TELEVISION SCANNING OF COLOUR FILM

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INTRODUCTION

Many manufacturers have introduced, or have announced that they intend to introduce, cameras using CCD image sensor arrays designed for the home CCTV market. These arrays have, typically, 300 x 200 picture elements and, as such, have insufficient resolution for broadcast use. Even if this were not so the present problems of fixed pattern noise and blemishes would militate against the use of such arrays in broadcast TV cameras.

However, there is one application that is feasible using present day sensors and that is the televising of film. This is because the motion of the film itself may be used to achieve the vertical scan; the sensor then becomes a single line of elements, which is of course easier to manufacture.

Fig.1a shows the layout of an experimental film scanner that has been used to study this application. The film is moved by a capstan at a constant speed controlled by optical sensing of the perforations. It is illuminated by a simple light source (a quartz-halogen lamp) and the image is focused onto the sensor by a copying lens.

Early work with this system used photodiode sensors (ref.1). However, these were not entirely suitable, because of difficulties with clock breakthrough and variations in dark voltage. Later work has used surface-channel (ref.2) and buried-channel (ref.3) CCDs; of all these types of sensor, buried-channel CCDs appear to be the most suitable at the present time. It has also been established that 1024 elements will provide more than adequate resolution for the present television system; the only exception to this will be if Cinemascope film is to be televised when it is possible that 1728 elements could be desirable.

USE OF SOLID STATE SENSORS IN A MONOCHROME FILM SCANNER

One of the major problems with the use of CCDs in cameras is the severe blooming that can be induced when the incident light level exceeds a certain threshold; this has been the subject of much effort and sensors with reduced tendency to exhibit blooming are now becoming available. However, in the case of film scanning, the maximum level of illumination is fixed (that level when the film is completely transparent). If it is arranged that this level is just less than that which would normally cause overload then it can be ensured that blooming will never occur.

At the opposite extreme, in the absence of light, there will still be a small signal from the CCD due to the generation of carriers by random thermal activity in the silicon substrate. This will cause an added dark current signal in the output and an increase in noise. Both these effects are proportional to the integration time; the 20 msec integration time used in cameras leads to objectionable levels of dark current and this is a major problem. However, the integration time used in the film scanner is only 64 μsec; with this short time the dark current is

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negligible at room temperature (less than 0.3% of maximum signal level). Nevertheless the dark current is strongly dependent on temperature, so it is not advisable to place a CCD where it will be subjected to a high ambient temperature. In extreme cases, cooling of the sensor with a small Peltier cooler may be considered.

Because of mask tolerances and other effects, the sensitivities of the individual photosites are not all identical. The effect of these variations is to modulate the picture information with a fixed pattern which will appear as vertical stripes visible mainly in the ligher areas of the final picture. These stripes can be removed (ref.4) by storing the pattern, in digital form, in a read only memory and re-modulating the signal by the inverse of this stored pattern.

Storage is also required to convert the signals from the CCD into interlaced form. Because the film scanner relies on the motion of the film for vertical scanning at 25 frames per second, the signal from the sensor is in a sequentially scanned from unsuitable for display on the UK television system. While this sequential-to-interlace conversion could be avoided by mechanical means (e.g. moving mirrors or rotating polygons) a digital processor using a field store avoids mechanical and optical complication and provides less maintenance, freedom from flicker and freedom from positional errors between odd and even fields. These advantages may well outweigh the intial cost of such a processor. The use of an 8-bit digital field store for this purpose has been demonstrated and found to work very well.

COLOUR OPERATION

For a colour film scanner the single sensor of Fig.1a is replaced by the arrangement of Fig.1b. Three sensors are required, one for each of the primary colours; a colour splitting block separates these red, green and blue components from the incident light. The signals from each of the sensors are then corrected for the variation in sensitivity from element to element and processed in the normal way. Finally they are converted from their sequential form to a standard interlaced format.

The first question to be answered is therefore whether it is possible to register the three sensors sufficiently accurately. Present day television cameras can attain very high registration performance; errors of less than 0.04% of picture width are commonly obtained in the central area of the image, falling off to 0.15% at the extremes of the picture area. This is made easier by the ability to control the registration electrically. Such electrical control is not possible with solid state sensors; some adjustments can be made by altering the drive waveforms but others remain which are not possible in this manner. Thus registration must be achieved by mechanical movement of the CCD sensors. In order to achieve the same precision as that obtainable from a camera this movement must be extremely precise; accuracies of ± 5 micrometre are required.

