CONSIDERATIONS IN THE DESIGN OF A LASER GRAPHICS SYSTEM

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ABSTRACT

Lasers offer a novel display technology with many unique properties. The sides of the beam remain parallel rather than diverge, consequently its projection is in focus at all distances and angles. The beauty and power of the multi-coloured output makes the laser ideal for applications requiring large format, long throw or high intensity display of low speed vector information. Because of the limited bandwidth of the deflection units, it is possible to digitally create and manipulate graphics under real-time control. Principles of laser operation and scanning techniques are reviewed for background purposes. The visual qualities of the beam are evaluated and problems in raster scanning and colour mixing are brought out. Non-scan visuals such as interference patterns and holograms are presented as alternative forms of non-electronic image formation and processing which rely on the phase coherence of the laser light. Finally, the highlights of a laser graphics system using a distributed intelligence architecture are outlined for a current design.

KEYWORDS: laser graphics, low speed vector scan system

1.0 INTRODUCTION

In the eighteenth century, Diderot spoke of the power of painting to awe him, to inspire him, to "regale his eyes" and move him to deep emotions. In the twentieth century, the brilliance and purity of the laser beam inspires a similar response, breathing wonder into the tired modern soul. Its vibrant imagery may be projected onto large screens, domes, or even clouds. Because of the negligible diffusion of this highly concentrated light source, the display yields unusual intensity, saturation of colour, and resolution, even when projected across great distances.

The limited bandwidth of the electro-mechanical deflection systems has relegated laser graphics to the class of low speed vector display, but the bandwidth also makes it possible to generate certain kinds of dynamic imagery under real-time control.

As a projection light source, lasers can be used for large screen or long throw, high luminance graphics. Laser graphics systems are most often found in commercial applications competing against multi-media presentations at tradeshows and conventions. Laser imagery is also used abstractly for its intrinsic visual richness, and semi-representationally to mimic, pun, or suggest certain kinds of experiences which are associated with the synchronized music in an entertainment format which is the 1980's extension of the lightshows of the 1960's. Currently, art colleges are also exploring laser technology and finding it has an important position in the photo/electric art movement.

1.1 APOLOGIA

Further interest in laser graphics may be justified by viewing its position in the overall landscape of computer graphics. Two major trends may be discerned:

On one hand, hardware intensive high-density raster displays with frame buffers typically as deep as 24 bits are supported by a host computer in addition to a graphics processor. The cost of this set-up was not a prime consideration in its development — much of the technology was pioneered by the military or in conjunction with the space program.

On another hand, the immense utility of vector graphics in modelling, especially three dimensions, led to software intensive systems for CAD/CAM in industry. The high level graphics packages for stroke displays required large minicomputers to run on. Here too, the cost of the technology put it out of reach of the non-corporate user.

On yet another hand, laser graphics force the design of strong but limited systems where the bandwidth places an upper bound on the complexity of the imagery but allows for real-time transformations and manipulations. Images may be quickly synthesized without the use of the terminal as the principal input channel. Graphic artists in commercial and entertainment fields have a distinct preference for the expressive control offered by pots, faders, joysticks, bit pads, and light pens over the syntax burden and linear mind-set too often imposed by high level languages.

Lastly, the low cost of the microprocessor based technology and its applicability to other X-Y display devices should bring real-time digital graphics to low budget users. In conjunction with the laser as a light source, this image synthesizer creates a visual spectacle which provides a radiant symbol of twentieth century technological achievement.

2.0 BASIC LASER THEORY

The basic theory behind a krypton ion laser is that it's the world's most expensive four-colour light bulb. But this is only true if we don't take into account the phase coherence and other optically unique properties of the laser beam. Perhaps it is best, though, to explain the four-colour output since this fact clashes with many people's concept of the laser's so-called "monochromaticity".

