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The Micron and the Map

The map maker is apt to overemphasize the importance of the micron (1 inch equals 25,400 microns) in his desire to achieve impressive performance.

ABSTRACT: *In the last decade, the threshold of photogrammetric accuracy has been pushed by a dedicated few very close to the micron. This is certainly a great and valuable achievement. A powerful tool is thus offered to science and engineering. It is neither possible nor desirable, however, for the cartographer to attempt to attain micron accuracy in the actual production of maps. Key links occur in the photogrammetric chain and a careful distinction should be made between the aerial triangulation and stereocompilation phases of the work. Error control is important, and the need and production of the small-scale map is associated with instrument capability. The anticipated stereocompilation needs of extraterrestrial mapping are specifically related to terrestrial mapping techniques. The cartographer should distinguish between "good" and "bad" microns, and the circumstances where it is not logical to wage all-out war against any of them.*

INTRODUCTION

THE MICRON, one millionth part of a meter, has become in the last 10 years a household word in mapping circles. We want our cameras, plotters and materials good to a few microns. Even those who make very small scale charts speak of a few microns of error as though this little micron fellow were causing them big trouble.

If we can't state our results to a few microns we prefer to keep quiet. In general this is a good situation. However, by being overly "micron-happy," don't those of us who actually make maps sometimes lose sight of just what a micron is, and the practical, as opposed to the aesthetic, purpose of the map?

Exactly who is this "micron" fellow? Well, very few people claim to have seen a lone micron—it would take a gang of 60 of them to stretch across the diameter of the average human hair. Most of us agree that isolated microns can be tolerated. When they run in packs, though, we get worried.

The purpose of this paper is to drop a hint that a general mania for micron-hunting ("Micronomania"), among map makers, is possibly open to question. In the hinting process, we will touch on the following aspects of this broad subject: (1) micron habitats and population figures; (2) micron control rather than elimination; (3) the small scale map, and (4) some stereocompilation equipment needs of extraterrestrial mapping.

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Micron Habitats and Population Figures

We know that grids etched on glass plates are almost free of these pesky little micron fellows. That is why we use grid plates as a standard to determine the inherent accuracy of an instrument. Operational photography, on the other hand, seems to provide good feeding grounds for unruly gangs of microns.

An Army Map Service (AMS) comparative evaluation,[1] involving six stereoplotting instruments produced the following results in the standard error of the Z-coordinate of a single point, in terms of the projection distance: (1) using grids, the results ranged from 1/6,100 to 1/30,400, and (2) using photography, from 1/3,700 to 1/7,800. On the average, the errors with photography were 2.6 times as large as with grids.

In the foregoing data, the best instrument was invariably the most accurate with both grids and photography; conversely, the poorest instrument was the least accurate in both instances. With grids, however, the best instrument was about 5 times as good as the poorest instrument; with photography, it was only twice as good. Of course, if the photography had only the inherent accuracy of the poorest instrument, (in this case, 1/6,100 h), then no instrument, regardless of potential accuracy, could possibly have yielded an accuracy greater than 1/6,100 h. It seems that operational photography is the great equalizer.

Each link in the photogrammetric chain has its own den of microns, some larger and more unruly than others. Let us refresh ourselves on some of the more important sources of error.

Starting at the beginning, the respectable manufacturer of wide angle cameras hesitates to admit the presence of more than 10 microns of lens distortion at any point in what he considers to be the usable field. Also, he insists that the flatness of the platen is well within specifications, at least insofar as the customer normally can prove. Generally, however, a modern cartographic camera will meet the specified rigid tolerances.

There is considerably more uncertainty with the *product* of the camera, the photography. It is true that the effects of systematic film change can be removed and stable-base film can reduce differential film change to negligible proportions. Still we have random changes up to the order of 10 microns even with the so-called "stable-base" films. What can happen to this plastic material called "film" during processing is enough to send shivers down the spine of the sensitive photogrammetrist. Hordes of new microns can very well jump in at this point. Once a glass diapositive of sufficient thickness is finally made, however, those micron fellows become stabilized at 2 or 3. They are put in a deep freeze you might say.

It should be made perfectly clear that the Army Map Service believes in ruthlessly hunting down those obnoxious microns in the aerial triangulation phase of the work. Aerial triangulation is a very favorable environment for them, and they tend to propogate rapidly by the square root of the sum of their squares. Our current efforts at micron control in this area involve both instrumentation and methods.

On the instrumentation side, we received the first Zeiss-Aerotopograph PSK Stereocomparator sold in this country. Zeiss was kind enough to loan us their prototype in the Spring of 1962 prior to the delivery of our series model. We completed our evaluation of this comparator a few months ago and found our results to conform, generally, to those of the Hanover (West Germany) Technical University.[2] Specifically, the grid measurements produced a standard error for a single setting of a grid point in the order of ± 2 microns.

On the method side, we have been breathing down the neck of Dr. Hellmut H. Schmid for several years, ready to snatch his analytical strip method before the ink gets dry. Right now, we are experimentally using an analytical cantilever strip based on the Schmid single model.

Yes, we have great respect for the micron in aerial triangulation. It is easy to see that after a strip is extended four models from the geodetically controlled initial model, the accumulation of random error is such that the accuracy is only one half of what it was to start with. Correspondingly, after 16 models, the accuracy is only one quarter of what it was.

It is also easy to understand that if the aerial triangulation has only the inherent accuracy of one quarter of the absolutely oriented model, it doesn't seem reasonable to compile on an instrument of the same order of

[1] AMS Technical Development Report, "Comparative Evaluation of Stereoplotting Instruments," January 1961.