In practice it is found that it is possible to register the sensors to this accuracy. The only remaining static errors are due to the tolerance in the sensors themselves and chromatic aberration in the copying lens; both of these factors can be kept to a very low level. The only errors noticed in the experimental system were short-term drifts due to thermal expansion while the mounting system was not in thermal equilibrium. It is felt that these should be able to be eliminated in future designs, if necessary by incorporating temperature control of the sensor assembly, including the colour splitting block.

The splitter block itself is one of the key components of the film scanner; its characteristics help to determine the overall colour analysis. This is not helped by the characteristics of the sensors; Fig.2 shows the spectral sensitivity curves of the three sensors used. The ripples in the curves are typical of CCDs using polysilicon electrode structures, as is the very low blue sensitivity. Both of these features create problems in designing a colour analysis system.

The curves may be split into two components; these are an overall sensitivity curve common to all sensors (caused by the response of a silicon detector and the transmission of the polysilicon coating) and a ripple component which is unique to each sensor caused by multiple reflection in the electrode structure. The overall sensitivity curve may be incorporated in the design of the colour analysis; the ripple components should not be incorporated, as they will very from sensor to sensor. Nevertheless the ripples will affect the colour analysis. For this reason the sensors need to be selected for each channel so that the ripple component has minimum effect; this is so when the region of interest lies either on a peak or in a trough of the ripple. Clearly a peak is the more desirable of the two cases as the sensitivity will be higher. If the sensors are selected in this fashion variations in colour analysis from machine to machine will be minimised.

The low blue sensitivity causes more of a problem, however. The situation is not helped by the fact that the light source used has its lowest output in the blue region of the spectrum. Most standard colour splitter blocks (it is clearly desirable to use a standard block if at all possible since special-purpose blocks are expensive to manufacture) have a substantial leakage of red and infra-red light into the blue channel. This is clearly undesirable in view of the high sensitivity of the sensor to light of this wavelength; fortunately it has been found possible to control this leakage by using infra-red filters in series with the light source.

If this is done then an acceptable colour analysis can be produced. It is possible to improve the characteristic slightly by including further optical filtering but this is done at the expense of reducing the signal to noise ratio. Nevertheless it is surprising how good the performance is, considering that the system uses "off-the-shelf" components.

The main consequence of the poor blue response is to reduce the signal to noise ratio of the film scanner in the blue channel. There are two dominant sources of noise in this application. The first is the noise arising from the discrete nature of the incident illumination (photon noise). The characteristics of this type of noise are that it increases as the square-root of the light level and that it has a flat frequency spectrum. From data supplied by the manufacturers the signal to noise ratio of the CCD when illuminated to near saturation level would be approximately 58 dB. In practice this photon noise is of little significance compared with the electrical noise generated in the CCD.

This electrical noise has, in common with many other solid-state devices, a frequency spectrum which increases at low frequencies. In addition the noise is independent of signal level at the output of the sensor. The properties of the television system and the eye are such that the overall effect is that of an obtrusive amount of low-frequency noise in dark areas of the final picture. This noise is subjectively more annoying than its level might suggest. For example the measured value of the unweighted noise in a 5.5 MHz bandwidth was 72 dB below the maximum signal level; nevertheless comparison with existing film scanners (whose signal-to-noise ratio is approx. 50 dB) indicates that the visibility of noise is higher for the CCD scanner. In addition the noise is concentrated in the blue channel because of the low sensitivity to blue light. This tends to produce blue shadows in dark areas.

It seems likely that, in the near future, sensors with improved blue response will become available. This will help to remove the unbalance in noise content between the red, green and blue channels but the effect on the visibility of noise in the final picture will not be large.

CONCLUSION

Solid state sensors are being used to produce full-resolution broadcast-quality television pictures from film. It has proved possible to register the sensors sufficiently accurately and to achieve a good colour reproduction using standard optical components.

The noise level remains an unsolved problem, however. While the introduction of snesors with improved blue sensitivity will help to equalise the noise levels in the red, green and blue channels, the overall visibility of noise will still be too high. In order to overcome this, sensors with low levels of electrical noise are required; such sensors have been developed for use in low light level camera applications (ref.5) but none are yet available which are suitable for this application. Alternatively the dynamic range may be increased by the use of on-chip exposure control (ref.6).