Our experience of "redness" is related to the distribution of wavelengths which we perceive in that end of the visual spectrum. A common "red" object lit by the sun will reflect a smear of red wavelengths which we gestalt as a particular shade. Monochromaticity refers to a spectral composition which is discrete and not a continuous smorgasbord. In a laser's output, there may be more than one colour present, but each "line" is tightly defined by the phase characteristic of the plasma resonance relative to the cavity resonance. This effect is minor and the laser can be seen as a multi-frequency oscillator where each colour is composed of a single wavelength.[1]

The number of colours a laser emits is related to the quantum physical properties of the lasing medium. Generally speaking, there will be one line for each stable energy state electrons might assume when they are excited or are returning to ground-state after excitation. The ubiquitous HeNe laser seen in many labs and schools produces only one line of ruby red with a wavelength of 632.8 nm because there is only one visible energy jump; a mixed gas KrAr will produce 15 lines at different wavelengths from ultra-violet to deep red, because of the numerous transition levels electrons pass through before reaching the energy for population inversion.

The krypton ion laser is the most often seen in graphics applications because it lases with lines of blue, green, yellow, and red. This, in theory, permits colour mixing to obtain intermediate hues. An argon ion laser has six lines in the blue-green portion of the spectrum with a large part of its output split between a pea green at 514.5 nm and an emerald blue at 488.0 nm. Usually the argon beam is used unrefracted for high power writing on clouds or forming beam matrixes in smoke-filled rooms.

A 1-watt krypton laser will brilliantly illuminate a 100 square metre screen at 20 metres. It might cost about $20,000 USD, will be about a metre long with a knee-high power supply, and will definitely require three-phase power and water cooling. The milliwatt output of the HeNe laser (which runs off 117 VAC) might adequately demonstrate scanning principles in the classroom but the intensity desired for large displays requires 15,000 watts of electrical energy to be converted into light with excess heat dissipated by flowing water. No one ever said they were efficient.

3.0 SCANNERS

The only methods to deflect a beam of light are optically with a mirror, or gravitationally with a black hole. Of these two possibilities, the former is used more often in graphics applications. A "scanner" is a precision galvonometer responsive to changes in current. This electromechanical device torques a small mirror attached to its shaft (10 mm x 10 mm). The movement of the mirror directs the beam in one axis on the image plane. In order to get two orthogonal axes two scanners are positioned at right angles to one another and the scanned beam of the first mirror will reflect off the second mirror. Note that the projection angle is twice the deflection angle of the scanner relative to the incoming beam or plane of light. (See fig. 1)

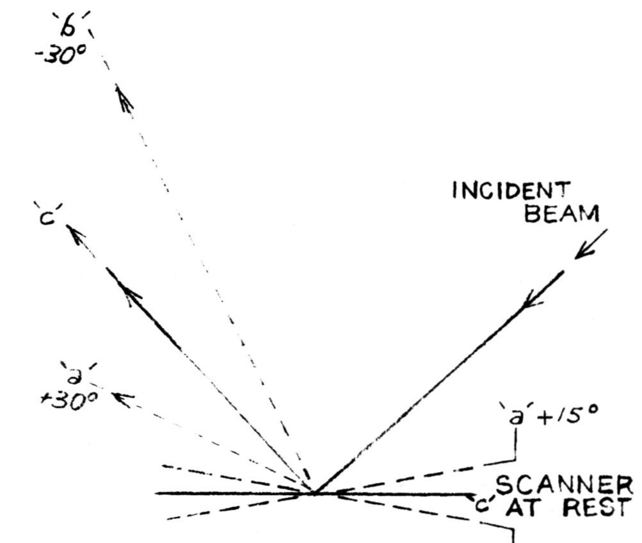


Fig.1

Some scanners are capable of covering 60 degrees of visual angle over their usable bandwidth, but nothing is perfect, and open loop scanners remind us of that rather often. Because of the mass ergo inertia of the scanner and the nonlinearities of the electromechanical transduction, hysteresis manifests itself as "ringing", "overshoot", "corner-rounding", and "hot-spotting". Remnant magnetization of the windings, resulting in non-zeroing after high amplitude signals are applied, can cause alignment problems between scanners as well.

