So you want to build a virtual reality system? If you think the cost is too prohibitive, here's how to do it on a shoestring budget

by Robert Suding

Low-Cost VR for the Virtual Hacker

How much is too much? The present cost of equipment for a VR setup may not seem like a lot to the owner of a boardwalk games arcade, but $7,000 for a head mounted display (HMD) and $15,000–$40,000 for a complete system is too much for the hobbyist. I will show the hobbyist how to build a VR system for less than $1,000 and how to purchase or build VR games, simulations, and business application software for the system at low cost. I will concentrate on the two most basic elements, the low-cost HMD and the hardware and software interfacing of the HMD with a standard 486 clone system.

BUILD IT YOURSELF

Commercially available three-dimensional VR headsets start at about $7,000. By using two LCD TV sets and some low-cost optics, a hobbyist can cheaply build a reasonably good VR headset. This design uses a pair of $2\frac{7}{10}$" TV sets from Radio Shack. These sets list for $200 each and are frequently on sale for $170 each. Another possibility is to use the LCD from the Sega game "Gear," which sells at Toys-R-Us for $100 each, half the list price of the Radio Shack LCD. However, the LCD is about $\frac{1}{4}$" wider, and since Sega won't provide me with documentation, the solution to the center-to-center spacing problem may be more costly. The three-dimensional effect requires each eye to see a slightly different image to give the illusion of depth. The first consideration is the human variation in eye spacing, which varies from about 2" apart to almost 3" apart. The most common eye spacing is slightly less than $2\frac{1}{2}$" apart. The center of the images must be set to equal this spacing for the least eyestrain.

The Radio Shack $2\frac{7}{10}$" TV has a diagonal LCD measurement of $2\frac{7}{10}$". However, the critical measurement is the width of the unit. The LCD has a horizontal measurement of $2\frac{1}{4}$", but the width of the TV is $3\frac{5}{8}$" ($3\frac{3}{8}$" without antenna). If the case and LCD housing can be eliminated, the TV has definite possibilities. The TV has built-in batteries and a speaker, which add considerably to the weight/balance problem when considering that they must be hung at a slight distance in front of the user's eyes. Issue 9 of *PCVR Magazine* has a step-by-step description on how to disassemble and modify these TVs for use in a VR headset, or the instructions are available directly from me.

These low-cost LCDs are a great way to get started, but they do have limitations. The horizontal resolution is rather poor, about 200 pixels across. If you try to magnify the image too much, you will become painfully aware of this poor resolution. Still, it's the best show in town.

Radio Shack also sells a direct NTSC patch cable for these TVs for $19.95, and a complete service manual is available for $4.50. A smaller version is also available, but does not offer the NTSC direct feature. I use the NTSC to couple a pair of camcorders to my LCDs.

The service manual shows that the LCD assembly includes the distinct possibility of separation from the TV tuner part, since the cable between the tuner board of this TV and the LCD assembly carries RGB signals, not NTSC at that point. This means that an RGB driver from a PC video system can be used without further degradation from converting to NTSC.

At the turn of the last century, a device call a Stereopticon or Stereoscope was developed that used a combination of prismatic wedge and lens to focus on stereo pictures on a card that had images about 3¼" apart. These devices used lenses that were ground asymmetrically so that one side was much thicker than the other side. You can duplicate the effect from stock optics by purchasing a prismatic wedge and a plano convex lens set. Get a pair of five degree Prismatic Wedges (Edmund Scientific P30265 —$41.75 each) to provide a suitable image divergence, and a pair of plano convex lenses for focusing your eyes on the very close LCDs.

I have experimented with several sets of Edmund plano convex lenses of varying focal length and have found three promising candidate lens sets. A 45mm × 78mm plano convex lens (Edmund P94828—$9.85 each) gives the widest angle, but requires grinding off the plastic frames of the LCDs to reduce the center to center spacing of the LCDs due to the low amount of divergence from these close focusing lenses. The 60° viewing angle is very impressive, but the 200 lines of horizontal resolution on the LCDs are very distracting. Another potential lens set is the irregular-shaped 57mm × 110mm plano convex lens (Edmund P96026 —$8.25 each), which gives about a 35° viewing angle, a bit too narrow for my liking, but the 200 lines of LCD resolution are much less distracting, and the longer distance from eye to LCD gives adequate divergence by the prismatic wedges so that the plastic frame of the LCDs does not have to be cut back. The best compromise is a set of 40mm × 92mm plano convex lens (Edmund P96019—$6.05 each), which gives about a 45° viewing angle, and the LCDs either can be cut back or not, depending on your eye spacing. I would recommend cutting the LCD frames and using these lenses. The parts cost will be about $435 for the left and right LCDs, wedges, and lenses.

