A photogrammetric system for registration of fast three-dimensional movements in laboratory crash tests

Anders Kullgren, Anders Lie, Claes Tingvall
Folksam Research, Chalmers University of Technology, Department for injury prevention, Karolinska institutet, Department of ENT.

Abstract

Tests in laboratory environment sometimes demand high accuracy three-dimensional measurements. These demands are difficult to meet when using traditional high-speed filming because of the low geometric stability and the small film format in the high-speed cameras. Using an extensive amount of equipment and sophisticated analysis tools, three-dimensional measurements from high-speed films can be extracted. Alternative image based systems giving high resolution, high speed and high accuracy are, however, not easily available.

During a test series for evaluation of systems for child restraint side-impact protection, a method using single or multi frame video photogrammetry and active targets (1000Hz) was developed. The flashing targets make high time resolution possible from relatively low time resolving video sources. The main advantage of this system is that it is easy to use and gives acceptable measuring accuracy (≈0.2% of field of view) as well as short time for evaluation. The system concept based on standard equipment has a relatively low cost, overall and per observation point. The result from this development is presented in this paper together with descriptions of the used equipment, test set-ups and working procedures. Some possibilities and disadvantages are discussed together with lines for further development.

Background

Laboratory testing of safety systems is an important part of research and development. Systems and subsystems are tested together with crash dummies allowing substitute for real life situations. The outcome of the tests are normally presented in dummy responses, such as measurements of impact severities and body movement measurements. Many parameters can be measured within the dummy with accelerometers, while others are best measured in pictures or films (1). There are therefore needs for fast and simple systems to verify and measure movements, sometimes also in three dimensions. Traditional high-speed filming is normally used for these purposes. High-speed filming is a fairly costly method per observation point.

A method based on photogrammetrical single frame cameras and light emitting diodes (LED) have been tested for measurements of spatial movements (2). This technical solution had however some disadvantages, especially when spatial movements occurred in small areas and light traces crossed each other because of object movements over a limited area of the film.

Parallel to the photogrammetric single frame cameras, video camcorders have been used for verification of the tests. If the video films could be used to collect movement information with higher time resolution, they could be well suited for test verification and measurement. The cost effectiveness using video technique is high. If real time video analysis can be substituted with analysis from video tape the cost per observation point is very limited, especially if standard amateur equipment can be used.

In this study video camcorders in connection with high frequency flashing LEDs are presented as a concept, simple tests are discussed and some results presented.

The objective of this study was to develop a method with,

- video camcorders as data collection devices.
- information stored on video tape for later analysis
- high time resolution (up to 1000 Hz.)
- short processing and analysis time
- three-dimensional measuring capabilities
- low cost standard off shelf products.

High speed motion analysis

High speed filming has traditionally been the dominant system for motion analysis in crash test environment. The filming, often using frame rates up to 1000 fps, has disadvantages such as time laps between filming and possible analysis, high demands for strong artificial light and high cost per observation point, both in investment and for every test. There are possibilities to perform three-dimensional measurements from high speed filming. Generally, simplified photogrammetric solutions are used because of the limited geometric stability in the high speed cameras. There are considerable positioning precision demands and synchronization problems connected to some solutions (3). Direct linear transformation (DLT) (4) has also been used for three-dimensional measurements in high speed films (5). Automated or semi-automated measurements from digitized high speed films, using DLT calibration in every frame, seems the most accurate system available.

High speed video has been used as an alternative to high-speed filming with frame rates acceptable for crash test use (6). This modern technique has eliminated some of the disadvantages with high-speed filming such as the need for extremely strong light. The cost per registration unit is, however, high. The high speed video seems to have potentials for three-dimensional measurements since synchronization and geometrical calibration of the systems appears to be straightforward.

Real time video based motion analysis systems have been available for years. These systems use active or passive targets on the object. The location of the targets can be calculated in two or three dimensions in real time. Three-dimensional measurements are generally based on DLT-mathematics. The registration rates can be up to 200 Hz. These systems are mainly working in real time with the camera units connected directly to the computers (7). Evaluation from videtape is also possible in some cases (8). In the systems the video signals are analyzed and the images are neither collected nor stored. The systems are based on target measurements where the target has unique clarity in the images. In this way the targets can be found in the video signal. This kind of system has shown two dimensional measuring accuracies around

0.05% of the field of view. This is better than the theoretical resolution of the video camera (≈800*600 pixel where one pixel corresponds to 0.13% of the field of view). Sub pixel accuracies are possible since the targets cover more than one pixel and the centerpoint of a target covering a group of pixels can be calculated with high accuracy.

