*Photogrammetry and the Photography of Motion**

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INTRODUCTION

THE object of this paper is to emphasize the broadening of photogrammetry into the fields of high speed and time lapse photography.

The word, "Photogrammetry" has long been associated with aerial mapping. It is true that many of the measurements made from aerial photographs are from "still" pictures, where size of subject, distance between points and elevation have been the prime objectives. In fact, Webster's Dictionary (Merriam, 1953) defines "photogrammetry" as, "the science or art of obtaining surveys by means of photography; specifically, the process of making maps from photographs, especially aerial photographs." The American Society of Photogrammetry, however, gives the following definition, "the art and science of obtaining measurements from photography."

Photogrammetry has been used by applying "x," "y" and "z" axes for space determinations; but with the newer concept of photogrammetry time must be added as a fourth axis, so that rates, velocities, accelerations and decelerations of subjects in space can be determined. Distances may vary from millimicrons to miles and kilometers.

The late Brigadier General Paul T. Cullen gave one of the first broadening definitions of photogrammetry, in a paper delivered before the American Society of Photogrammetry.† He defined it, as follows:

> "It was just a year ago that I was pulled out of the annual meeting of this Society to be informed that I was responsible for the AAF portion of Crossroads photography. Let me warn you here that whereas this report will attempt to remain impartial—'tis inevitable that it will be mostly concerned with Air Force participation.
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> "The problem was first stated in the following words: 'Put a Fastax camera in two B-29's and follow the bomb carrier into the target because we want pictures of the first two seconds of the burst.' Please note that we were not given an accurate statement of the problem, instead we were given a partial solution. Actually, it took us weeks to determine exactly what the scientists, the Air Force, and the Navy wanted. Normally, problems if clearly stated, can be analyzed, the possible solutions laid out and the most practical selected. However, because of the lack of knowledge about atomic phenomena, and failure of our people to make an analysis of the end desired, our operational planning was kept in turmoil. We actually received a *new* photographic requirement just three days before Able Day!"

However, many rotating prism high speed cameras, intermittent motion picture cameras, oscillographic cameras, time lapse cameras, pulsing aerial cameras and still cameras were eventually used on this project.

* This is one of the papers included in the Report of the Reporter for U.S.A., Commission V, International Society of Photogrammetry.

† PHOTOGRAMMETRIC ENGINEERING, Page 96, Volume XIII, 1947.

General Cullen's comments about the planning and execution are usual. It is extremely unfortunate that this same condition exists even today. Equipment is designed and experiments planned and, at the last minute, the photographic requirements are made known. This necessitates many important phases of the permanent photographic recording to be made with improvised set-ups.

Gomer T. McNeil presented an excellent summarization of some of the non-topographic aspects of photogrammetry in PHOTOGRAMMETRIC ENGINEERING, March, 1955, pages 49–56. Several points, however, need clarifying.

The High Speed Photography Committee of the Society of Motion Picture and Television Engineers was organized in January, 1948. In the minutes of the first meeting the requirements for good measurements were stressed. If Society correspondence were examined, it would be found that the term, "photogrammetry" had to be "sold" to the Society. This is examplified bythe Symposium on data reducing equipment, presented at the Society's fall meeting in 1955.

Another point to be clarified is that Mr. Shaftan was named Chairman of the Sub-Committee on Nomenclature. This was, and still is, a sub-committee of the High Speed Photography Committee of S.M.P.T.E. After the preliminary work by Messrs. Shaftan and Sultanoff (also of S.M.P.T.E.), a working glossary is is approaching completion under Messrs. Morgan and Waddell assisted by many organizations and interested individuals.

There have been two great differences of approach to the nomenclature project: Whether the glossary should be extremely scientific; or whether it should be less scientific and more easily understood and translated. The latter conception is being followed by the Committee. It is hoped that this glossary will be ready for presentation at the Third International Congress on High Speed Photography, which is to be held in London, September, 1956.

DISCUSSION

The phase of photogrammetry relating to high speed motion pictures, time lapse pictures, still and multiple image photography and oscillography is primarily the photography of motion. The measurements, when the term is used broadly, are either qualitative or quantitative. Jean St. Thomas points out, in nomenclature being prepared by the Society of Photographic Engineers, that all nomenclature should be quantitative only; but in a glossary of high speed photography, being prepared by a Committee of S.M.P.T.E., it was decided that the terminology should be a working manual applied to both the qualitative and quantitative measurements.

To illustrate the points of comparison just mentioned, the method of observation and analysis of data presented on the picture bears consideration. Table I gives the comparative methods.

In the qualitative observations, comparative sizes and distances only are needed; but for quantitative measurements, size, distance and time increments must be known.

The time increment factor is important. The accuracy of the final results is dependent upon the accuracy of the recorded time. Electrically operated clocks are dependent on a frequency drift, or lack of drift, in the generating station. Because of the inter-area networks, this phase is relatively unimportant. Sixty cycles per second, for all practical purposes, is 60 cycles; but 60 cycles in a field generator can be practically any frequency between 50 and 70 cycles.

