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Firewire Untethered: High-Quality Images for Notebook Computers

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Until recently, no solution existed for acquiring high-quality color images in real-time with a regular notebook computer, even though a high-quality color image acquisition system for notebook computers would open the doors for a wide array of portable applications. In particular, such a combination would be ideal for mobile robots that use high-resolution color vision, which is part of our area of research.

While a large selection of frame grabbers is available for PCI desktop systems, only a few have been available for PCMCIA notebook systems. Unfortunately, most PCMCIA frame grabbers accept video only in the NTSC format, which allocates much more bandwidth to luminance than color. Consequently, the NTSC signal is adequate for gray-scale image processing, but its color content is too noisy for any reasonable color image processing. In particular, the NTSC encoding allocates very little bandwidth to the blue channel, which is more delicate than the red and green channels to begin with. The source of the problem is that most CCD sensors are least sensitive in the blue spectrum. This problem is further exacerbated indoors, where the illumination is often yellow and contains little power in the blue spectrum. As a consequence, the already noisy blue signal from the CCD sensor is further weakened by NTSC, resulting in a very poor signal-to-noise ratio.

Digital Cameras

In theory, higher-quality color images can be acquired from digital cameras than from analog cameras. Digital cameras typically allocate the same number of bits for all three color channels, thus avoiding additional encoding noise in the delicate blue channel. Of course, allocating equal amounts of bandwidth to all three color channels is a property also found in analog systems that use an RGB video format and frame grabber.

However, a digital system has two advantages over an analog RGB system: First, the A/D conversion is performed close to the CCD sensor, thus keeping the amount of electronic noise to an absolute minimum. After digitization, the video signal is immune to noise, such that a digital camera can be several meters away from the computer without any risk of picking up additional noise. Second, unlike analog camera systems, digital systems do not suffer from pixel jitter, which is especially observable on the right side of images that have been captured with an analog frame grabber. In fact, with a digital camera system, each captured pixel value corresponds to a well-defined pixel on the CCD chip. Vertical edge detectors can thus be applied to digitally captured images without any precautions for pixel jitter.

Digital cameras that connect to a notebook computer through the serial port or the faster USB port have been available for a few years. However, most of these cameras are intended for the consumer market, and are equipped with cheap CMOS sensors to keep prices low. CMOS sensors in general have much higher dark currents than CCD sensors. In fact, the quality of the blue channel of most of these cheap consumer cameras is about as bad as that obtained with a decent CCD camera and a NTSC frame grabber. Nevertheless, USB cameras offer a great low-cost solution for acquiring images of NTSC-like quality. However, these cameras are limited to a maximum throughput of only 12 MBits/s, resulting in rather slow frame rates for images of decent resolution.

IEEE-1394 Digital Cameras

Fortunately, a new class of digital cameras that recently appeared on the market offers high image quality as well as fast frame rates. These cameras, which adopt the IEEE-1394 specifications and communicate over the IEEE-1394 high performance serial bus, are an ideal solution for acquiring high-quality images with a regular notebook computer. The fastest IEEE-1394 cameras present image data at a guaranteed bandwidth of 400 MBits/s. This bandwidth allows the acquisition of 30 frames per second, even at very high image resolution.

IEEE-1394 cameras offer other advantages beyond speed. Many IEEE-1394 cameras are equipped with a high-quality CCD sensor, which substantially improves the quality of the blue channel. IEEE-1394 cameras are also very versatile. The user can typically choose from several modes of image resolutions and from several frame rates. Moreover, all adjustable camera parameters can be controlled through the IEEE-1394 link.

For our research, we chose the DFW-V500 camera from Sony. The two photos show our set-up, and the diagram illustrates the elements in it. The camera is equipped with a high-quality 1/3" CCD sensor with progressive scan and square pixels. The camera supports four resolution modes, with a maximum resolution of 640 x 480 in YUV (4:2:2) format. The frame rate can be set at 3.75, 7.5, 15, and 30 fps. Basically all camera parameters can be adjusted through the IEEE-1394 link: shutter speed, gain, gamma factor, brightness, sharpness, hue, saturation, and white balance. Of particular note, the shutter speed can be adjusted from very short (1/100,000 sec) to very long (5 sec). This camera also adopts the popular C mount optical interface.

