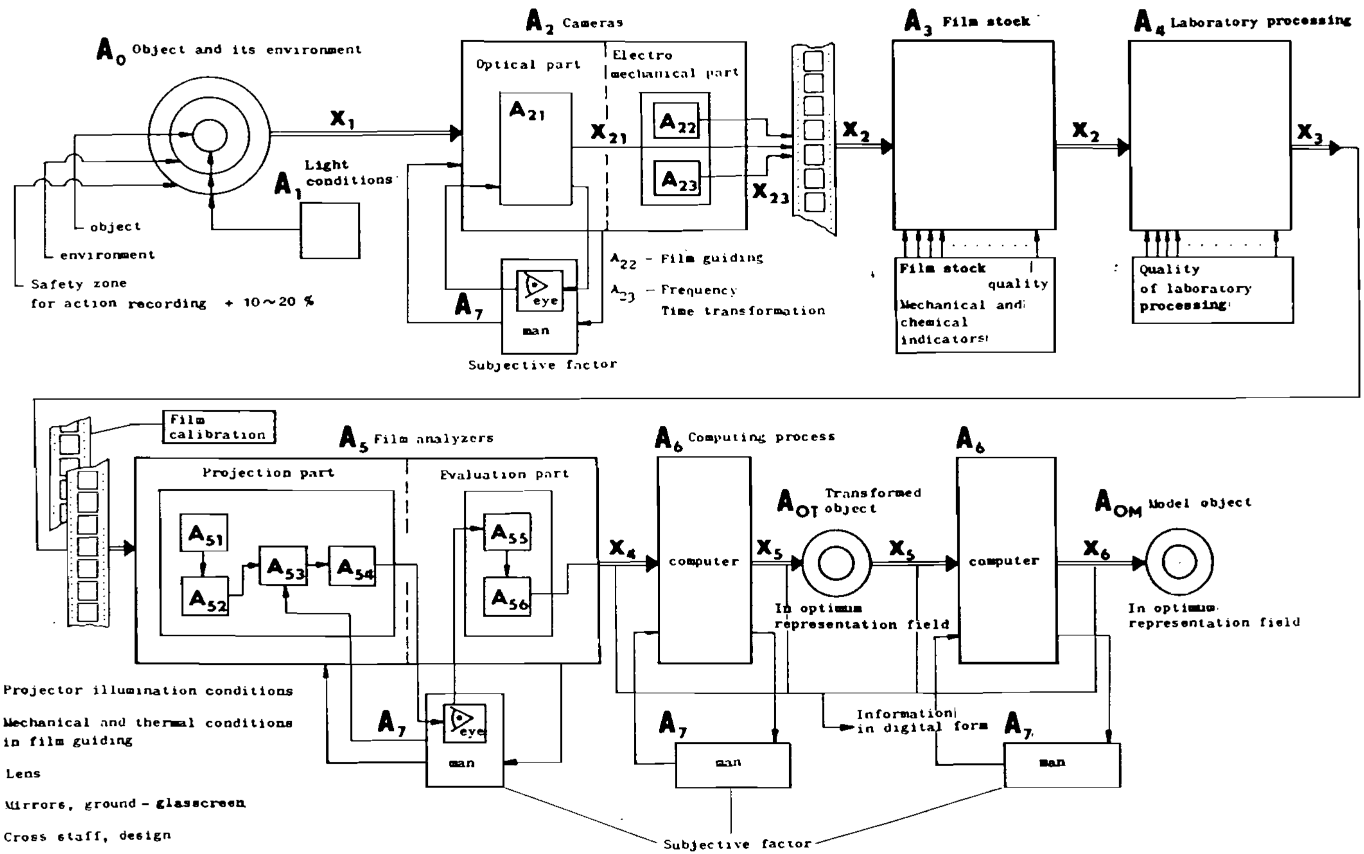
The Theoretical Problems of Information Transfer by Means of Three Dimensional Biomechanics Cinematography

P. Sušanka[1], J. Böswart[2], A. Borůvka[2]

1) Biomechanics dept. and computing dept. of FTVS Charles University, Prague
2) Biomechanics laboratory - SVMC VMO ÚV ČST, Prague
2) Laboratory of elite athletics - SVMC VMO ÚV ČSTV, Prague, Czechoslovakia

Biomechanical analysis of human movement is being undertaken by an ever increasing number of research centres that have at their disposal modern high-speed cameras (HSC) and film analyzers. A more detailed look at the literature available reveals that there are several centres where the more complicated method of three-dimensional analysis is used; the films are shot by two or more synchronised cameras depending on the character and scope of the action under scrutiny. Another step in the methodology of 3-D analysis has been taken by the use of mobile cameras. Together with a whole chain of operations from making a film picture of the object to producing a model object in the optimum representation field by means of computers, that fact has been causing a great deal of problems that are having to be tackled, particularly in terms of making the method more accurate. If the results of biomechanical analyses undertaken by different research centres are to be mutually comparable, research staff should not rely on the guarantees of equipment manufacturers, but should check each individual step in making and processing film material, as indicated by the block diagram in Fig 1.