This paper has discussed the performance of presently available sensors and shown their ability to produce high quality television pictures. However, they are not entirely suitable for this application and it is to be hoped that manufacturers will find it possible to bear in mind this use when designing a new generation of sensors.

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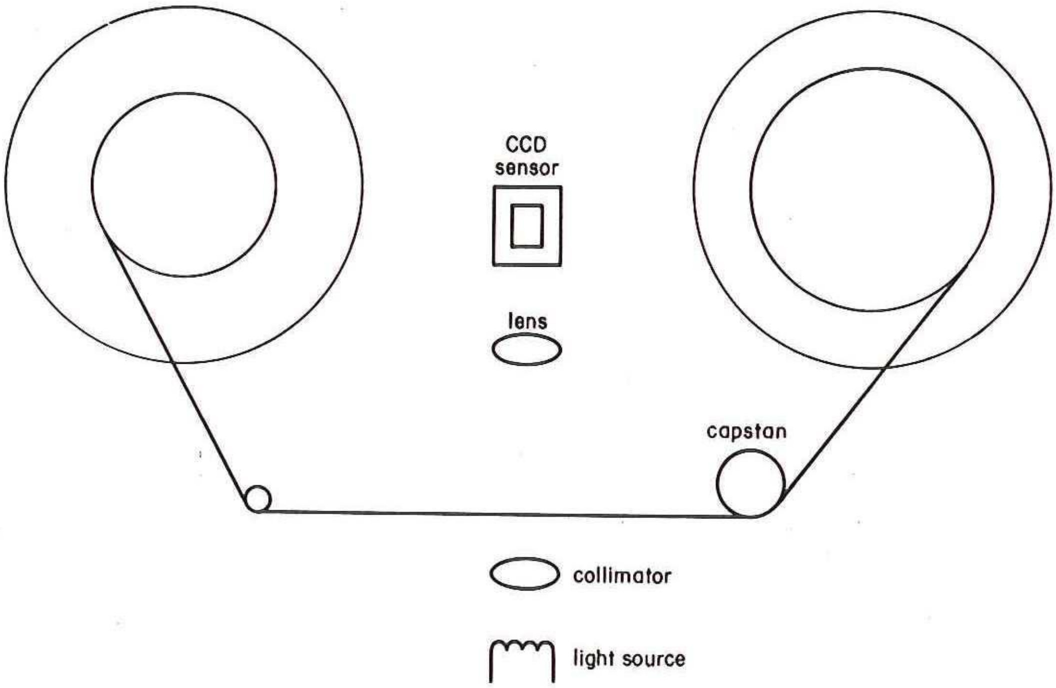

