Technical Factors in Aerospace Photography

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Camera system research and engineering keep pace with intelligence demands upped from wartime low obliques to spy-in-the-sky reconnaissance.

John W. Cain

Aerial photography has been recognized since World War II as a prime means for acquiring intelligence; detailed analysis of the camera's faithful and permanent record of what falls within its view produces information of unusually high reliability. In recent years its product has been particularly valuable, and an insight into some of the technical factors involved in getting high-quality aerial photographs may be helpful to those in the intelligence community who make use of the resulting information.

In many respects intelligence aerial photography, for all its sophistication, is dependent on techniques and equipment which basically approximate those used by an amateur photographer. The same fundamental concepts and elements of procedure are present at both of these extremes of photographic acquisition. The amateur photographer taking snapshots from the window of a commercial airplane to some degree supplies by human judgment and manipulation many of the devices for improving picture quality which are mechanically incorporated into a complex aerial photographic system. He selects a lens of proper focal length to get identifiable images at the plane's height and distance from the subject. He uses a "haze-penetration" filter to sharpen the image by blocking off diffuse, non-image-forming light. He selects the right film for the results he wants and for the filters he uses. He insulates the camera from vibration by keeping it and his own body off vibration-transmitting elements of the airplane. He compensates for image motion by using an adequate shutter speed and by "panning" the camera in the direction of the motion.

All of the factors which the amateur photographer, sometimes subconsciously, thus takes into account plus many more must be analyzed and provided for by mechanical or other means in an aerial camera system designed for intelligence acquisition. The system is particularly complicated if it is to be operated remotely, whether just out of the photographer's reach or many miles away. The value of the product will depend both on the quality of individual elements of the system and on how well opposing considerations are resolved in putting them into combination. In evaluating different systems an effort has been made to arrive at standard units of measure for the quality of their photography.

Measuring a System's Potential

Each major component of a camera system--lens, body, film, film-advancing mechanism, motion-compensation devices, etc.--contributes its own separate image degradation factors, depending upon its design. The way in which each is combined with the others, considering their individual and joint performance under dynamic conditions, determines the quality capability of the system. Many of the elements determining the ultimate image quality of which a camera system under design will be capable are subject to objective measurement, but some aspects of performance can be learned only by trial. The most important criteria include the following.

Photographic resolution. The most generally used measure of photographic resolution is the number of lines per millimeter distinguishable on the film. A photographic line is actually a pair of lines, one black and one white or, more correctly, one of a given photographic density and one formed by the space between it and the next line. The number of these line-pairs that can be separately identified and counted within one millimeter, under any amount of magnification, on the exposed and processed photographic material constitutes one measure of the end quality of the photographic system used. Until quite recently these counts were for the most part made subjectively, and wide ranges of resolution have consequently been reported for the same type of material. Unless the test was made by photographing a prepared "resolution target" whose smallest line separations were a challenge to the system's resolving capability, accurate resolution figures for high-quality photography were difficult to obtain. Electronic devices to measure resolution more accurately have recently been designed and are now being calibrated by the U.S. National Bureau of Standards.

Acutance. Photographic acutance, or image sharpness, is measured by the linear distance on a piece of exposed and processed photographic material between the end of an area of one density and the beginning of an area of another. A combination of film, exposure, and chemical processing which permits transition between two levels of density over an extremely short distance is one which will produce sharp or high-acuity photographic imagery. This is a quality measurement which can be made objectively with the aid of a microdensitometer. Density is defined in terms of the light transmission (or reflection) characteristics of the chemically developed photographic material. The transparency index is the ratio of the amount of light passed through the material to the amount of light falling on it. Opacity is the reciprocal of the transparency, and density is the logarithm of the opacity. For example, if one-tenth of the incident light is transmitted through a piece of material, its opacity is ten and its density is one.