Electric timing clocks with electro-magnetic clutches are useful if several precautions are taken into consideration. The clock motor should be running continuously and not started simultaneously with the operation being studied.

TABLE I

Type of Picture	Method of Observation	
	Qualitative	Quantitative
Motion Picture (High Speed, Normal Speed and Time Lapse)	In a motion picture projector as a motion picture	In a film "reader" or a "time and motion study" projector, frame by frame
Still Photograph	Visual observation	Physical measurement of the amount of smear of the moving subject
Multiple Image Photograph	Visual observation	Physical measurement of the distance between successive exposures
Oscillograph	Visual observation	Physical measurement of time amplitude and frequency

If d-c clutches are used for stop and start, the same voltage should be used at all times, so that the delay between energizing the electro-magnet and actual operate time is constant. The operate time should be known when millisecond accuracy is required. A glow-lamp can be used for calibration whenever a timing device is utilized. Clutches operated on a-c are more erratic because the operate time is dependent on the part of the sine wave on which the operate impulse is received.

A number of oscillator circuits have been designed for furnishing a time "pip" to a glow-lamp. These vary from the crystal-controlled oscillators to battery-operated oscillators. Those which are battery-operated will have some drift, depending on the length of time that they have been left on. The characteristic frequency becomes more stable with longer operating time. The factor of permissible, experimental error in the analysis will be the controlling feature in selecting a circuit. If a 1,000 cycle oscillator is actually delivering 987 cycles, one millisecond (.001″) can be used for most purposes; for more accurate work, .001013″ should be used.

The rate at which the pictures are being made is computed from the number of pictures divided by the time, or in the case of a continuously moving film, the length of film divided by time. With cameras running at a stipulated rate, several conditions will affect the evaluation program:

(1) Initial acceleration of the camera,
(2) Steady (?) rate of the camera, and
(3) Deceleration and stopping of the camera.

Another phase of measurement that has not been emphasized enough is in the field of optics. With the use of lenses having focal lengths of 360 inches and 600 inches, calibration of focal lengths is necessary and extremely important. It is not only needed for the longer focal length lenses, but for the shorter ones as well. The focal length calibrations should be determined not only at temperatures of approximately 75°F.; but at −80°F., −20°F., 32°F., and 160°F. Also, with the increasing use of lenses in aircraft, in missiles, in the Arctic and in the desert and tropics, this information is necessary for accurate measurements. The ASA standard of ±2% tolerance in stipulated focal lengths is no longer good enough.

Flatness of field is also an increasingly important factor. As film bases are being developed with lower shrinkage characteristics, the field flatness requirements become more stringent.

And film analyzing equipment (readers) must have optical equipment which is equal in performance to the recording equipment. What value does a film have when the distortion has been kept to $\frac{1}{4}$ of 1%, if the lens on the film reader has 2% or 3% distortion and has to be refocused after the center has been read in order to read the edges?

The fiducial marking systems, too, have to be well designed. The fiducial marker should be brought in through the objective lens, not laid down at the film plane, where notched aperture plates are used. If there is poor registration frame to frame, the x and y notches are practically useless. With the fast, fine-grained films the use of the beam splitter, fiducial marker system is plausible. It overcomes the objection of the lack of consecutive registration.

A typical subject for the analytical treatments, discussed in Table I, is the electrical relay. A relay is selected because of the variety of phenomena that can be studied by its performance. Among the reaction studies are:

(1) Operate time
(2) Release time
(3) Contact chatter
(4) Contact arcing
(5) Contact erosion
(6) Contact spring performance
(7) Reset spring performance
(8) Stud performance
(9) Effect of temperatures and pressure on performance
(10) Effect of acceleration and deceleration
(11) Effect of shock
(12) Effect of vibration
(13) Effect of corrosion

In conducting the photographic phases for the tests outlined above, the procedures and methods of analysis may be summarized, as follows:

(1) Operate time. High speed motion picture photography will be used to record the event. The electrical impulse time can be simultaneously photographed by adding a neon, or argon, lamp in the field of view, or a cathode-ray oscilloscope trace can be simultaneously recorded. A timing light is used to provide the time axis. The time difference between impulse and the movement of the armature and/or the closing of the contacts are read on a "film reader" or a "time and motion study projector." (Quantitative and qualitative.)
(2) Release time. Same as "operate time."
(3) Contact chatter. "Close-up" high speed motion pictures are made. The timing light with 1,000 cycles will provide the measurements of gross chatter. A 10,000 cycle wave is better for fine chatter. This is put right across the making or breaking contacts and shown on an oscilloscope. This is recorded simultaneously on the film as the picture is made. This can be both qualitative and quantitative.
(4) Contact arcing. Again high speed motion pictures are made. If they are enlargements of the subject, the flow of melted metal and the formation of pits can be observed. This is primarily a qualitative analysis. It becomes quantitative if the current across the contacts is varied and measured and plotted against arcing time.
(5) Contact erosion. The high speed motion pictures made with macro-techniques allow a qualitative analysis of the flow of the molten metal while arcing is taking place. The quantitative measurements are made from time lapse pictures. These pictures would be taken with a stipulated number of operations occurring between each picture; for example, the pictures programming

would be 0, 10,000, 20,000, 30,000 operations and so on, until locking up or failure occurred. In the case of d-c relays, the polarity should be noted. The magnification of the contact points should also be calculated for accurate determination of deformation.