Video at standard TV frame rates works at 50 Hz or 60 Hz interlaced fields giving full resolution at half these frequencies. This will generally not be sufficient for detailed crash test analysis. Standard video can anyway be considered a very cost effective mean to verify dummy movements etc. Modern video cameras have electronic shutters giving possibilities to use very short shutter speeds. This results in relatively high quality pictures without movement blur.

Photogrammetry is a three-dimensional measuring technique based on image pairs showing the object of interest. For simple non real time measurements in video pictures, a monocomparator style system is suited giving possibilities to use simple measuring procedures and sophisticated mathematical solutions. Two solutions are available when choosing cameras for photogrammetric measurements. Traditionally, special photogrammetrical cameras (metric cameras) are being used with known and calibrated focal length, known distortion and controlled film flatness. All these factors are essential for high accuracy angular measurements. When advanced analytical solutions are being used there are also possibilities to use non-metric cameras (4). This solution demands a higher amount of control measurements when the photographs are being taken.

Method

In this study an amateur video camcorder was used (Sharp VL-MX7). The camcorder is equipped with two lenses, one ordinary zoom lens and one fix-focused wide angle lens. The fix-focus CCD lens system was found well suited for the study. Optical system stability is necessary if the camera is to be used as metric camera, for photogrammetric restitution. The camera was calibrated for focal length, principle point and distortion. For the calibration a three-dimensional testfield with 122 accurately measured points was used. Three images taken in different positions were measured and the camera parameters were calculated in bundle block adjustment (9). The calibration images were captured in the same way as the motion analysis images. The camera calibration program developed for metric cameras was used as it was without changes.

For the computing and image analysis a personal computer was used (Apple Macintosh fx). Images were first recorded in the camcorder and then grabbed from the video tape to a personal computer as images in TIFF-format. The frame grabber card (Data Translation DT2255) captures frames in a 768x512 pixel format in 256 shades of gray. The 768x512 pixel format resolves the 240 TV-lines of the camcorder. The resolution is approximately half the resolution in 16 mm high speed film with an 80 line pairs per millimeter resolution. The images were measured manually on the computer screen using an image analysis software (NIH Image).

Image capturing is normally done from the running video tape which gives a stable video signal with little blur. In this study a controlled single image capture was needed. The frame of interest can easily be found using a video cassette recorder having single frame jog and shuttle features (Panasonic NV-FS90). The still image video signal is, however, of lower quality than images from a running tape. The low quality of the still video images generates noisy images when capturing to the computer. This problem was overcome using a video mixing table with synchronization puls regeneration and digital frame storage (Panasonic WJ-AVE5). The mixing table was capable of grabbing the noisy still video signal from the video tape recorder and sending a good stable single image video signal to the frame grabber card in the computer. The images captured from still images had a tendency to be somewhat dislocated when compared to the image coming from the running video tape. The still images were therefore compensated for these "movements" using stable control points. The control points were first visible in an image grabbed from running tape and then also visible in every still image.

The video images are based on two interlaced signals, the odd lines and the even lines. These two fields (50 hz) are superimposed to one frame (25Hz). The grabbed frame can easily be split into the two fields in the computer. Modern CCD-camcorders often have possibilities to take images with very short exposure time, why sharp 50 Hz capture of fast events is possible. In this study, the 1/50th second exposure time was used and the sharpness of the images was substituted with long duty cycle. There were no data directly available concerning the duty cycle of the camera used, but practical tests showed that no 1000 Hz 10% duty cycle flash was missed in a long series of images.

To get a higher time resolution than available when using the 50 Hz video frame rate, flashing targets have been used. In this study active targets in the form of light emitting diodes (LED) were choosen. The targets had two LEDs mounted close to one another (≈20mm). The LEDs were driven from a central unit supplying 1000 Hz and 125 Hz flashes with a 10% duty cycle. Flash rates correspond to 40 and 5 flashes per video frame (20 and 2.5 flashes per video field). The targets were connected to the central unit via narrow and highly flexible wires. The LEDs were attached to the objects using adhesive tape. The frequencies are best chosen so the targets have moved at least two target sizes between the flashes. For movements having a wide span of speeds multiple flash rates are useful. For small objects the light from the LED can be distributed to the measuring point using optical fibers. The targets can also be made by retro-reflective material illuminated by strobe light mouted around the camera lens (10).