REDUCE THE SPACING OF LCDS

If the TVs are now placed side by side, they will be about 3" apart. A pair of five degree Prismatic Wedges (Edmund Scientific P30265 —$41.75 each) will cause your eye path to diverge instead of converge, but this divergence is not very great, and if your eyes are narrow or you wish very close viewing optics for a wide-angle effect, you will have to reduce the center-to-center spacing of the LCDs some more.

The LCD assembly from the Radio Shack TVs has a plastic frame that can be cut back slightly so that the right and left TVs can be placed closer together. The LCD used for the left eye image should have its right plastic frame ground back, and the LCD used for the right eye image should have its left plastic frame ground back. The result will be about ⅛" closer spacing for each LCD so modified, for a total center to center spacing reduction of ¼". The resultant 2¾" spacing works beautifully with the previously mentioned wedges and lenses.

VIDEO/AUDIO SIGNALS

Issues three and four of *PCVR Magazine* introduced some ideas for deriving a three-dimensional NTSC signal from your PC. The Radio Shack 2.7/10" TV as modified above can accept the PC-provided NTSC signal if two of the special Radio Shack patch cords are hooked up between the LCD and the PC. Although this may be a rather expensive and less than satisfactory solution, it is a rather simple way to get video to the headset LCDs. Since the LCDs are designed for RGB as well, I am more interested in an interface between the VGA output of a PC and the 200 pixel LCDs, and eliminating the green Radio Shack tuner board and patch cords.

Audio can also be derived from a variety of stereo audio board systems for the PC. I am designing a special interface for audio. The Radio Shack speakers from the 2 7/10" TV are very low quality, so much better quality speakers capable of adequately reproducing echo depth perception are needed.

The Radio Shack 2 7/10" TV has much less bulk after these modifications, but must still have a considerable amount of supporting circuitry attached. The LCD module is attached to the orange tuner board by means of a 22-pin flat cable carrying the RGB and Sync signals as well as a number of tuner signals. Weight balance problems can be alleviated by making two 22-pin flat cable extensions as well as a pair of four wire backlight cable extensions, and mounting the support circuitry on the rear of the head for counter balancing the pair of LCD modules. Eliminating the NTSC base architecture gives the possibility of eliminating the whole tuner board and providing a three-dimensional RGB driver board in its place at a more favorable location to achieve HMD balances.

I made a very simple VR headset mounting for this video system in a few hours. The first thing to do is to bolt the two LCDs together. The LCD cover that was removed had a small metal grounding strap riveted and welded to the backside. Carefully drill out the rivets from both straps with a 1/16″ drill. Then break the weld by prying off the strap with a small screwdriver. You will find that the spacing of the two rivet holes is just perfect for holding the two LCDs next to each other. Cut the straps to about ½″. Attach these straps to the four LCD holes on the mating sides of the front of the LCDs. Make two more straps for holding the backside. Make these about ¾″ long so that the displays are slightly angled by 10° to maintain parallelism to the diverging optical path. Next I made two 6″ × 2½″ separators from ¼″ model airplane balsa. One separator goes between the back of the LCD and the component side of the tuner PCB. Notch this separator so that it allows clearance for the cable that connects the LCDs to the tuner PCBs. The other separator goes between the tuner PCBs and the power supply PCBs. I then placed four rubber bands around everything to temporarily hold the whole works together. Finally I made a 6½″ wide × 3″ high × 3″ deep box out of more ¼″ balsa. I cut out openings for the optics and nose. When this box is placed over the LCD assembly—Whoppie!!—VR. I hooked a pair of Sony 310 8mm Camcorders to the NTSC and started experiments.

Several types of three-dimensional image controllers are possible

PERSONAL VR VIDEO CONTROLLER

Several types of three-dimensional image controllers are possible. The first alternative would be a system that takes the conventional VGA output of an IBM clone system to a VGA to NTSC converter board or unit. The NTSC output of this unit is then switched alternately to each LCD display. While this sounds simple, it results in several problems. The display is connected to the NTSC for 1/30 1/30 second, then just gets nothing for 1/30 second while the other display gets the signal. NTSC is designed for a continuous signal, and this switching will cause a twitchy image. The 30 frames/second rate is too slow, and the twitching picture will also be flickering since about 45 frames/second is considered the slowest refresh rate to avoid annoying flicker. The conversion to NTSC will also degrade the video quality, as the NTSC is limited to about 2.5mHz bandwidth compared to the VGA 70 or more mHz bandwidth.