Similar considerations should also be given to the accuracy of



A_{51} – Projector illumination conditions

A_{52} – Mechanical and thermal conditions in film guiding

A_{53} – Lens

A_{54} – Mirrors, ground - glasscreen

A_{55} – Cross staff, design

A_{56} – Sensors X,Y

Fig. 1

measuring in applying video equipment in biomechanical analyses, and to laying down approaches that will provide comparable results, recording the real action of the object under scrutiny as closely as possible, in model form.

A_0 — THE OBJECT AND ITS ENVIRONMENT — THE OBJECT FIELD

In order to achieve the optimum application of the cinematographic method and to record the action throughout its scope, the object field should be specified in an optimum way, respecting three basic conditions:

a) ensuring the maximum available differentiation of the object under scrutiny
b) ensuring the required precision of the time differentiation of action structures
c) producing a pictorial record that enables objective measurement and evaluation.

In general, the object field is determined according to the formula Fig. 2.

$$OF = (a_0 + 2b) + 20\%$$

where a_0..... the object

$a_0 + 2b$..... the optimum object field

OF..... the field actually outlined, including a safety zone providing for unexpected action of the object.

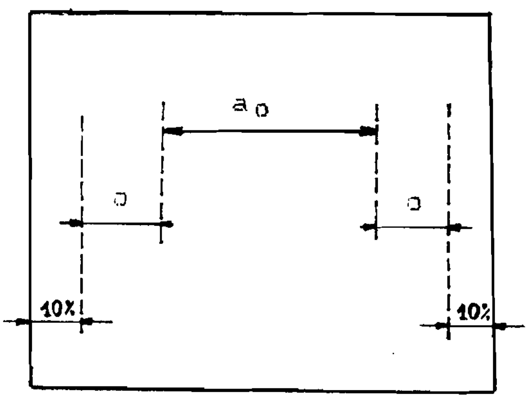


Fig. 2

Shooting an object field that is excessively large lowers the resolving power. Similarly, shooting with the camera too close to the movement plane where low focal lengths have to be used (with the object field identical in size), again impairs the resolving power, as shown clearly in Fig. 3. The size of the object field shot with 16 mm stook and with camera distance from the object between 5 and 100 m is shown in Table 1. The effort to record action in as small an object field as possible results in the use of panning cameras. At the same time we always make a point of having the cameras as far as possible and of using higher focal lengths f (while maintaining the size of the object field); the danger that the object may be hidden by other athletes on the field is a risk that cannot be avoided. The use of sighting cubes, camera fixing, identification targets and other fixed identification points by means of a theodolite and other surveying equipment is indispensable for successful filming anywhere.

TABLE 1

THE SIZE OF THE FIELD TAKEN (in om)
WITH CAMERA DISTANCE FROM THE OBJECT
UP TO 100 m. FILM 16 mm (SIZE OF THE FIELD 7.5×10.4 mm)

