Dig*Image*: Recommended Cameras

Evaluation of Sony XC-77RRCE & Cohu 4910 Series

One of the fundamental problems with video technology is that a single frame consists of two interlaced fields transmitted sequentially. The first field contains all the even numbered video lines, and the second the odd numbered lines. The field rate (50Hz PAL, 60Hz NTSC) is therefore twice the frame rate (25Hz or 30Hz). Most modern CCD cameras have effective shutters which open and close at the field rate with an exposure time less than or equal to the field period. This means that the information contained in the even field represents the state at a time 1/50s or 1/60s earlier than the information in the odd field. In a large number of applications this time delay between the two fields is not acceptable, and it is therefore necessary to discard one of the two fields and thus reduce the vertical resolution. In many cases this reduced resolution is acceptable.

When tracking particles it is desirable to keep the particles as small as possible. The lower limit on the size of the particles is imposed by the wish to locate them with subpixel accuracy. Subpixel accuracy requires that the particle extends at least two pixels in both directions. However, if the particles are moving more than approximately 50% of their diameter between one video field and the next, it is possible to use information in only one of the video fields. In order that the particle extends at least two pixels vertically in the reduced resolution of a single field, it must extend at least four pixels vertically relative to a complete frame, thus requiring the particles to be twice the size. Moreover, while this gives subpixel resolution, it is subpixel relative to pixels twice the size.

To complicate matters further, different cameras construct the two video fields in different manners. In some cameras the even field corresponds to the even lines of pixels in the CCD chip, and the odd field to the odd lines of pixels in the CCD chip. In such cameras not only must the vertical resolution be reduced by discarding one of the fields, but because there is no information about what is happening in the other set of pixels, the effective resolution for small entities such as particles is significantly worse than half the full frame resolution.

Slightly better are cameras which produce an average of the even lines and the preceding odd lines for the even field, and the odd lines and the preceding even lines for the odd field. With such cameras it is still necessary to discard one of the fields, but at least the remaining field has information from all the pixels in the CCD chip.

The Cohu 4910 & 4990 series and the Sony XC-77RRCE (PAL) & XC-77RR (NTSC) are unusual in a number of respects. First they offers the choice of either of the above methods of generating the video fields. In "field integration" mode it uses the average of the even and odd rows of pixels for each field, while in "frame integration" mode it uses only the even rows for the even field and the odd rows for the odd field. With "field integration" the shutter speed can be set anywhere between 1/50s (1/60s NTSC) and 1/10000s (Cohu) or 1/2360000s (Sony). Realistically shutter speeds up to 1/250s are of practical value for particle tracking. Most useful, however, is the ability to have a separate 1/25s (1/30s NTSC) shutter for each of the fields in "frame integration" mode.

For normal cameras the slowest shutter speed is equal to the field period (*i.e.* 1/50s or 1/60s), with both the even and odd rows of pixels being reset at the same time. Both rows are also transferred to the CCD shift registers at the same time, with the adjacent even/odd pairs of rows being summed. In *frame integration* mode the camera proceeds as follows: the accumulators for the even rows of pixels are reset at some point up to 1/25s (1/30s NTSC) before the even rows are transferred to the shift registers. 1/50s (1/60s NTSC) after the even rows were reset, the odd rows of pixels are reset, and

1/50s (1/60s NTSC) after the even rows were transferred to the shift register, the odd rows are transferred to the shift registers.

The following diagrams illustrate the timings of the two integration modes. The resetting of the accumulators is indicated by `R`, and transfer to the shift registers by `T`. The frame boundary is indicated by `F` and field boundary within a frame by `f`. The contents of the shift registers is `e` for even lines only, `o` for odd lines only, `f` for the sum of the even and preceding odd lines, or `p` for the sum of the odd and preceding even lines. The field read out is given by `EEEEE` for the even fields and `OOOOO` for the odd fields, with `S` representing the vertical sync.

```
FIELD INTEGRATION:

Timing      ---F-------f-------F-------f-------F-------f-------F-------f---
Even pixels R--T----R--T----R--T----R--T----R--T----R--T----R--T----R--T---
Odd pixels  R--T----R--T----R--T----R--T----R--T----R--T----R--T----R--T---
Shift reg.  ppp fffffff ppppppp fffffff ppppppp fffffff ppppppp fffffff ppp
Read Out    OOOSEEEEEEESOOOOOOOSEEEEEEESOOOOOOOSEEEEEEESOOOOOOOSEEEEEEESOOO
```

```
FRAME INTEGRATION:

Timing      ---F-------f-------F-------f-------F-------f-------F-------f---
Even pixels R--T------------R--T------------R--T------------R--T-----------
Odd pixels  --------R--T------------R--T------------R--T------------R--T---
Shift reg.  ooo eeeeeee ooooooo eeeeeee ooooooo eeeeeee ooooooo eeeeeee ooo
Read Out    OOOSEEEEEEESOOOOOOOSEEEEEEESOOOOOOOSEEEEEEESOOOOOOOSEEEEEEESOOO
```

