for overall intensity control. However, a few have a separate intensity device that works on the final, mixed color beam. For these systems, there will have to be separate signals and separate point offsets for intensity and color.

The following is a brief discussion of the major types of color laser pro-