f	5 m	10 m	15 m	30 m	50 m	100 m
12	341 × 473	682 × 945	1000 × 1387	⋆ × ⋆	⋆ × ⋆	⋆ × ⋆
15	258 × 359	536 × 743	773 × 1072	⋆ × ⋆	⋆ × ⋆	⋆ × ⋆
18	208 × 289	416 × 577	625 × 867	⋆ × ⋆	⋆ × ⋆	⋆ × ⋆
20	188 × 260	394 × 547	577 × 800	1136 × 1576	⋆ × ⋆	⋆ × ⋆
25	150 × 208	300 × 416	441 × 612	892 × 1238	⋆ × ⋆	⋆ × ⋆
28	134 × 186	268 × 371	395 × 547	798 × 1106	⋆ × ⋆	⋆ × ⋆
35	107 × 149	214 × 297	326 × 452	625 × 867	⋆ × ⋆	⋆ × ⋆
40	93 × 128	188 × 260	278 × 385	577 × 800	938 × 1300	⋆ × ⋆
50	74 × 103	150 × 208	227 × 315	441 × 612	750 × 1040	⋆ × ⋆
58	⋆ × ⋆	129 × 179	192 × 267	394 × 547	641 × 897	⋆ × ⋆
75	⋆ × ⋆	99 × 137	150 × 208	300 × 416	490 × 680	⋆ × ⋆
90	⋆ × ⋆	⋆ × ⋆	125 × 173	250 × 347	410 × 570	833 × 1140
105	⋆ × ⋆	⋆ × ⋆	107 × 149	214 × 297	350 × 490	714 × 990
120	⋆ × ⋆	⋆ × ⋆	94 × 130	186 × 260	310 × 420	625 × 867
135	⋆ × ⋆	⋆ × ⋆	82 × 114	167 × 231	270 × 370	550 × 700
150	⋆ × ⋆	⋆ × ⋆	74 × 103	150 × 208	240 × 340	490 × 680
180	⋆ × ⋆	⋆ × ⋆	⋆ × ⋆	125 × 173	200 × 280	410 × 570
210	⋆ × ⋆	⋆ × ⋆	⋆ × ⋆	106 × 146	170 × 240	350 × 490
240	⋆ × ⋆	⋆ × ⋆	⋆ × ⋆	93 × 128	150 × 210	300 × 420
300	⋆ × ⋆	⋆ × ⋆	⋆ × ⋆	74 × 103	125 × 174	200 × 280
400	⋆ × ⋆	⋆ × ⋆	⋆ × ⋆	⋆ × ⋆	94 × 130	180 × 250
500	⋆ × ⋆	⋆ × ⋆	⋆ × ⋆	⋆ × ⋆	75 × 104	140 × 200

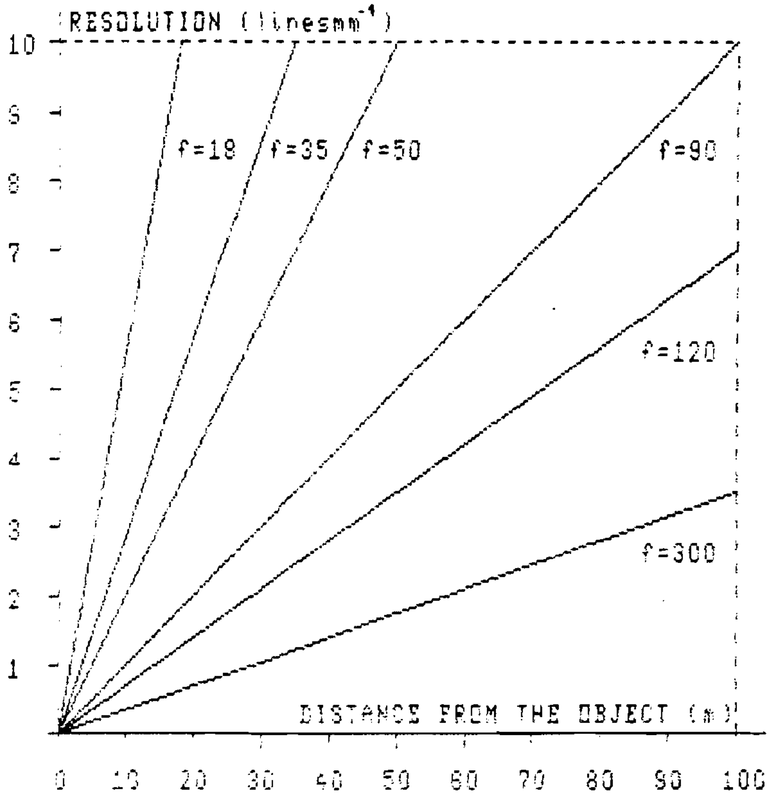


Fig. 3

A₁ LIGHT CONDITIONS

Light can be taken as electromagnetic waves assessed by the human sight. The ability to see differs in each member of a set of people both in terms of quality and quantity; all illumination values are defined by means of an average observer.

Objects are visible if they emit light themselves, reflect light or transmit light. Light is defined as an area of electromagnetic waves in lengths of 360-760 mm, perceived by the eye (Fig. 4).

In filming, exposure time of the stock is measured by a quality luxmeter, taking into account the speed of the stock, with a view to achieving optimum exposure and thereby maximum available resolving power (Fig. 5).