People with HeNe's are inclined to economize on scanners by glueing mirrors to loudspeaker voice coils, but these rarely boast more than a highly unfaithful 150 hz bandwidth.[2] The state-of-the-art is currently set by position feedback scanners which output signals corresponding to current position and velocity. These can be employed in a feedback loop to correct for positioning, thereby overcoming the open loop distortions.

It is best to close the loop at the scan amp which converts the stream of digital words or analog control voltage through PDM into the current to drive the scanner. By monitoring the input signal and anticipating large velocity changes, a bias signal can be applied to counteract momentum effects. Commercially available closed loop scanners cost about $1000 USD, and it is possible to obtain a 2khz bandwidth over a good scan angle, and 3.5 khz with very small deflections. Compared to raster graphics or a stroke CRT, this is quite limited and lasers have to justify their utility in other ways besides bandwidth.

3.1 VISUAL QUALITIES

Fortunately, the visual qualities of the laser are outstanding. While the contrast ratio of a CRT might be 50:1 and film might be 70:1, the laser's is 300:1. In low ambient light conditions, this and sheer luminance will overpower people conditioned by CRT viewing. Aspect ratio is only limited by scanner arc and electronic correction for the skewing distortion of off axis projection permits a degree of freedom in setting up at odd angles. There is usually no persistence associated with the screen which should just be a high gain reflective surface. The reflective and diffusive properties of the screen material will determine the dot size, but two inches across is typical. Of course, rear projection can be used too, with appropriate cautions to avoid possible hazards to viewers.

No optical correction is needed for keystoning because the pixel is in focus at all distances. The non-divergent aspect of the laser beam creates an infinite depth of field. Over very long distances, beam expansion will be noticed, but collimation will shape any beam to the desired profile.[3]

3.2 RASTER SCANNING AND COLOUR MIXING

In order to accomplish raster scanning at NTSC rates, two basic problems must be solved: first, the laser must be able to scan the 15.75 khz sawtooth on the horizontal and the 60 hz staircase on the vertical; second, the drastic power drop accompanying modulated intensity as opposed to modulated position scanning. Perhaps the fixed frequency nature of the scan will allow a custom scanner (eg. a rotating polygonal scanner) which will function over a small angular range. Assuming we want RGB, the power problem is not so easily overcome. To brute force it, a 3 watt krypton has a ten foot long head and often runs off a generator; obviously, this is not what we are looking for. Separate lasers for each colour also leads to huge expensive systems. Additional complications like the increased mass of the heavy duty mirrors needed for high power scanning causing greater inertial distortion incline us to believe that raster scanning lasers aren't feasible with current technology.

Colour mixing to obtain a full spectrum beam is certainly possible, but one clearly superior and economical approach has not emerged. The raw krypton beam must be refracted by a prism into its components, which are individually attenuated and recombined. One device which should definitely be considered as an intensity control device (ICD) is the acousto-optic modulator, which works like an electronic diffraction grating where the gain of the RF control signal determines the transmissivity of the first order beam and the frequency determines the angular displacement. Insertion loss is about 10-30 per cent, but blanking bandwidth extends into the megahertz. Off the shelf, an A/O with its RF amp is about $1000 USD, but the five watt, 60 Mhz, 30vp-p carrier circuit is about half the cost, and can be easily fabricated.

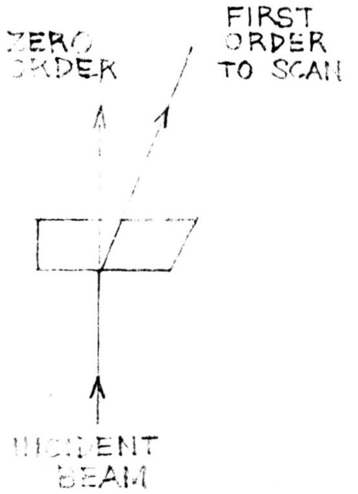


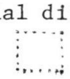
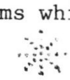
Fig.2 (Note 4)