Granularity. The light-sensitive emulsions used in all manner of camera systems are generally, even today, of the conventional silver halide variety. After exposure to light and chemical processing, silver is deposited in granules to form the opaque areas of the negative. The emulsions which are the most sensitive to light exposure--the fastest film--are the ones which form the coarsest silver granules when chemically processed, and those which are slowest in image formation on exposure to light form the smallest granules when processed. Obviously, it is desirable in a high-quality camera system to use a film which forms the finest possible silver grains consistent with the amount of light available for proper exposure; the compromise that has to be made between speed of exposure and granularity is governed by the ambient light conditions expected during the exposure period. Granularity is a factor which can be objectively determined as a measure of film quality.

Tonal range. All photographic materials can be measured to determine their tonal range, the number of discrete image densities or gray tones they can record. Since normal photographic scenery consists of a variety of colors, as well as textures and tones, it is important that black-and-white photographic material separate these in as wide a range of discretely different shades of gray as possible. A high-quality photographic film is expected to record a sufficient variety of gray shades that the human eye, which can distinguish among a large number of barely different shades, will interpret the photograph as an accurate representation of the scene.

Scale. Though scale is not a quality factor determined by camera system components alone, it is certainly one which affects the information potential of aerial photography. It can be objectively measured, being nominally the quotient of lens focal length by distance to the subject. The design of modern reconnaissance cameras, however, precludes such a straightforward determination of scale. In the panoramic aerial cameras now used in order to increase lateral ground coverage the picture is projected onto the film by a rotating lens or prism, and the scale changes constantly in a complex geometric pattern. It can be calculated at any point only by experienced photogrammetrists using sophisticated procedures.

Ground detection size. During the past several years this term has become a common means of expressing the quality capability of an aerial camera system, but differing definitions are given to it. Although the minimum size of object whose image can be detected on a film can be determined accurately with relative ease, the question is whether detection or recognition is the criterion. On purely physical grounds a detectable image must be at least as large as the width of one line-pair, the limit of the material's resolution capability, but an image of minimum size would be formless and unrecognizable. This physical minimum has been used as a starting point, however, in attempts to arrive at a figure for the number of line-pairs defining the minimum size required for identification of an image through its shape and dimensions. Different photographic scientists have set various figures for this, ranging from 21/2 to 10 line-pairs. If then a camera system can produce a resolution of 100 lines per millimeter, a density change covering one-hundredth of a millimeter could be detected, but the image would have to have dimensions from 0.025 to 0.1 millimeter before its shape could be determined, its size measured, and the object it represented recognized. A four-inch object photographed from 10,000 feet at a focal length of 1 foot could just be detected; estimates of the dimensions that would be required for recognition range from 10 to 40 inches.

Volume. The square footage of film which can be carried during a photographic mission is an important determinant of the total information potential of the camera system. The film width used by a particular camera system is generally determined by the type of camera and the characteristics of the lens. The length of film required for the amount of ground coverage desired is subject to the weight and space limitations of the camera-carrying vehicle.

Weather. Clouds and atmospheric haze are a factor to be reckoned with in estimating a camera system's net information-producing potential. The scattering of light by haze lowers photographic resolution by reducing image contrast. A camera system giving a resolution of 100 lines per millimeter in high-contrast imagery (density ratios on the order of 3:1, or 1000:1 contrast in opacity) will give only a fraction of that, say as few as 50 lines, in low-contrast imagery (densities on the order of 1.02:1) . Timing of aerial photography missions for the best seasonal and daylight hours with the help of the best weather forecasts to be had is the only means available to counter this factor.

Twenty Years' Refinements

The quality of the aerial photography done for intelligence purposes today is at another order of magnitude than that found acceptable twenty years ago. In the measurement most often used for image quality, the resolution given by the camera systems of World War II averaged about 20 lines per millimeter, and this was good enough to meet wartime requirements with the camera-vehicle techniques employed. Today camera systems are producing photographic resolutions on the order of 150-175 lines per millimeter. Engineering analysis indicates that an operational capability of 200 lines per millimeter is quite feasible for the near future. Extrapolation from this extremely rapid improvement, which would have been unbelievable if predicted twenty years ago, leads photographic scientists to believe that resolutions on the order of 600 lines per millimeter will be achievable within the next five years. With the imposition of serious intelligence requirements for more and better aerial photography, the photographic industry's scientists, given sufficient time and relatively unrestricted financial support, have always produced the necessary technology. There is no apparent reason why this progress should not continue.