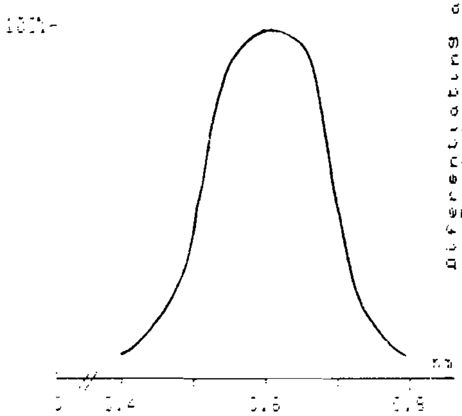


Fig. 4

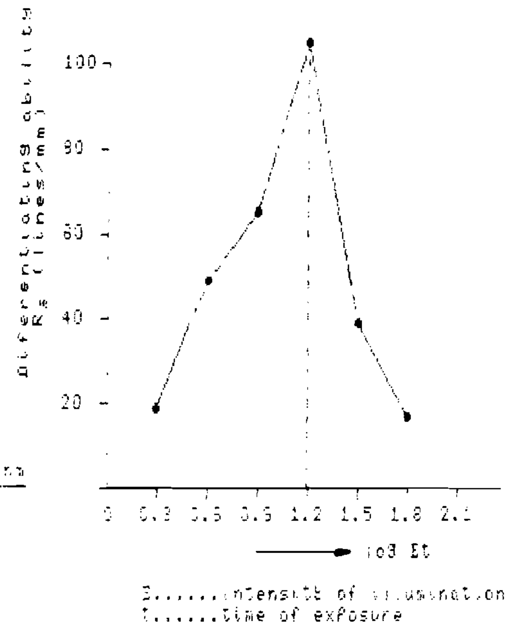


Fig. 5

High speed cinematography is undertaken in a certain optical environment. Vacuum is the ideal optical environment. Practical work, though, is done in the optical environment of the Earth's atmosphere. It is an environment lacking in homogeneity, has varied density and hardness: all that causes changes in the velocity of light propagation, giving rise to the so called noise.

The optical environment that changes white light into coloured is the optical filter. A filter absorbs a part of the spectrum light, letting through only the beams of a certain wavelength: that property is called selective absorption. The manifestations of the quantum nature of light include interference, diffraction and polarisation of light.

The lacking homogeneity of the optical environment and the varying density (hardness) of layers cause partial interference of light which, in turn, is manifested by unequal illumination of the object. That is eliminated to some extent by the use of antireflexive material. Partial refraction must be taken into account at the boundary of optical environments differing in hardness; the refraction index is almost negligible, though. All those factors are stringly affected by air turbulence, humidity, dust and the presence of various gases. The component points of the object are not pictured optically as points but, owing to the refraction of light, as an area. That fact is expressed by the limit of resolution (in mm). The reverse value of the limit of resolution is the resolving power, expressed in the number of discernible details per mm (lines per sq. mm).

A_2 HIGH SPEED CAMERAS

PhotoSonics 500 and LOCAM cameras have been used over the past five years in the framework of an international research project.

A_{21} The way the optical system may affect the precision of photographic information has mostly been ignored: the general opinion is that as a medium of the transmission of photographic information, the optical system is clearly superior to film stock. Manufacturers specifications emphasise the higher transmission quality of the lenses (up to 500 lines/mm), but can be demonstrated only in the lens axis. Preliminary measurements of lenses, on the contrary, have made it clear that the values of the parallax and astigmatism significantly affect the results achieved, particularly in the corners and edges of the object field. Our work is often performed in conditions that necessitate the use of lower f-number diaphragms to achieve accurate exposure, which is why the errors must not be neglected, but should always be taken into account.

A_{22} Accuracy of Film Guiding

The chief concern in cameras with the claws system of film feeding is the accuracy of setting the sprocket holes vis-a-vis the claw mechanism, in particular the register pins. The accuracy of guiding improves with two-side perforation, i.e. film feeding in two levels.

Lack of precision may be caused by:

a) translation and rotation of stock (can be eliminated by means of fixed sighting points);
b) the film plane deflecting from the assumed picture plane (cannot usually be eliminated; this error causes a change in scale and image blurring, with parts of the frame differing in the scale of representation).

The present state: In terms of mechanical qualities, the cameras in general use are highly sophisticated; auxiliary sighting points are not required, and a uniform scale can be used for the whole shot. The cameras feature internal heating, and have worked well even at extremely low temperatures. Lack of accuracy that might occur cannot be detected by the methods used for detecting it.