3.3 NON-SCANNED IMAGE FORMATION TECHNIQUES

Many interesting optical phenomena arise because the beam of the laser travels in one direction and doesn't disperse like other lights, both artificial and natural. The light is coherent, that is the distance between wavefronts remains constant, and as a result, interference patterns are caused by translucent materials which act to randomize the phase of the light. These non-scanned images add an important class of images to the laser vocabulary which cannot be created through any scan technique. The closest relations to this look are the watery colourizer effects of analog video synthesis. The effect produced varies greatly depending on the glass or plastic used, the way it is treated and its orientation in the beam, but often a webby, nebulous form will change composition as the material is moved. Many of the best effects can be purchased in the shower-door and fluorescent light cover department of hardware stores.[5]

The word most often associated with laser must be hologram. It would appear (the whole problem with holography has to do with appearances) that there are a number of misconceptions concerning this remarkable form of photography. Speculative science would have us believe that in the near future we'll be watching three dimensional technicolour movies at home. Unfortunately, reality falls short on three big points. First, holograms do not, as of yet, really move. There are multiplex holograms produced from 35 and 16 mm film which only capture horizontal parallax and time but are not true "feelies". Second, holograms are monochromatic, taking the colour of the viewing laser,or anchromatic, being black and white. When white light is used to illuminate the holographic plate, as in a reflection hologram, the colours of the spectrum are all present, but not in a way which corresponds to the colouring of the object. A full colour technique remains to be perfected. Third, although holograms can be projected into free space, the severe limitation is the close proximity of the object and the recording medium.

The holographic image is a reconstruction either in front of (real) or behind (virtual) the holographic film plane which occurs as the viewer looks through the film while a beam is passing through. There is considerable difficulty in making large enough holograms to be viewed by more than one person, let alone a mass audience.

There are more things to do with holograms than just to see a spatial portrayal of Mickey Mouse ears. In the category of regular (pre-fabricated) holograms, there are many different kinds of diffraction gratings. These provide a fixed technique of multiple instantiation. By projecting through a one axis diffraction grating, copies of the image will appear along the axis at right angles to the grooves of the grating. The number of orders and their intensities is determined in the holographic process. If the initial beam/image is moved (the zero order copy) then all other images will move likewise. Diffraction gratings can be crossed for matrix arrangements or rotated for real fun. There are also special diffraction holograms which give square  or cluster  backgrounds.

4.0 SCANNED IMAGE GENERATION

In older analog machines, image synthesis was primarily accomplished through the addition of several fixed waveform oscillators onto the X and Y axes. These closed linear forms are known to engineers as Lissajous figures, and they are often seen on oscilloscopes to display the relationships of phase, frequency, and amplitude between two signals. Simple trigonometry will demonstrate, for example, that two equal amplitude, equal frequency sine waves, 90° out of phase, will form a circle centred at the origin. This is a basic quadrature oscillator. By combining a large number of oscillators tuned harmonically it is possible to create rotationally symmetric mandala-type patterns. Slight frequency and phase differences will animate the figure and DC offsets will position it in the XY plane. The most sophisticated analog projector is used by Laser Images, Inc., of Van Nuys, California in their Laserium productions seen in many cities across North America.[6]

The ability to enter hand drawn graphics by bit pad and frame animate by sequential accesses of stored points immediately makes a digital system incomparably superior to an analog one. Information on current systems is scanty, but it would appear that all known designs are microprocessor based, using an 8 bit word to represent position on one axis.[7] Of course, this seems like very low resolution but in the context of projecting graphics onto screens no larger than 10 metres on a side it is marginally acceptable. If the beam terminates in a dot 5 cm across then 256 pixels per axis will result in only slightly objectionable jagees when the beam moves diagonally at a slow rate.

In order to avoid staircases at long distances such as in sky writing, the position word must be 12 bits. This is indistinguishable from analog in its resolution. By maintaining a 16 bit data path arithmetic operations may be carried out to greater precision. Of course, this necessitates a 16 bit processor to keep up throughput. It has been found convenient though to use an 8 bit processor as well to download new parameters of operation to the 16 bit processor through a dual port RAM.