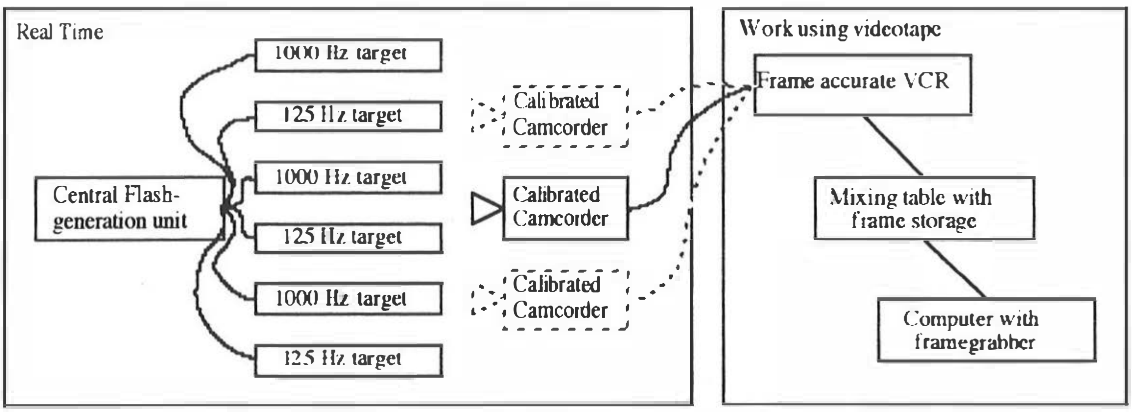

Fig. 1. Video system layout. The real time part is clearly divided from the post event analysis

The captured images were analysed manually in a personal computer. Every grabbed image was split into the two time fields and image coordinates for the flashing targets were measured manually on the computer screen. The image analysis software, NIH Image, has a macro language available for the user. The macro language gives possibilities to develop simple user specified program procedures.

In the images every target was measured and the image coordinates were stored in a text file. A special macro for measurements was developed. The measurements are done in two steps. First a rough measurement activates a digital zoom-in, then a more precise second measurement is performed. Manual point numbering was used. The image coordinate text file was thereafter analysed and processed.

Test set-up

In this study the system was tested in a child restraint side collision set-up (2). The test set-up was developed to evaluate new side collision protections in a child restraint. One of the components tested was a modified head area. The aim of the head area was to keep the head from rotating out of the restraint system. The movement of the dummy head was studied with and without the new head area. On the head four LEDs were mounted. The collision was photographed witd photogrammetric still cameras. The tests were also filmed with several video cameras of which only one was calibrated. The tests were performed in 45 kmh, with a simulated door intrusion of 200-300mm. There was no additional light used. There was a dark background used to enhance the contrast and clarity of the targets. On still paused video images the movement of the head could be seen directly after the test. The flashing LEDs were a good help in the visual analysis.

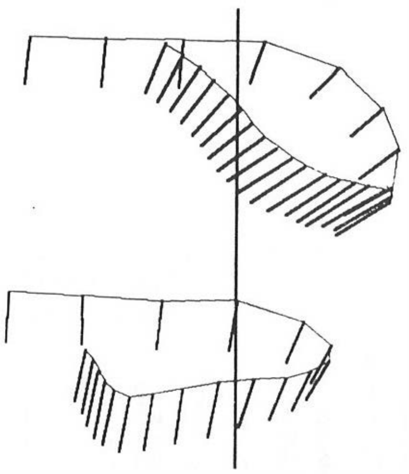

Fig. 2. Movement of two points on dummy head with original (upper) and seat with head ejection protection device. Measurements from photogrammetric still cameras.