A_{23} High-speed cameras with a grabbing mechanism are constructed for frequencies up to 500 fr/s. At slower frequencies, undamped vibration of the electromechanical feedback loop — the servesystem — occurs. That's the accuracy of setting and keeping the frequency, on which the quality of the servesystem depends. The servesystems used are analogues, comparing the set tension with that generated by the speedodynamo coupled with the mechanical guiding of film. The short fluctuation of frequency depends on the mechanism of the film displacement and the quality of the film stock.

The run-up duration of the camera, i.e. the time necessary for reaching the set frequency, depends on the frequency value and the quality of the supply sources. It is about 1 s for reaching the frequency of 100 fr/s and 1,5-2 s for that of 200 fr/s.

During the synchronous run of two and more cameras in master-slave regime, the regulating loop of the slave camera is being steered from the master camera. The duration of the run-up till stabilisation of frequency is then longer, e.g. for the frequency of 200 fr/s cca 2-2,5 s.

The time transformation:

In comparison with the normal shooting frequency of 25 fr/s, at that of 500 fr/s the real time is 20 times slowed down; the action in time is quantified by 2 ms.

The accuracy of setting and reproducing the shooting frequency is cca ± 1 frame. By comparing data of the time signals exposed on the margin of film and generated by a crystal oscillator with the accuracy better than 1.10^{-6} Hz, it makes it possible to define the set frequency backwards with an accuracy better than 0,1 fr/s.

A_3 FILM STOCK

As the methods of 3-D analysis improve, requirements on the quality of the stock rise too.

The quality of the picture is defined by the measure of similarity between the object and the picture produced by the system of representation. No system can fully reproduce all the details of the object, either in terms of dimensions or light. The main demands on film stock are high sensitivity and contrast, outstanding resolving power, low veil and grain rate, colour balance, perfect anti-halo, and a thin, strong and flexible carrier. None of the films available can fully meet all those requirements: stock is therefore chosen with a view to the conditions and the use envisaged. On the other hand, all the conditions of shooting must be observed with a view to obtaining the maximum values specified by the stock manufacturer, and to preventing any damage to the stock throughout the process, from purchase to the library storage of the finished product.

Film stock used in cinematography Tabl. 2.

16 mm size

a) colour stock

b) black and white stock

Most of the stock has been subjected to sensitometric tests. The best results have been achieved with EKTACHROME 7293: here the results of the examination are almost identical with the specifications of the manufacturer; the resolving power is even better. Each batch of stock ought to be subjected to sensitometric tests.

TABLE 2

FIRMA — SORTE	TYPE	DIN (DAYLIGHT)
Eastman Ektachrome High Speed Film	7250	25
	7251	27
Eastman Color Negative Film	7293	23
	7224	28
Kodak TRI-X Reversal	7278	24
Gevachrome Reversal Film	732	24
Agfa High Speed Color Negative Film	XT 320	24
Orwo Color	NC 3	19
Orwo Chrom	UT 15	15
	UT 17	17
Fujicolor High Speed Negative Film	AX 8524	27
Fomachrom	MD 17	17
	MD 24	24
Orwo	NP 7	27
	UP 27	27
Orwo Fernseh - Universal	UP 32	21
	UP 52	26
Fomapan	NP 21	21
	NP 27	27

A_4 LABORATORY PROCESSING

Essentially a black-box procedure, since it cannot in any way be influenced.

Tests aimed at obtaining information about the level of laboratory processing are made before and after the laboratory process:

a) a sensitometric test of the quality of the stock (Fig. 6).
b) evaluation of the entire system (camera, stock, processing) by means of the line test shot in laboratory conditions; differences from the quality obtained are determined (Fig. 7, 8, 9)
c) shooting the test part of the film (line test again) in actual working conditions in the stadium before beginning to shot the event concerned
d) identifying the geometric distortion in the picture and determining differences from reality, done by shooting a linear scale and by means of a sighting cube. The differer ces must be determined in order to eliminate errors in computer processing.