Fig.1(a) Simplified layout of monochrome CCD telecine

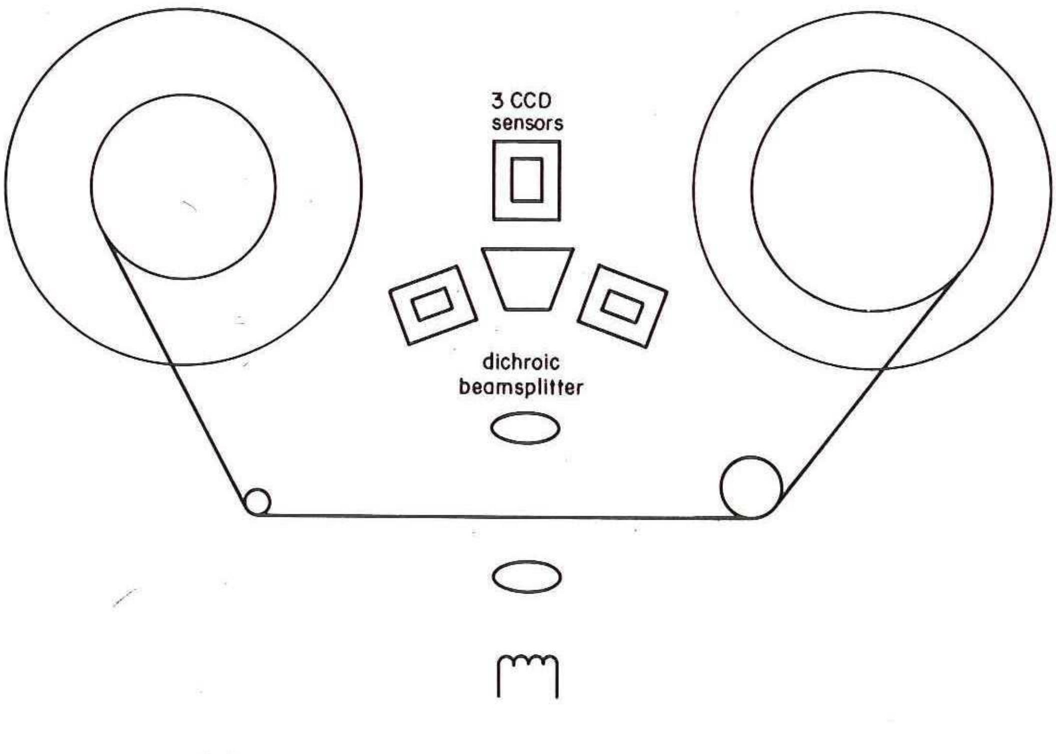

Fig.1(b) Modification for colour operation

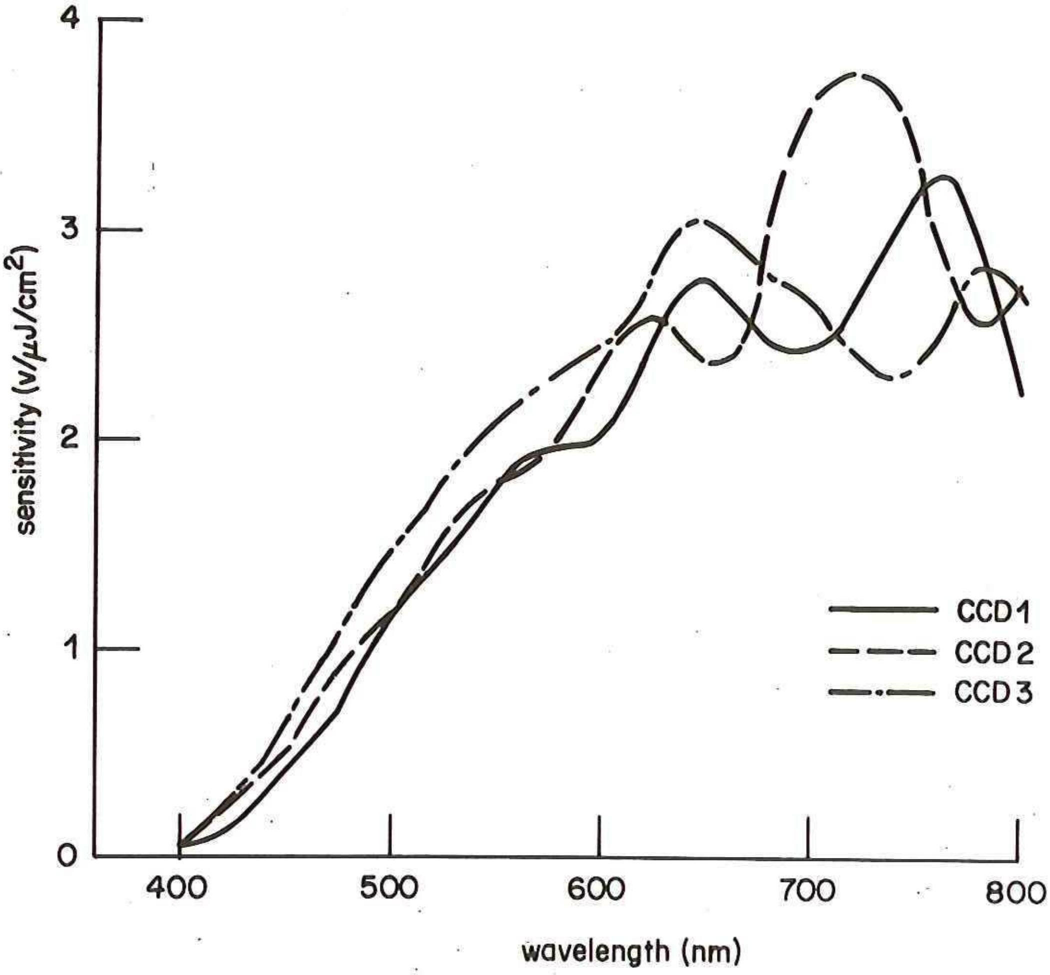

Fig.2 Spectral sensitivity of three CCDs