The frame integration feature of the Cohu and Sony cameras is not by itself a major improvement over standard video cameras. However, if a mechanical shutter is used with the camera in conjunction with a 1/25s (1/30s NTSC) electronic shutter, it is possible to expose the two fields at the same instant in time, thus allowing the full vertical resolution to be used. The diagram below uses the same symbols as those above but with a full frame electronic shutter. The external mechanical shutter is open for the period indicated by `MMM`.

```
FULL RESOLUTION FAST SHUTTER:

Mechanical

Shutter     M             MMM             MMM             MMM             M
Timing      ---F-------f-------F-------f-------F-------f-------F-------f---
Even pixels ---TR--------------TR--------------TR--------------TR----------
Odd pixels  -----------TR--------------TR--------------TR--------------TR--
Shift reg.  ooo eeeeeee ooooooo eeeeeee ooooooo eeeeeee ooooooo eeeeeee ooo
Read Out    OOOSEEEEEEESOOOOOOOSEEEEEEESOOOOOOOSEEEEEEESOOOOOOOSEEEEEEESOOO
```

The mechanical shutter is opened while the odd field is being displayed, shortly before the end of the even field integration period, and shortly after the start of the odd field integration field, thus exposing both fields associated with the next frame at the same time.

Extensive trials have shown a slight improvement in the horizontal velocity resolution for rapid flows, and a dramatic improvement in the vertical resolution. Some of this improvement is due to an improved signal to noise ratio when compared with the standard camera used in this trial, but most of it is due to the improved vertical resolution. The method of driving the mechanical shutter differs for the Cohu and Sony cameras.

With the Cohu, the camera can lock onto mains frequency, allowing a simple synchronous AC motor to be used to driver the shutter.

In contrast the Sony always uses its own internal crystal to provide the base frequency. As this will typically differ very slightly from mains frequency, a mains driven synchronous motor is not appropriate. We have used an optical switch in combination with a DC servo motor and analogue control circuit to drive the shutter. Alternatives such as the use of a phase-locked loop or a low voltage AC synchronous motor (with the driving wave form derived from the camera output) may be used instead.

Both cameras also offer a further advantages over standard video cameras when detailed intensity measurements are required. While CCD sensors exhibit a very linear response to the incident light, nonlinearity is built in to standard cameras ("gamma correction"). This nonlinearity is included to allow for the nonlinearity of phosphorous display devices (the argument being that it is cheaper to build the correction into the relatively small number of cameras than the large number of display devices, TVs, videos etc.). As the frame grabber does not undo this nonlinearity, the digitised intensity is a nonlinear function of the intensity falling on the CCD sensor. Both cameras allow the gamma correction to be turned off, thus providing a very linear response if the camera is connected directly to the frame grabber. Tests have shown that the output of the Sony is more linear than the Cohu.

Unfortunately the response of the video tape the signal is normally recorded on is not perfectly linear, so that a recorded image will contain some nonlinearity. Never the less this tape nonlinearity is much less than that introduced by the gamma correction.

A feature of DigImage is both static and dynamic calibration of the intensity scale, thus allowing digitised intensities to be mapped onto a reference level and/or some associated field. While this feature is able to correct the nonlinearity associated with the gamma correction, a better intensity resolution is obtained if the nonlinearity is as small as possible. The linearity of the camera (with gamma correction turned off), excluding video tape, is sufficient to provide reference values for the video tape intensity transfer function, while with standard cameras some external method of measuring or producing relative intensity is desirable.

For most uses the Cohu is arguably the better camera. The main reason for this is that it uses newer technology (it has been available only since the start of 1993 compared with 1991 for the Sony). More specifically the advantages are as follows:

- It is cheaper (£680 compared with £2015).
- It is far more sensitive (close to a factor of 20 according to the specs, possibly only a factor of 10 in reality).
- It is much easier to make a mechanical shutter for (unlike the Sony, it can lock into mains frequency which then allows a simple synchronous AC motor to be used to drive the shutter).
- It has a variable manual gain as well as an AGC (the Sony only had unity gain or AGC).
- It has a variable black level. When combined with the manual gain, this will enable the maximum use of the available intensity range.

Stuart Dalziel
30 March 1992
Revised for Cohu camera July 1993.