Another possibility would be to design a direct VGA to RGB conversion board. This would be a much better situation, but this design will require as much if not more circuitry for frame buffering as this alternative version, while offering less flexibility.

Another solution would be to use two VGA cards with digital to analog converters. However, they never come with adequate documentation to support the needed modifications, would be much slower than the system being used, and cost more in the long run.

I am presently testing a special PC to dual RGB LCDs printed circuit board (PCB) which interfaces the IBM clone ISA bus to my HMD. This special PCB interfaces the I/O mapped or memory mapped 16-bit wide data from the ISA bus of a 486 clone to the LCDs which need a set of analog RGB and sync signals delivered to them. This interface must operate real time to provide the user with the feeling of presence in the viewed scene. I call this solution a Personal Virtual Reality Video Controller, since it provides an individual the opportunity to experiment with full virtual reality at low cost. The design costs well under $1,000, including the LCD HMD.

Several major functions are required to support this real-time three-dimensional VR system. Starting from the LCDs, a pair of RGB D/A converters are needed. The application may involve full color ranges besides just color blocks, so the potential colors are set for a full 16 bits, or 65K different colors capability to avoid color fringing and contouring, especially on skin tones.

The images must be held in buffers to avoid completely overloading the computer with simple refresh problems. Several architectures are possible here. This interface system must be able to read out the old image data and load in new image data simultaneously. A simple solution is to have two buffers for each eye, a total of four buffers, so that one set is dedicated to reading ont to the D/As while the other set may be loaded if new image data is available. When the computer is done loading the new image, the computer commands the buffer sets to swap. The former old buffer now is loaded with newer images and the former new buffer set provides the latest image. The size of the buffers is controlled by the desired resolution of the low-cost RGB LCDs that are being used in the HMD. The Radio Shack LCDs have a potential 262 horizontal lines timing, but with vertical sync and vertical blanking considered, this realistically becomes about 240 horizonal lines being displayed. Interleave is not used. The major limitation is the number of definable horizontal picture elements, which is about 200 horizontal tricolor vertical lines. Multiplying the 240 by 200 gives 48,000 definable picture elements on each LCD. If a much more expensive miniature active matrix VGA LCD were to be used in the HMD, the buffer size would be as much as four to six times greater. Each picture elements has 16 bits of potential color, so the end result is a 96K byte buffer per LCD, which on binary boundaries becomes 128K bytes. A single $30 128K byte 70ns access time Static RAM IC can be used for each buffer.

The next consideration is the timing system needed to read out the old image into the D/As and the providing of horizontal and vertical synchronizing signals to the LCDs. Several CRT controllers are available that will provide the needed logic and timing signals. A low cost ($2) 6845 can be programmed to provide the needed signals. The programming is provided as a part of system board initialization.

Interfaces between the VR software and the display have been made as simple as possible. The software designer has many problems trying to maintain the real time updating of the three-dimensional images, so considerable help from the video controller is provided to lighten the load. Color fills are automatically performed by having the programmer specify the fill color, the buffer starting address, whether the update is for the left LCD, the right LCD or both LCDs, and the length of the fill operation in sequential pel. These bit manipulations result in up to three 16-bit memory-mapped output commands. The color command is optional, only needed when a different color is to be filled. The 16-bit starting address is also optional, only needed when the next sequential address is not the first address to be loaded. The final 16-bit command consists of two bits used for indicating which or both LCD buffer areas are to be updated, and 14 bits of extent giving the potential capability of filling up to $\frac{1}{4}$ of both LCD screens with a color with one, two, or three word commands. The loading control is then turned over to the PVR video controller to update the new image along with displaying the old image. The programmer is notified when the fill is completed. When all the desired updating is accomplished, the programmer tells the PVRVC that it can now swap buffers. The buffer swapping normally occurs at vertical sync time to avoid picture jumping due to glitches. Interface to the IBM clone could be via the ISA bus, the EISA bus, the VESA bus, or it could simply plug into an unused SIMM memory connector. The slowest of all the alternatives, ISA, was selected because it offers the largest potential base of users a low-cost entry into the world of three-dimensional VR. Everyone, except for people with microchannel IBM systems, will be able to use this PVRVC with a 386 or 486 clone, since they all have a 16-bit wide, 8 Mhz ISA interface.

The Personal VR 3-D Video Controller is be built on a single ISA bus card that measures $4\frac{1}{2}$" high by 13" long with a double set of connectors for the ISA bus. A second board will be required for the four-channel three-dimensional VR sound interface and the HMD interfaces that detect the head orientations and relay these back to the application software. ☆

Robert Suding is with SAI, based in Conifer, Colo.