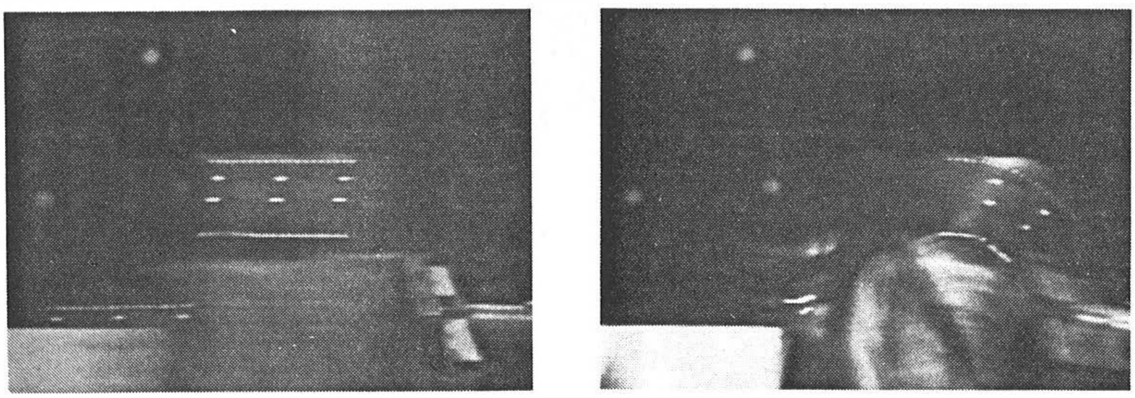

Fig. 3. Two video images from a child restraint test

Images showing the movement of the head was captured into the computer and the image measurements were processed.

A photogrammetric software package was available for the restitution of images. Since only one calibrated camera was available when the tests were performed there are no three-dimensional calculations available. The software package is based on traditional analytical solutions with inner-, relative- and absolute orientation (11). The more strict photogrammetrical approach simplifies the test set-up since no control measurements of camera position or control points are needed.

Synchronization of the cameras is not needed since significant features in the movements easily can be found and correlated to one another when measuring a set of images.

Results

The calibration of the camera shows a residual standard error of 1.3 pixel, corresponding to 0.17% of field of view. There were no residual errors in measurements after calibration larger than 3 pixel.

To check the accuracy in the manual screen measurements, repeated measurements on points in one single image were performed. The test showed that the measurements have a ≈0.3 pixel accuracy (corresponding to 0.04% of field of view).

The dispersion of the points on the dummy moving with constant speed prior to impact can be used for measuring accuracy estimation. A series of measurements on points over two images was used. The medium speed over the thirty measured points was 10.7 pixel/ms. Test speed was roughly 11m/s. The test shows an accuracy of ≈1 pixel, corresponding to 0.13% of field of view.