The essential distinction to be made between the functions of the two CPU's is that the smaller one is operating on quasi-static parameters, those changes which occur as a result of user initiation. The larger and faster processor provides the control for a group of recirculating RAM "oscillators". Compared to the bandwidth of computation for real-time rotation, changes in parameters caused by the operator altering controls on the console do appear to stand still. The 8 bit processor provides interrupt driven pot scanning, stores updated values in the "post-office" (one might imagine a wall of cubby holes where one processor stuffs messages into one side of the box to be removed by the other), and supports the terminal with its command language. The 16 bit processor picks up the information and performs the needed computations using outboard multipliers and other resource units on a time-sliced bus.

Though the sample frequency can be less than a quarter of that needed in audio synthesis, the number of simultaneous lines causes a very high rate of data flow. Almost any architecture would want separate outputs for the X and Y axes of four scanner pairs (one for each line in krypton) and intensity control for up to four A/O modulators. One of the consequences of this throughput is that it is difficult to economically store the actual signals on anything except a video recorder (although 16 track studio recorders and FM instrumentation recorders were adapted for this purpose in the analog days). At more than 1 megbaud, it isn't practical to store animation sequences of more than a few seconds.

The oscillators access RAM which might represent the digitized sine wave in a waveform buffer. Through digital synthesis, lissajous figures could be created which emulate whole analog complements by combining the different simple waveforms into a complex composite one which is also stored in RAM. It is also possible to generate interesting imagery through waveshaping synthesis and digital FM.

If the contents of our memory correspond to the points entered via bit pad and they are accessed 30 times per second then the waveform buffer is functioning as a frame buffer. Key frame animation or "inbetweening" can be done, even in realtime, by adding and shifting right corresponding points in two frames to interpolate an intermediate frame. Peter Foldes' 1974 film "La Faim" is an impressive example of keyframing low information images with standard computer graphics equipment.

Special consideration must be given to the console ergonomics, especially if the projector is performance-oriented. Often, standard three quarter turn pots don't have the resolution needed to fine-tune image construction. Software control of virtual pots implemented via CRT or scanned and converted analog potentiometers allows pot range or step size to be set to match the parameter. Bit pads, damped joysticks, switches and faders are also needed to control the different intensity devices and oscillators while a terminal is needed for interfacing to the command language. 8

5.0 SUMMARY

Hopefully, laser graphics has been presented as an interesting subset of computer graphics. Besides its spectacular visual qualities, a laser graphics system offers the user real-time image synthesis and transformation. The special property of beam phase coherence is responsible for the intriguing interference patterns and holograms which are unique to this medium. The beam's non-divergence allows simple keystone correction and infinite depth of field. By employing a distributed intelligence architecture it is possible to exploit the sophistication and accuracy only possible with computer control. It should soon be possible to see artists exploring affordable visual synthesizers as the technology develops and drops in price.

6.0 REFERENCES

1. The laser may be considered as an optical oscillator whose inherently low gain is overcome by massive input power. Resonance is related to the atomic/molecular properties of the lasing medium and feedback is provided by the optics of the laser's resonant cavity.

2. One of the very few articles on lasers for graphics suggested this approach. See "The Amateur Scientist", by Jearl Walker in the August, 1980 Scientific American.

3. Laser beams do diverge hyperbolically. For short distances, this is scarcely noticeable but in high power argon cloud writing, the beam expands 5-7 cm/km of travel.

4. A detailed explanation of these devices is given by Robert Adler, Zenith Radio Corporation in the IEEE Spectrum, May 1967.

5. T. Kallard's Laser Art and Optical Transforms discusses different caustics and documents their differences with many photographs.

6. This company and its founder, Ivan Dryer, basically discovered laser graphics in 1971. Since then more than 10 million people have seen Laserium. A very articulate and informative review of Laserium by Andrew Kagom may be found in March 1978 Arts Magazine.

7. Lighting Dimensions gives superficial treatment to Soleil Laser Productions in April, 1978 and Lovelight in October, 1979.

8. System Block Diagram