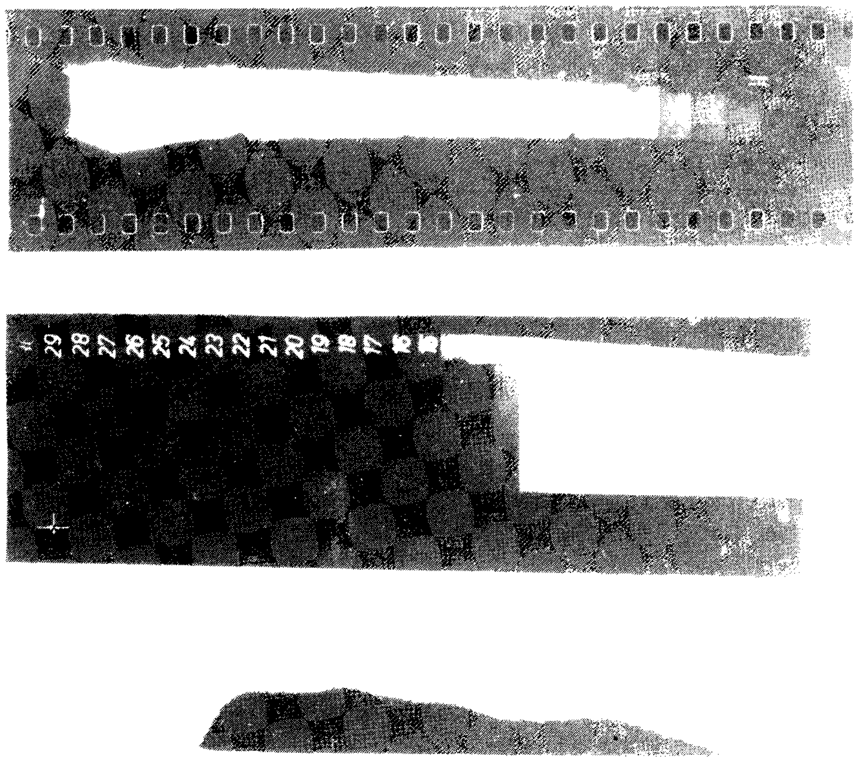


Fig. 6

Planche 1

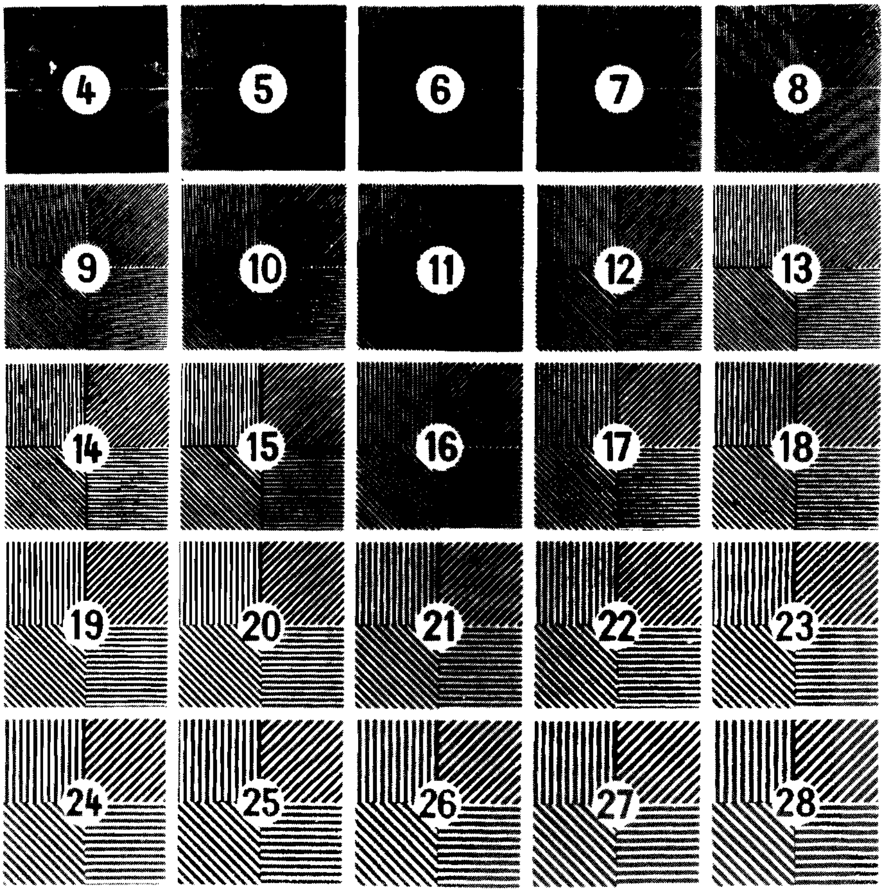


Fig. 7

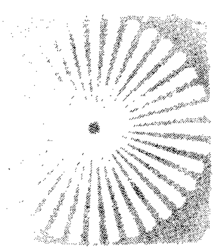


Fig. 8

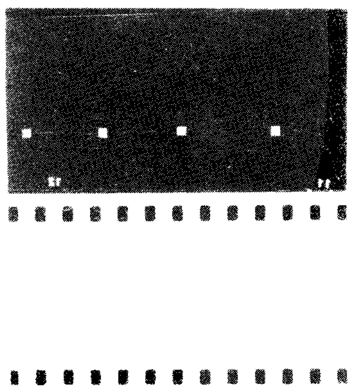


Fig. 9

A_5 PROJECTORS — FILM ANALYZERS

The projector most frequently used for purposes of analysis is the DYNAMIC FRAME model DF-168 manufactured by NAC.

