the human skull which from the medical view point are most important for the identification of a person alive or dead, even though his face may have become disfigured by facial surgery, accident, death, or other causes. Criteria and dimensions outside of the planes of the two profile planes may easily be derived by the projective method and measurement on the resulting model surface.

Figure 13 shows the practical setup of this stereo triplet in the projectors on the Bausch & Lomb supporting unit. Here the two stereo bases are installed by their B_x and B_y components. This results in the vertical orientation of the central projector, and a convergent orientation by the angle of two Alpha of the lateral projectors. The plane of projection to which all measurements with the tracing table are referred is normal to the central projection axis. All spatial dimensions can be derived from the planimetric position and the elevation differences read from the tracing table counter.

In many cases, photographic copies presenting the two main profiles will suffice to reconstruct or identify the matter of investigation by two dimensional measurements. These copies can be directly obtained on the supporting unit by placing a copying easel inclined to the angle of Two Alpha on the working table (Figure 13) and exposing photographic paper to the profile image, projected from the central projector. In this application the Scheimpflug ring is adjusted to cant the lens to that position which will result in the best photographic focus over the tilted emulsion plane. This application of Mono-Photogrammetry is capable of supplying unambiguous records to all organizations, which are concerned with the identification of human beings whose record may be famous or humble, honorable or criminal.

ACCURACY CONSIDERATIONS

From experiences in aerial topographic mapping in which we deal with the base-height ratios of from 0.6 to 1.2, we can justly extrapolate the accuracy which we may obtain by the procedures described. The setting accuracy of the measuring mark on the model surface will of course greatly depend upon the surface properties of the object of investigation. These properties may range from excellent to poor. The relative distance error under average conditions can be expected to be in the vicinity of .1 mm or better. Since the reconstruction of the spatial object takes place at a scale of two-thirds to three-quarters of the natural size, we can expect that the standard error of spatial dimensions will also be of that order of magnitude. It will not be necessary here to dwell on the error theory of this procedure. The interested reader is referred to Dr. B. Hallert's paper on the theory of errors in terrestrial photogrammetry; this may be logically applied to Mono-Photogrammetry.

SOME ASPECTS OF "NON-TOPOGRAPHIC PHOTOGRAMMETRY*"

Gomer T. McNeil, Executive Director, Photogrammetry, Inc., Silver Spring, Maryland

EVEN although the term Photogrammetry has been defined by its most logical spokesman, the American Society of Photogrammetry, as being "the art or science of obtaining reliable measurements by means of photography," it has

* Presented at Semi Annual Meeting of the Society, Philadelphia, Pa., Sept. 16, 1954.

been deemed necessary to utilize the phrase "non-topographic photogrammetry," quite as if the original definition had really been stretched too far in its all-inclusiveness. We are thus rather being relegated to the dictionary definition, which reads: "the science or art of obtaining surveys by means of photography; specifically, the process of making maps from photographs, especially aerial photographs."

Accordingly it is of interest to trace the origin of the term "non-topographic photogrammetry," since its continued use seems not only to define by negation, but also to negate the definition of the concept "photogrammetry" as an overall science, by denying it the intended all inclusiveness implied by the American Society of Photogrammetry definition.

In 1950, Dr.-Ing. Otto Lacmann, Professor at the Technical University of Berlin—Charlottenburg, presented an excellent book in German entitled. "Photogrammetry in Its Application to *Non-Topographic Fields*." Lacmann pointed out that after World War I, some attempts were made to pursue the application of photogrammetry to fields other than mapping. However,the results were discouraging due to the instruments utilized being usually designed for other purposes, and because the technical personnel were inexperienced in the new field. The developments were limited to a relatively few. Lacmann found desirable the creation of a central research body to concern itself with research in photogrammetry as applied to non-topographic fields. This institution would support science and industry with advice and deed, as well as investigate new fields of application and develop suitable instrumentation. Lacmann attempted to develop research and practical solutions at the Institute of Photogrammetry in Berlin but his work was terminated at the outbreak of World War II.