It is important not to confuse IEEE-1394 digital cameras with DV (digital video) cameras, although both types communicate over the fast IEEE-1394 serial link. While IEEE-1394 digital cameras are geared for the machine vision market, DV cameras are geared for the consumer market. The main difference between the two types is image quality. DV cameras compress image data in order to record longer movies onto a DV tape. Unfortunately, the image compression is lossy. Although the image compression is optimized for human vision, the image compression artifacts can pose serious problems for machine vision applications. In contrast, IEEE-1394 digital cameras do not compress the image data, as the goal is maximum image quality for each individual frame, not image storage.

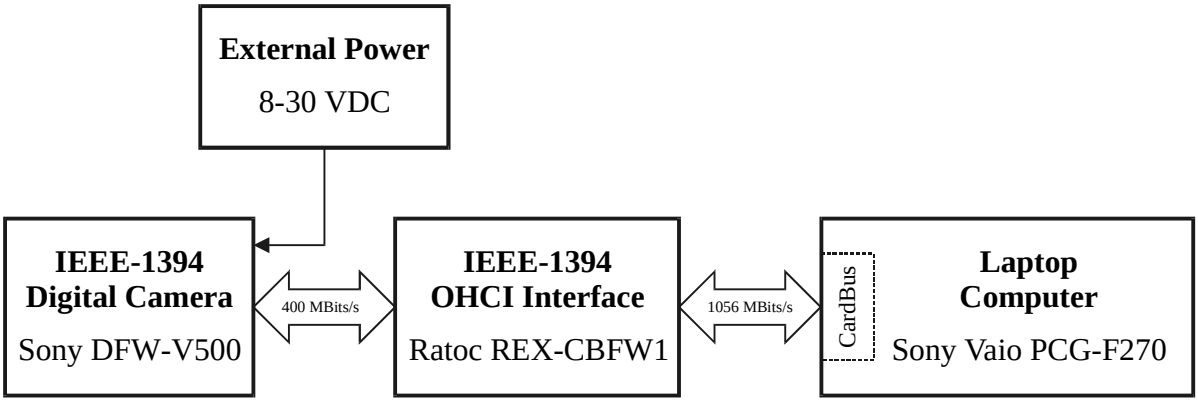
Software Support

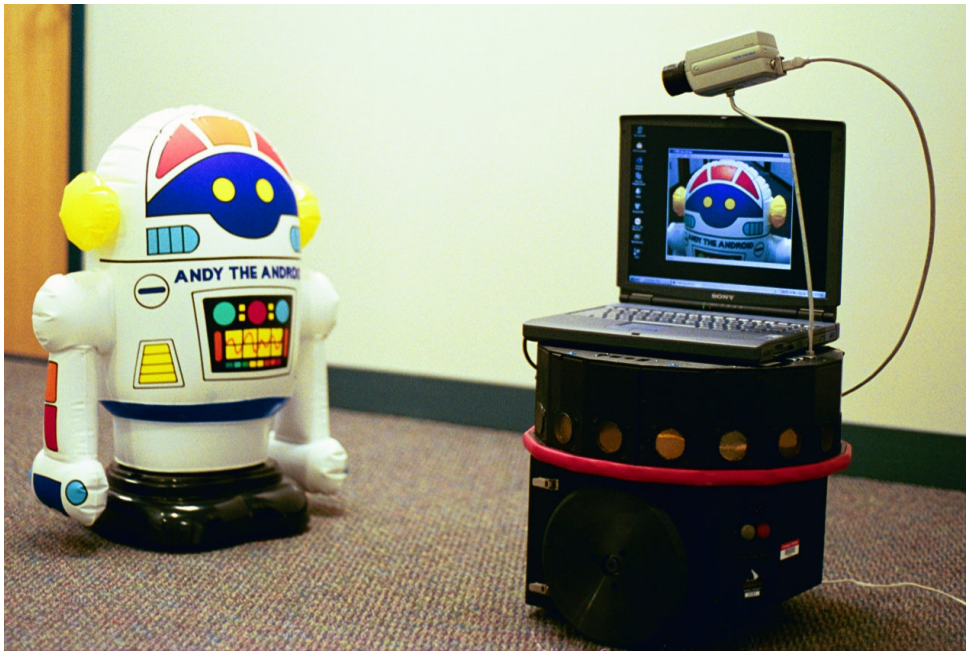
The good news is that hardware support for notebook computers is available in the form of a IEEE-1394 CardBus card manufactured by Ratoc Systems. The bad news is that until recently, no software support has been available! While both the camera manufacturers and Ratoc Systems claim that their products perform according to the IEEE-1394 digital camera specifications, neither has provided the necessary software drivers for programmers to access the incoming video stream.