One of the most important parts of a film analyzer is the lens that determines the quality of the information transfer from the film picture to the analyzer screen. The manufacturer's specification for the Dyn. Frame..... is a resolving power of 200 lines/mm. All the projectors and/or analyzers in current use should be checked to find out if the specifications are not the maximum rate, i.e. in the axis of the optical system. Optimum results cannot be achieved unless the projector lens has a resolving power above 100 lines/mm as far as the very edge (corner) of the picture, and a high contrast rate. These would generally be six or eight-lens systems of the so called Gauss type. The lens speed ranges from 1:1,0-1.1.

A_{51} Dependence of the lens resolving power on the illumination conditions of the projector: the following method of determining the dependence have been proposed on the basis of practical experience:

a) sequential control of the projector bulb intensity by means of thyristor control with a calibrated potentiometer (the result in per cent)
b) same as a, only the intensity of light measured by a lux-meter (chromatics temperature)
c) screen blackening to be evaluated by comparison, i.e. pre-shot wedges of a known density; visual comparison of the optical density.

A graph of the dependence (Fig. 10) has been plotted on the basis of the measurements made, according to a, c.

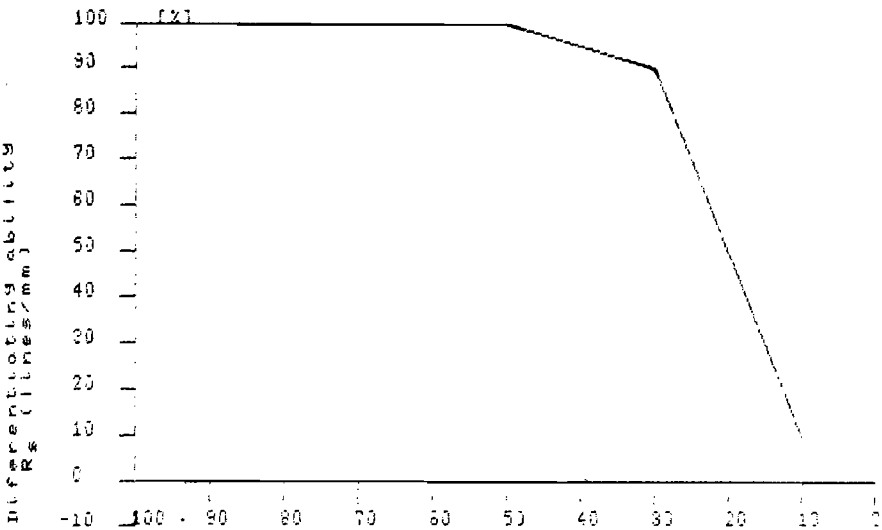


Fig. 10

The resolving power drops significantly when the projector bulb enters the red band of the spectrum. The resolving power approaches maximum values with film density D-1.1.-1.2., dropping to both sides owing to the decreasing contrast.

Measuring the temperature of exposure: precise measurements can be made with a MINOLTA COLORmeter chromaticity temperature meter. The instrument has two opening with, respectively, a red and a green filter, both calibrated. The temperature of exposure (deg. K) is measured by the logarithmic subtraction of two passages through the filters.

1) black and white stock
   a) panchromatic — the speed of the stock drops slightly (Fig. 11)
   b) superpanchromatic — the higher speed in this area is utilized (Fig. 12)
2) colour stock — transition from daylight to artificial light may cause problems.