Ever since the review of Lacmann's book by our Moderator, Mr. Landen, in the September 1950 issue of PHOTOGRAMMETRIC ENGINEERING, the term, "non-topographic photogrammetry" has received more and more usage, although Lacmann himself did not use it. Rather did he say: Photogrammetry in *non-topographic fields*. It is suggested that the use of the term "non-topographic photogrammetry" be discouraged, since it is negative in approach. It was compounded to a word that clicked on the spur of the moment, because of the kinship of the system of coordinates used in its application.

Authorities in the field of the diversified application of photogrammetry, for example Lacmann and Hallert* recommend at the conclusion of their papers that the advantages of photogrammetry are not readily known in the various fields of scientific research, and that an educational crusade is in order, to spread its uses. Imagine the weird facial expression of a doctor if informed that he was practicing non-topographic photogrammetry when he analyzed stereo-X-rays for the location of a foreign object in the body of a patient.

The term used by Lacmann was justifiable in the context of his work, and this should not detract from the eminent merits of his remarkable compilation. The further derivation, however, as used today, is a most unfortunate development, likely to hamper those engaged in this field.

The sheer mass of the material presented in Lacmann's publication is perhaps responsible for obscuring a term which emerged in the last sentence of his conclusion: "That there should be created a central research organization which would concern itself with the study of new applications of photogrammetry, and with the development of the INSTRUMENTATION which would guarantee the most effective adaptation of photogrammetry to the specialized requirements (to be encountered)."

* See References.

Lacmann's term *Instrumentarium* is not a current, everyday word of the German language. It is rather a latinized collective noun of which the intended meaning exactly parallels our own word *instrumentation*. It was most fitting that Lacmann should have culminated his treatise with this term.

It is also particularly appropriate to introduce the extended term, *photographic instrumentation*, at this first meeting of the International Instrument Congress and Exposition.

Any discussion regarding photographic instrumentation must eventually also introduce the name of Kenneth Shaftan, since he first proposed the definition. Shaftan was well known within the Society of Photographic Engineers and the Society of Motion Picture and Television Engineers. It is regrettable that he was known to relatively few within the American Society of Photogrammetry. Shaftan's significant contributions were:

(1) The recognition of photographic instrumentation as a major research tool by the scientists.

(2) The definition of photographic instrumentation in terms which have been accepted and applied in the scientific world.

(3) The proposed organization of the knowledge in the field of photographic instrumentation.

Shaftan deplored the fact that the prior state of this science should be so widely scattered throughout the vast technical literature as to be practically lost to the searchers in the field. His proposed organization was intended to prevent further such losses. He also specifically deplored the International Decimal Classification System not being geared to accommodate photographic instrumentation because photography, class 77, is organized under the general class 7, Fine Arts, Applied Arts, Architecture, Entertainment, Sport!

Shaftan's efforts were cut short a few years ago in a fatal plane crash. However, he had presented sufficient proposals in his published papers to serve as a nucleus for further accomplishments by all interested parties, regardless of their allegiance to specific professional societies associated with metrical photography. As the result of his endeavors, a Photographic Instrumentation Committee exists in the Society of Photographic Engineers. The Society of Motion Picture and Television Engineers has an interested High Speed Photography Committee.

Shaftan's broad outlines, contagious enthusiasm, and limitless energy were, prior to his death, unofficially released to the American Society of Photogrammetry through our President, Mr. A. C. Lundahl and myself. While topographic photogrammetry was regarded by Shaftan with due reverence, it occupied only one pigeon hole in his tabulation of the many means to achieve photographic measurements. He was particularly interested in a comprehensive organization of the scattered field of photographic instrumentation, to serve as an efficient source for the dissemination of knowledge and to foster the recognition and acceptance of its comprehensiveness by industry and science.

Twenty years ago a handful of imaginative topographic engineers banded together and founded the American Society of Photogrammetry. Their basic objective was to advance and disseminate knowledge in the art and science of photogrammetry. The profession of the great majority of the founders and those that followed, was that of photographic, surveying and the supporting services. This was a natural process that justified an economic need. However, our predecessors' concepts were somewhat broad, as is evidenced in the official definition of Photogrammetry as being "the art or science of obtaining reliable measurements by means of photography." Note that the camera is not confined solely to a platform in an airplane for the purposes of mapping. Instead the photography can be effected for the purposes of procuring measurement data, in the office of a physician, in an industrial laboratory, 100 feet below the Twelve Mile Reef, in outer space, or within the confines of an electron microscope.