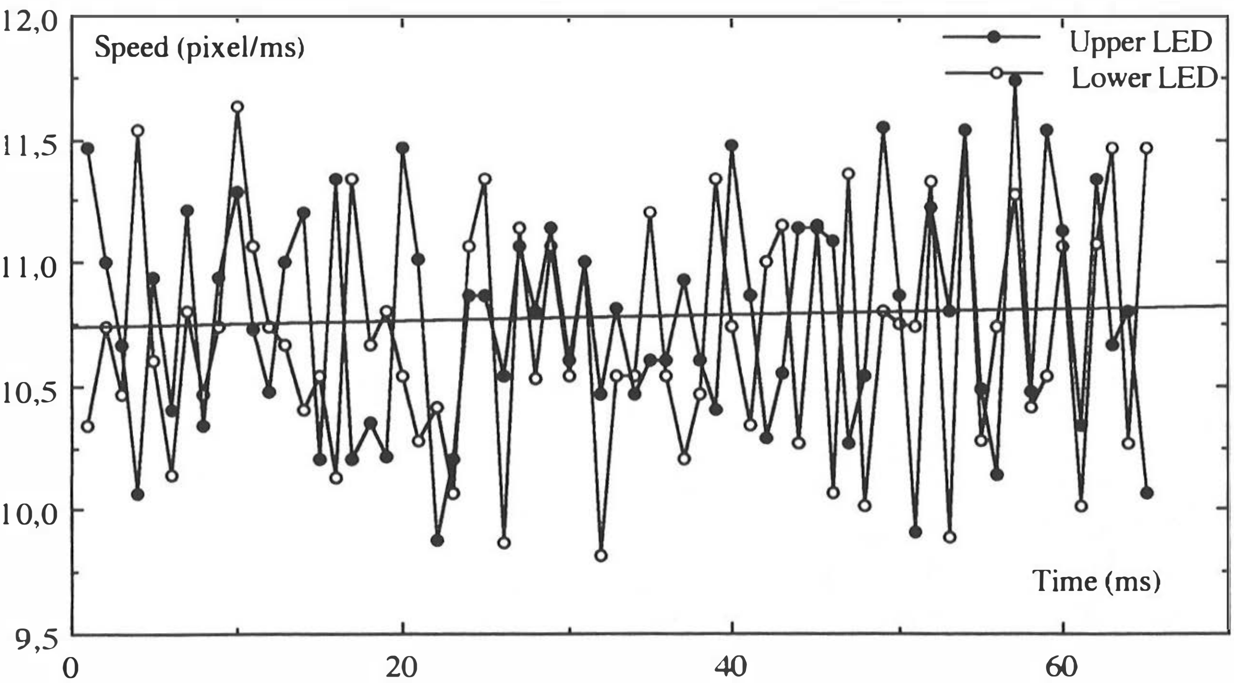

Fig. 4. Speed between two points. (Unit = pixel/ms corresponds approximately to m/s)

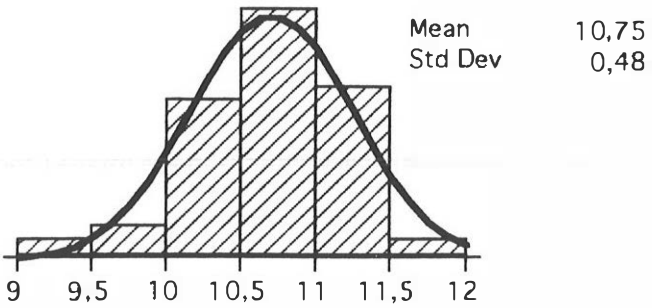

Fig. 5. Distribution of speed between two points. (Unit = pixel corresponds approximately to m/s)

As a complement to the speed test, a test of the distance between to LEDs on the dummy head was performed. The distance should be constant is the camera is aligned parallel to the test track. The distance changes in a constant way if the image plane and the movement plane are not in parallel. This test showed the same accuracy level as the speed test.

In the tests, the area covered was ≈1.5x1 m. The ≈1 pixel accuracy over the area results in an ≈2 mm accuracy in two dimensions.

To test the real world accuracy, the angle of the head prior to collision was calculated using two targets on the head. The angle is constantly changing in a smooth way. The angle estimation had an accuracy of 1 degree.

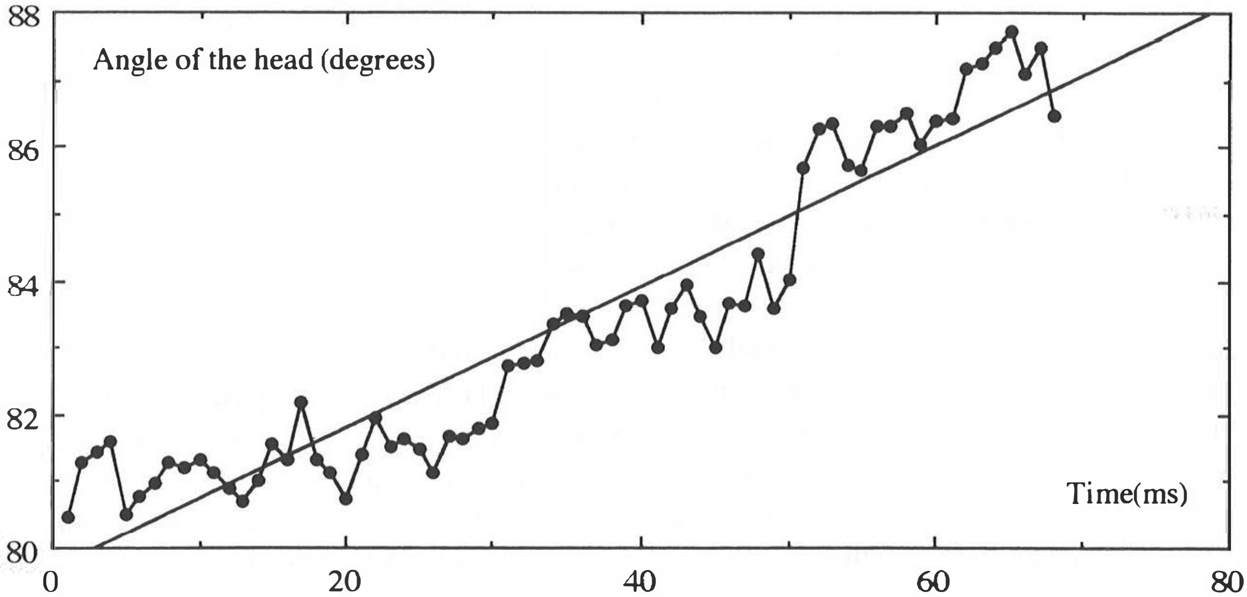

Fig. 6. The angle of the dummy head prior to collision.