Thus the tremendous gains in photographic quality are the result of requirements for intelligence extremely difficult, if not impossible, to collect by other means. During wartime operations intelligence mostly of a tactical nature was provided in large amounts through comparatively close-range aerial photography. In peacetime, and especially in the recent years of nuclear equipoise, the emphasis is on strategic intelligence requiring much broader photographic coverage, and at the same time the camera vehicles are excluded from close range to their target areas. Substitutes for short-range photography had to be found.

One might think that new techniques to compensate for the forced increase in range would center on increasing the focal length of lenses. As the focal length is increased, however, the lenses become extremely large, and because of weight and space limitations in the vehicles researchers had to seek improvements in other areas. While the camera designers were improving their film-handling mechanisms, as described below, the film industry was researching light-sensitive materials of ever higher quality. With significant technological advances in this area, the crux of the problem shifted back again to the lens designers, who now had to devote their attention to making lenses which would transmit the larger amounts of light required by the inherently slower emulsions of extremely high quality.

Since the basic means of getting more light transmitted through a lens is to increase its diameter, here again was the problem of increased size and weight. One way of alleviating it was found to be lens coatings. Though the familiar f/number describes the nominal transmission characteristics of a particular lens, in aerial cameras a more definitive "T-stop" figure is used, which takes into account the light losses by absorption in the glass and reflections at the airglass surfaces. An f/3.5 lens, for example, would have with surfaces uncoated a T-stop value of 4.1, but this could be increased to T/3.7 by treating the glass surfaces with an antireflective coating. The effect of the coating is equivalent to an increase in diameter from 5.8 to 6.4 inches for a lens of 24-inch focal length without significant increase in weight.

Camera, lens, and film producers thus worked together quite closely to insure that technological breakthroughs in one area would be matched by parallel improvements in others. Especially important has been the fulfillment of the requirement to provide large volumes of photographic coverage while maintaining camera and film weights at a minimum. The use of thinner, yet stronger support material for photographic emulsions has in recent years about doubled film footage per unit of weight. At first, however, this innovation created serious problems for the tracking and movement of the film within the camera, and novel techniques had to be found for guiding the very thin films through the maze-like paths of sophisticated reconnaissance cameras.

For example, thin-base films cannot be edge-guided by the use of flanges on rollers. Precise alignment of all of the lengthy film paths is therefore required, and this now can be accomplished by self-leveling rollers which sense any lateral movement of the film and provide constant corrections. When 45°-rollers used for right-angle turns of film hypersensitized it by their pressure and produced fogging, it was found that air forced through the porous material of sintered metal rollers would permit the film to "float" around the corners without contact. Space requirements for film have been further reduced by space sharing between supply and take-up storage. Normally when a supply spool is full the take-up spool is empty, but empty or full they require the same amount of space. New spooling techniques have now been developed which permit film to be rolled on a flangeless supply core, which can be placed close to the take-up spool with the full roll protruding between its empty flanges.

As each separate problem was encountered and surmounted, additional improvements in other areas have necessitated continuing research and development. Even as this is written, laboratory experiments are being conducted with film bases comparable in thickness to the cellophane on a cigarette package, about one-half as thick as those currently considered thin. Indeed, the coatings of light-sensitive emulsions may soon be thicker than their supporting base. The advantage of such films in increasing area coverage potential is obvious, but the problems they create for camera drive mechanisms and automatic chemical processing equipment are a serious challenge to their design engineers.

The evolution of radical techniques in lens design as a result of the newly produced high-resolution film emulsions has been greatly helped by the advent of electronic computing capabilities. Where weight and space have imposed severe limitations on the use of large refracting lenses, a switch to optical reflectors has been given serious consideration. In the midst of this, the dimensional stability of the new thin film bases is challenging the lens manufacturers to provide optics that match them in preserving the geometric fidelity of the imagery.

Such has been the story of progressive improvements in aerial camera systems' components, all made in an attempt to provide a close-up look from distant camera vantage points. As operational limitations are continually increased, pictures will be taken from even farther away. And since the same or even higher quality will be required, research and development on aerial intelligence camera systems will continue to be sponsored at a commensurate pace.

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