Another current significance of the use of the term, "non-topographic photogrammetry," is its negative reception by other photographic technical societies such as the Society of Photographic Engineers and the Society of Motion Picture and Television Engineers. While these societies do not advance the theory and application of "non-topographic photogrammetry" as such, they have been applying photographic measurements to a variety of fields of application. The metrical photographic data secured are not confined to space, but include time, velocity, acceleration, density, temperature, stress, strain, energy, flow rates, pressure, concentration, and counting. The variety of the work done is staggering. There follows a number of random examples not normally encountered by our photogrammetrists to which metrical photography has been applied in the solution of problems in every branch of science and industry:

In hydrodynamics, phenomena have been measured by schlieren photography of the shock wave refraction patterns, shadowgraphed by a spark source located below a glass bottomed water tank, marked with precision grid reticles.

The virtual mass of materials has been derived from photographic space-time data obtained on the vertical deceleration of spheres when entering a body of water from various heights.

The safe dimensions of the approach zone for various glide-path angles of landing aircraft at the end of airport runways have been determined by metrical cameras especially designed for the purpose.

Electron microscope time-space coordinates of the effects of electron bombardments on coloidal crystals and the determination of size and charge of microscopic particles have been ascertained photographically.

Supersonic flow in wind-tunnels is studied by means of schlieren cameras provided with metrical space-time coordinates. Schlieren photographs are also used for spatial flame distribution and velocities, and radial variations of gas temperature in arcs.

Interferometric photography has been used for the metrical analysis of aerodynamic flow, thin-film measurement, crystal growth, evaluation of defects in mica, the examination of oscillation in quartz and for studies in photo elasticity.

In medicine, X-ray stereoscopic methods, both cavity cameras, retinal cameras, form the basis from which photogrammetric data are being obtained.

Ultraviolet microscopy, phase contrast microscopy, two-wave-length microscopy, and electron microscopy represent the means with which micro-photogrammetric studies have been conducted. In each case metrical adjuncts are incorporated in the instrumentation.

Image converters have yielded writing speeds of 100 mm. per microsecond with a time resolution of more than 10^{-9} seconds.

Sound waves have been transformed to visual images for visual metrical analysis on the photograph produced.

Extremely accurate synchronization systems have been developed to permit photography in exact timing with a phenomenon of known repetition rate. Multiple camera installations, where precision is maintained within 1 degree of shutter rotation, are possible.

Space-time information in the take-off and landing characteristics of aircraft is produced by photographic instruments with complex multiple optical systems.

Flight velocities of missiles between two stations are measured by electric chronographic means which actuate ultra rapid light sources for the photography at intervals up to a second with an accuracy of 0.1 microsecond.

High altitude rocket studies for missile speed and orientation are constantly being effected, and possibility exists of determining earth curvature data from rocket-borne metrical cameras rather different from the known aerial mapping cameras.

The burning velocities of fast burning mixtures for jet and rocket propulsion have been metrically computed.

The measurement of convection currents near a carbon arc is effected by recording particles in a dark field close to the arc.

Photographic oscilloscope trace-recording is obtained and metrical evaluation of wave forms is derived. Writing speeds to 1 inch per microsecond have been recorded.

It has been possible to obtain extremely graphic studies of events by combining cathode-ray oscilloscope recordings together on the same frame with the image of the event or object under study.

Cathode-ray photography has been practiced for the measurement of horizontal and vertical growth of thunderstorm propagation.

Correlation between optical and electrical effects of lighting has been determined.

Recording of displacement versus time has been effected with cameras which operate with continuously moving film. A point source of light moves with the body under study. Added precision of the time coordinate is obtained by pulsing the point source of light.

Shock-vibration studies by means of so-called streak cameras have yielded data where objects or movement of several inches have been measured to an accuracy of 10 microseconds.

Detonation velocities of explosives have been measured under widely varying atmospheric pressures.

Mechanical engineering data are provided by stroboscopic cameras which record events on continuously moving film, by means of high intensity lights flashing at a rate of 1,000 per second with flash duration 1/1,000,000 of a second.