(6) Contact spring performance
(7) Reset spring performance
(8) Stud performance

The contact and reset spring and stud performance are very closely interlinked. The performance of springs on original design is notoriously poor. The formulae for the design of springs are approximations only. Until comparatively recently, the performance of the spring was judged by life tests. This did not show why the spring failed; but when the spring failed, the guess work began. And there were no apparent short cuts. Then the high speed motion picture camera was used to slow down the action and, consequently, phenomena, such as standing waves, flexibility, points of stress and strain, and snubbing action, could be observed, both qualitatively on projection, and quantitatively with frame by frame analysis. When the snubbing action of the stud could be observed it was found that a small fraction of an inch change in position would often break up the standing waves, which cause contact chatter. The whole gamut of springs, such as flat, helical, coil, et cetera, were natural subjects for similar analysis. The engineering time saved cannot be calculated. One spring analysis with a high speed camera would more than pay for the cost of the high speed laboratory.

(9) Effect of temperatures and pressure on performance. These effects overlap the other reaction studies of operate time, spring behavior, et cetera. For certain analysis it might be necessary to use a camera in the cold or hot test chamber; therefore, the camera must be designed to work under these conditions. There has always been a question as to how arcs behave under reduced pressure, such as is encountered at high altitudes. Obviously, any method of study will lead to many interesting conclusions. A particular study, at present, might be the difference in 400 cycle and d-c arcs at altitude conditions up to 100,000 feet of more.

(10) Effect of acceleration and deceleration
(11) Effect of shock
(12) Effect of vibration

The effects of shock, vibration and "g" tests are important. If any of these phenomena cause unwanted closure or opening of contacts, serious malfunctioning of the associated equipment may occur. The majority of these tests would be qualitative. The advantage of the high speed camera is that it is capable of picking up erratic or aperiodic actions; while irregular malfunctioning usually cannot be seen with a stroboscope.

(13) Effect of corrosion. The effect of corrosion can best be studied with a time lapse motion picture camera. This would cover moisture, salt spray and chemical vapor effects, as well as atmospheric oxidation. For example, if a corrosion test was going to last 200 days, and for a sequence of 600 pictures (25 seconds projection time), one picture would be taken every 8 hours. The lighting would have to remain the same for each picture. It is true that fading of the latent image might affect the produced picture; but the film manufacturer would probably be able to give approximate figures on the effect of fading with original exposures on request.

The action of the relay was selected as a typical study in both qualitative and quantitative analysis. Similar analyses can be made of anything that moves.

Some typical subjects would be:

Physical and Chemical:

- Velocities and speeds
- Acceleration and deceleration
- Shock
- Vibration
- Mechanical action
- Flow patterns and hydraulics
- Temperature effects
- Phosphorescent decay
- Electro-magnetic effects
- Tensile testing
- Impact
- Photoelasticity
- Evaporation and condensation
- Crystallization
- Mixing and agitation
- Oscillation
- Effects of sound
- Shock waves

Mechanical design, behavior and fabrication:

- Springs
- Levers
- Gears
- Cams and followers
- Rachets and pawls
- Machine tools:
  - Lathes
  - Millers
  - Drills
  - Punch presses
  - Automatics
- Soldering
- Welding
- Wrapping
- Coil winding
- Extrusion

Animal behavior:

- Locomotion
- Vocal chords
- Heart action
- Ear drums
- Muscular reaction

Astronomy:

- Sun spot behavior

Aviation:

- Fuel studies
- Carburetor studies
- Vibration effects
- Propellers and blades
- Bomb releases
- Landing

Military:

- Ballistics
- Detonations
- Impact
- Field testing of equipment
- Hull design
- Cavitation

Sports:

- Does a baseball curve?
- Swimming and diving
- Classical ballet and popular dancing
- Tennis
- Football

Household:

- Washing machines
- Electric mixers and blenders
- Vacuum cleaners
- Fire extinguishers

A growing interest in the field of metrical photography is indicated by the fact that Muybridge's classical pictures, taken in the 1880's, are being reprinted, "The Human Figure in Motion" (1956) and "Animal Locomotion" (June, 1956) by Dover Publications, New York.

Any photograph when used for measurement, qualitatively and quantitatively, is a part of the science of photogrammetry.