Because we strongly believe in the future of these digital cameras, we chose to fill this void by writing the software driver ourselves and making it available to the general public, at no cost, on our web site: *http://www.cs.cmu.edu/~iwan/1394*.

The result of our work is a C/C++ software library (DLL) that is compatible with Windows 98 and higher. The driver should also work under Windows NT, although it has not yet been tested. In general, our software library can be used with any computer that is equipped with an IEEE-1394 OHCI interface. In order to use our library with a regular notebook computer, the notebook needs an open CardBus slot. The notebook can then be equipped with a low-cost IEEE-1394 CardBus card, which provides the necessary IEEE-1394 OHCI interface.

In its current version, the software offers two different modes for acquiring images, and allows control of all camera parameters according to the specific model. While the software has only been thoroughly tested with the Sony DFW-V500 camera, it should work with other IEEE-1394 models as well. Our web site also includes documentation, links, and the source code for a simple demo program, which illustrates the use of the library routines.

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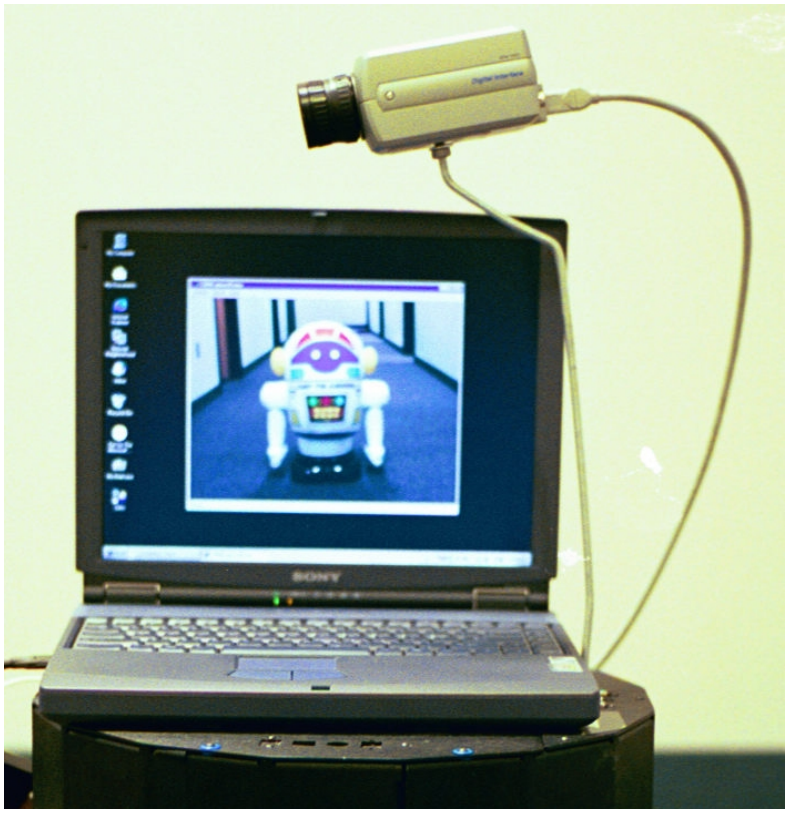
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