It takes an instrument capable of 1,000 frames per second to study de-ionization time of long carbon arcs.

A high speed camera at 1,500 frames per second, measures the velocity of blood flow during a cardiac cycle.

At 3,000 frames per second some ballistics velocities are photographically determined.

A photographic instrument capable of a 4,000 frame rate per second is required to observe and to measure the effects of arc current versus gas pressure, the types of gas produced, or perhaps to measure the effect of a magnetic field on the motion of a cathode-ray spot, and its quantitative behavior with regard to current variations.

At 6,000 frames, the impact of rain drops on fabrics has been determined, and the pressure computed from the deformation of the drop center of gravity.

At 5,000–6,000 frames, the shutter action of looms, the flow of metal from extrusion mills or in die presses, the flow of molten metal in foundries or the lever action of a typewriter are metrically computed.

High speed, wind tunnel, aerodynamics studies concerned with structural deformation and high strain-rate-breaks, require instruments producing calibrated photography at 10^{-4} second.

Miller of Batelle Institute has studied flame progression velocities in fuel combustion *inside* an engine with a camera of his design which produced 50,000 frames per second and higher.

A British instrument designed by Marley produces ballistics figures from a 96,000 frame per second rate.

It should be noted that Cranz of Germany was able to produce metrical data at a rate of 100,000 frames per second in 1909.

Bartels and Eiselt, in Germany, developed a photographic instrument capable of recording phenomena of 1 microsecond duration at 2 microsecond repetition rates. This is equivalent to half a million frames per second.

The Iconoscope used as an electro-optical shutter has yielded exposures of 0.1 microsecond.

Metrical information gathered at the various atom bomb tests was essentially from high speed cameras coupled with intricate space-time data compilation and reduction systems. The outstanding of these instruments is capable of stopping a beam of light in increments of only 65 feet between frames, shooting 96 consecutive frames at a 15,000,000 per second rate.

Members of the aforementioned Societies have been advancing and disseminating photographic instrumentation information while we have been concentrating on topographic mapping. There is much to be gained by an actual contact with these societies for purposes of a coordinated classification and organization of knowledge. Otherwise, as so often happens, we (or they) are apt to discover and re-invent basically the same things independently.

The proposed coordination is particularly appropriate for the application of photogrammetry to the various sciences. For example, the photogrammetrist can make his contribution to the previously mentioned photographic societies in the realm of interior orientation, exterior orientation, and calibration while the Photographic Engineers and Motion Picture Engineers collectively might contribute in the field of still photographic instruments, of high speed photographic instruments, in the complex special lighting field, in processing, and in data reduction systems.

It is evident that two or more scientific societies are, at times, covering kindred but not necessarily overlapping lines of endeavor; calling the rose by another name does not utilize the wealth of existing but unorganized knowledge.

At the Seventh Meeting of the International Society of Photogrammetry held in 1952 at Washington, D. C., I concluded my paper for Commission V (Special Applications and Measurements) as follows: "it is believed that a greater utilization of photographic instrumentation will develop in proportion to the integration of metrics and scientific photography and the time required to make known the availability of such a system to organizations that will be most economically or professionally benefited."

Robert E. Altenhofen, 1953 Publication Committee Chairman of the American Society of Photogrammetry, initiated a Symposium on Non-topographic Photogrammetry with the assistance of Professor B. Hallert at the Royal Institute of Technology, Stockholm, Sweden. The symposium papers were published in the September and December 1953 issues of PHOTOGRAMMETRIC ENGINEERING and are a significant contribution to the bibliography of this field.

Altenhofen reported in the preface to the symposium issue that "All photogrammetrists are fundamentally interested in the identification, form and extent of the subject photographed. Furthermore, topographic portrayal is most effective, be the subject the microscopic scratches of a tooth filling, the miniature extent of a denture, or a walnut or the macroscopic sweep of the earth's surface. Therefore, these special applications of photogrammetry are not properly described as non-topographic. Topographic expression is frequently the means employed by the specialist to portray his subject. . . . "

Hallert also reports in the introduction to the symposium that "The knowledge of photogrammetry is still too limited among people other than the photogrammetrists. Also, among photogrammetrists themselves there is sometimes too little knowledge about, or interest in, the methods and possibilities of non-topographic photogrammetry.