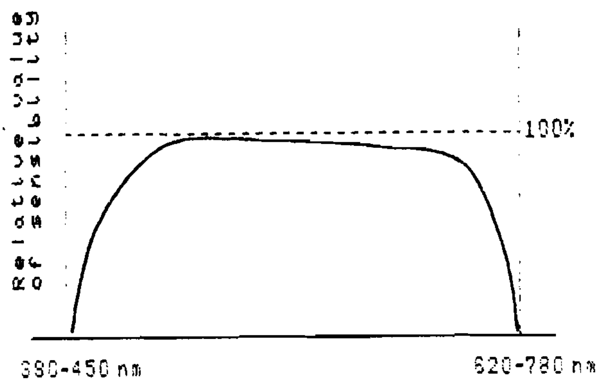


Fig. 11

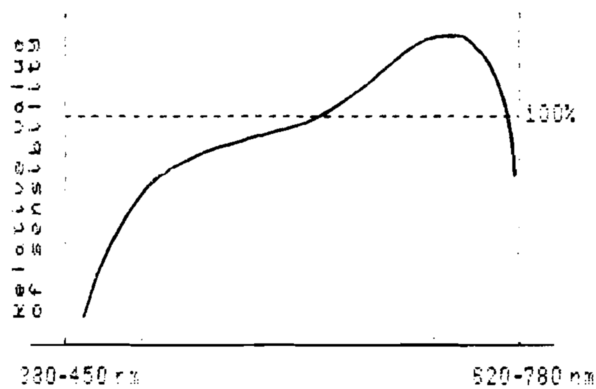


Fig. 12

In using predominantly colour stock, the temperature of exposure should be measured while filming in the field; the values obtained help to adjust the correction by means of..... filters; the filters affect sensitivity, though.

A_{52} The light source is separated from the stock and is actively cooled to prevent stock deformation by heat. The mechanical equipment for film feeding in the analyzer is designed on the same principle as stock feed in a cine camera. But it is designed for speeds of 25-30 frames/s. and can be reversed. It works in the smooth run mode even when stepping, frame by frame, where each film field can be precisely identified.

A_{53} In addition to the requirements on the lens enumerated above / the quality of the optical system consisting of the lens, mirror and ground glass screen, must, as a minimum requirement, be on par with the quality of the camera (optical system) it should be emphasised that what is valid for exposure is also valid for setting the optical system. In the course of analysis, the optical system must not be re-adjusted, e.g. by changing the focus.

A_{54} Unlike filming equipment, analyzers have the added problem of the planparallel planes of film, mirror and ground glass screen. It should be checked before analysis is started (the centre of the projection screen vis-a-vis the edges).

The quality of film setting, assuming perfect planeness of mirror and ground glass screen, is determined by the quality of the reference pattern used for calibration etc.

A_{55} Analyzer Designs.

The main difference is between top and bottom projection. Some analyzers facilitate enlarging an image area, pinpointing a detail. The accuracy and readability depend largely on the quality of the cross staff. Looking in the direction of the light-beam travel, the cross staff is placed in front or behind the ground glass screen.

(Note: In front of the ground glass screen, in top projection, the cross staff obscures the point under scrutiny. In front of the ground glass screen in bottom projection, it must be controlled by a complicated mechanism. Behind the ground glass screen in bottom projection, the subjective error in reading is made even worse by the thickness of the ground glass screen and the definition of the view direction).

A_{56} The Principle of Coordinate Reading (Read-Out)

a) digital

b) analog

a) Incremental scanners with resolution better than 0.05 mm of the size of the ground glass screen.
   — origin can be set
   — scale cannot be set
   — high linear character and uniformity of reading
   — digital output (no analog output)

b) Potentiometric, induction or acoustic scanners
   — precision better than 0.1%

Potentiometric	— origin can be set — scale can be set — analog output — lower linear character than incremental — higher failure rate, higher wear — precision depends on reference power source
Acoustic	— least precision, resolution ± 0.1 mm of the area of the ground glass screen — simple mechanics — only bottom projection — high subjective error
Induction	— simple mechanics — mostly only top projection, less suitable — analog principle, but mostly digital output — probably the best in the long-term prospect

A_6 COMPUTING PROCESS

Problems connected with the origin of errors when using the computing technique are discussed in the V. Kohl's paper «Computational Aspects of 3-D Kinematic Analysis».

The errors are discussed from the point of view of the unaccurate definition of camera location, following digitalization and primary processing coordinates. Further the errors which can arise during the calculation of 3-D coordinates and separate kinematic values.

CONCLUSION

The paper indicates the general block-scheme of gradual steps during the transformation of an object from the object field into the optimal imaging field.

The formation of a most faithful model object with corresponding kinematic or possibly dynamic characteristics must be attended by the persistent effort of elimination (or at least minimization) of all possibly arising errors in every single gradial step, from the choise of the magnitude of the image field A_0, ..., till the computing process A_6 and formation of the model object A_{OM}.

As a step towards reaching comparable results of the 3-D analyses from different work-places, we recommend the introduction of a «calibration» scheme of bodies with a preconceived trajectory and kinematic characteristics of the given motion system and by means of it the control of the hardware and software equipment of the individual work-places.