Since only one calibrated camera was available when the tests were performed, the photogrammetrical calculation of three-dimensional coordinates has not yet been possible to perform. A simplified formula for error estimation (12) gives help to estimate the error in the measurements. The formula estimates the error in the coordinate away from the camera which normally has the largest error.

$dy=y^2*dp / b*c$ Eq. 1

dy = error in the measurements
y = camera to object distance (1m)
dp = estimated error in the coordinate measurements in the image (2pixel)
b = distance between the two camera locations (1m)
c = camera constant (approximately the focal length) (4mm)

With the values found and used in these test and three-dimensional accuracy of ≈3mm can be expected. This corresponds to 0.2% of field of view.

Discussion

Dummy movement recording and measurement is an important complement to dummy response measurements. Some points of dummies and vehicles are impossible to measure by accelerometers. Visual analysis can give a good compliment to the understanding of dummy measurements. In dose-response analysis, of the interaction between crash severity and injury outcome, knowledge of the dose isolated from the biofidelity dependable response of the dummy is important. For some body regions the contact speed measurements are considerably closer related to the dose in the collision than the response in form of acceleration data for the dummy. This is important when setting dimensions and surface criterion for a new construction. It can also be used for injury estimation depending on seat position, dummy size etc. In complex test set-ups, it is important to know if a dummy response measurement is due to the material contacted rather than the contact speed. Calculating acceleration, especially high accelerations due to contact, from film requires high measurement accuracy and is connected with problems because of the double derivation of the measurements.

The directness of video technique is evident and the possibilities to start the evaluation directly after the test is valuable. The work in this study showed that high frequency flashing diodes were a good help in the visual analysis on the video-television screen and on the computer screen. The flashing targets make high time resolution possible from relatively low time resolving video sources.

Finding target frequencies suitable for the test set-up can be complicated. Too high frequency makes it impossible to distinguish every single flash, too low frequency results in low time resolution. In this study two flash rates were used. However even more frequencies would have been valuable to cover the full range of velocities occurring in the test.

The system described in this paper has not been tested together with traditional high speed filming, with high demands for strong light. In many cases the combination of the two methods is valuable. It is, however, doubtful whether that is possible since the flashes from the targets must have a considerably higher luminance than the background.

Three-dimensional measurements are essential in many laboratory test set-ups. The possibilities to perform spatial measurements with high time resolution are limited. The video technique presented adds one solution to high speed motion analysis.

The system presented in this paper is cost effective and based on easily available components. No specially developed equipment was used. Only very little programming was performed. Existing software for camera calibration was used, and readily available computer programs for analytical photogrammetry will be used.

The measurements have been manually performed in this test. This can be a tedious and time consuming procedure. More sophisticated image analysis to help in the analysis phase can be developed.

The major complication today is the phase where the images are taken from the video tape to the computer. Low quality sychronization pulse in the video signal results in noisy and blurry images.

The fast development in the multimedia sector of the computer arena is pushing systems for real time video in computers. Already today, systems are available with real time or near real time capabilities for small images (≈100*100 pixel). When full video resolution real time series of images, (≈750*550 pixel) can be captured from live video the system outlined in this paper will be more easy to handle. Real time computer capturing of images direct from cameras will produce high quality images. The cost per observation point will, however, be high. Capture from videotape is more cost effective.

Conclusions

- Standard amateur video cameras can be calibrated for photogrammetrical use with a 0.2 % of field of view accuracy.
- Active high frequency light emitting diodes can be used as active targets for multiple registration on video tape.
- Frame grabbing from still image video tape is problematic but can be overcome with digital frame memories.
- Screen measurements from video tape can be done with 0.04% of field of view accuracy.
- Two dimensional measurements of flashing target have 0.13 % of field of view accuracies.
- Three-dimensional measurements of flashing targets are expected to have an accuracy of 0.2% of field of view.

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