"We will have to work hard to improve these conditions. The manufacturers of photogrammetric instruments must be stimulated and guided to make new types of cameras and other facilities. There must be closer cooperation between photogrammetrists and other scientists who may profit by the use of photogrammetry. Finally, photogrammetric training must be expanded to non-topographic methods.

"Some of those points of view were given at the sessions of Commission V at the International Congress for Photogrammetry in Washington, D. C., 1952, and were also accepted in the resolution of the commission."

It is of interest to point out that all papers comprising the Symposium were of European origin. Papers from the United States were lacking for many reasons: failure to recognize the kinship which exists among all practitioners of photographic metrics; also security requirements. This situation is rather disturbing inasmuch as it is my responsibility to report the "Special Applications and Measurements" for the United States at the 1956 International Society of Photogrammetry Meeting to be held in Stockholm, Sweden. Security requirements should not be compromised, but there are many special applications of photogrammetry that do not fall under the shadow of the security umbrella. I request you to assist me through bringing to my attention any unclassified special applications of photogrammetry that have or will be conducted by you or your associates. To recapitulate, some already published work in the fields of science in which metrical photography has contributed, is not sufficient for an International Symposium on the subject. Plans and factual data must be presented and be made available to stimulate interest for further application. Workers in any field should be *shown* in order to enable them to adapt the findings of others to the requirements particular to their own investigations.

CONCLUSION

The ramifications of metrical photography not concerned with topography are many. It is fitting that the problems of the special field of photographic instrumentation should be presented at this International Instrument Congress. The field straddles the interests of several technical photographic societies. But the knowledge which concerns those vitally interested in the instrumentation and the metrical methods for its use, is scattered far beyond the respective journals of these societies. It also happens that only on occasion do purely instrument publications publish information regarding photographic instrumentation.

The knowledge relative to this science will continue to be scattered as in the past and will not be available to the searcher unless it can be organized and codified.

Codification cannot take place under the present International Decimal System because it is intolerable that engineering interests should be a subclassification of a pictorial art. Codification is also hampered by the lack of scientific terms necessary to designate the new fields of interest. It would be more appropriate for instance to substitute "chronogrammetry" for "high-speed photography" when used for metrical purposes. A paper will be presented by Mr. Jean St. Thomas at the Society of Photographic Engineers Annual Conference at West Point next Spring, proposing a logical structure of scientific nomenclature to serve as a unifying back-bone for the organizational detail suggested by Shaftan.

It is suggested that work for organizing metrical photography be actively undertaken by committees appointed by the American Society of Photogrammetry, The Society of Motion Picture and Television Engineers, and the Society of Photographic Engineers. Such a joint committee would be the logical body for the preparation of an outline for a metrical photography handbook which might be published jointly. It is *not* suggested that these Societies merge, since each is essentially concerned with branches of technical photographic knowledge of extensive, specialized and non-overlapping nature.

It is further suggested that appropriate inter-society efforts be concentrated on the recognition of the field of metrical photography and photographic instrumentation, and that such recognition be sought at a level commensurate with the mathematical and engineering knowledge necessary to engage in this new professional direction.

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THE MM 100 OPTICAL COMPARATOR*,†

Everett L. Merritt,
Technical Director, Photogrammetry, Inc., Silver Spring, Maryland

I. Introduction

The comparator, sometimes referred to as a measuring machine, is one of the most basic instruments in the realm of research, experimentation, fabrication, production, and manufacture. The measurement of data is a fundamental activity shared by the physicist, chemist, engineer, and instrument maker. The comparator, therefore, is the instrument familiar to, and employed by, men in the fields of science, engineering and industry. Photogrammetry is the science of measurement with photographs. The primary purpose of photogrammetry is to serve the field of science, engineering, and industry in that capacity. While the idea of a comparator precedes the maturation of the science of photogram-

* A preliminary report published by *Photographic Engineering* is in part included in this paper with the permission of its editors.

† Presented at Semi Annual Meeting of the Society, Philadelphia, Pa., Sept. 16, 1954.