[2] Lehmann, Gerhard, "Test Measurements on the Zeiss Precision Stereocomparator," Zeitschrift für Vermessungswesen, Vol. 85, 1960, No. 12, Translation by G. Richter.

accuracy as the triangulation instrument, unless the compilation instrument costs no more than, and is just as efficient as, those of a lower order of accuracy.

The Army Map Service has two general categories of compilation instruments: 750 and 1500 *C*-factor equipment. We use the type that most efficiently meets the mapping requirement. For 1:250,000-scale mapping, Multiplex is our proven "workhorse" in spite of the fact that the operator can read a point with it to only ±100 of those nasty microns at the scale of his stereo model.

Before we conclude our discussion of the major photogrammetric micron habitats, perhaps we should say a few words about people. AMS tests,[3] involving 10 different operators who were rated as average or better, concluded that there is as much variation in results among operators as there is among instruments and methods. It seems that people, to varying degrees, are good micron habitats, and consequently are carriers of the diseases caused by microns.

It was gratifying to read that the Swedes[4] also have conducted studies of the human being; moreover, they kept their work on a practical plane. Among other things, they wanted to find out what influence the common vices of alcohol or tobacco had on the operator's, ". . . precision of setting in a stereomodel." For those of us who are addicted to these vices, it is consoling to know that no adverse effect from either alcohol or tobacco was noted when used in moderation, of course. The Swedish author admits the investigation to be quite limited. Perhaps we should assist in producing corroborative data.

Control Rather than Elimination

In some cases, we don't have to annihilate those little microns; we can live with them if we control them. For example, why not permit controllable distortion if it will permit an increase in resolution? Why should we care how much distortion is in the aerial camera provided (1) the distortion is symmetrical (thereby permitting precise laboratory compensation) and (2) all cameras of the same series have the same pattern?

Theoretically asymmetrical distortion is no problem in analytical aerial triangulation, but it would seem to be quite a formidable assignment to grind an asymmetrical compensating plate. It also gets quite expensive and cumbersome to be required to use groups of compensating plates for each camera type.

An important need exists in camera manufacture for: (1) an increase in quality control so that the asymmetry in the distortion pattern is not as great as the average distortion itself; and (2) a camera calibration system that is significantly superior to the stated distortion values. A calibration certificate that shows a maximum distortion of the order of 10 microns to a probable error of ±10 microns is apt to leave disturbing questions in the user's mind.

This past December (1964), the Army Map Service received a letter from Zeiss-Aerotopograph. This letter enclosed calibration certificates of both their own calibration, and that of the U. S. National Bureau of Standards (USNBS), of an RMK A-21/23 aerial camera. To my knowledge, this is the first time such a comparison has ever been made at the instigation of the manufacturer. The distortion values were given along four radii, one in each of the four quadrants. However, rigorous comparison is not possible because: (1) Zeiss used a goniometer whereas USNBS used a collimator bank; and (2) Zeiss gave distortion values every 10 mm. out to 150 mm. (35.5°) where USNBS gave a value every 7.5° out to 30°.

In general, everything is fine out to about 15°. From there on, the USNBS shows larger distortions; Zeiss shows greater asymmetry. Neither certificate conflicts with my previous statements. Zeiss is to be congratulated, however, for volunteering this comparison which seems to be a great step forward.

In line with efforts to improve camera calibration and increase its usefulness to the user of the photography, AMS has recently suggested that celestial methods of camera calibration be incorporated in the handbook, "Military Standard Photographic Lenses" (MIL STD-150A). Those stars were put there in great abundance, and given rigorous laws to obey, by the Master Project Engineer. All we have to do is use them, and we need depend only on the accuracy of the measuring procedure.

The Small Scale Map

You would hardly know it by studying the mapping literature, but vast areas exist in this world where the inhabitants aren't concerned about a property boundary marker being off a couple of centimeters. They are

[3] Theis, J., "A Key Link in the Photogrammetric Chain—The Human Being," Photogrammetric Engineering, Vol. XXIX, No. 2, March 1963.

[4] Torlegard, Kennert, "Investigations of the Setting Precision Under Various Conditions in Photogrammetry," *Svensk Lantmateri Tidskrift*, (Special Issue on Photogrammetry), March 1964.

concerned only with survival. When the hunger pains aren't bothering them too much, they dream of a better life for their children. One key to giving these people a better share of the goods of this world is the map. In most cases the need is for a small scale map that can be produced and put into use quickly. The workhorse map here is at a scale on the order of 1:250,000. To these people, it is a blueprint for a better life.

This small-scale map is the first step in helping them locate their resources, and plan their transportation networks to reach these resources, process and distribute them. In fact, maps at scales of approximately 1:250,000 concern man's very existence; the larger scale maps, where microns become significant concern mostly refinements to his existence.

What is the status of world mapping efforts? The most meaningful information on this subject can be found in publications of the United Nations.[5] A quotation is as follows:

> "The United Nations is concerned with the entire world. But it cannot proceed intelligently in the solution of world problems when adequate information is lacking for three-quarters of the world's land areas . . .
>
> "It is doubtful if more than 25 per cent of the land areas of the world have even reconnaissance maps of 1:300,000 or 1:250,000 scale, or larger, compiled from aerial photographs or systematic ground surveys.
>
> "With the possible exception of a few European nations and very limited areas in other countries, the status of surveying and mapping is nowhere adequate for full and economical development of natural resources. . . . "

The accuracy of the 1:250,000-scale map makes the micron hunters get all choked up. But this map gets the job done, which is a factor in its favor. The U. S. National Standards of Map Accuracy require that 90 per cent of all planimetric features be positioned to ± 0.02-inch, or, 0.5 mm., which, incidently is 500 of those horrible micron fellows. In the vertical sense, 90 per cent of the contour data must be good to one half the contour interval; all good to a full contour interval.

The contour interval is largely a function of the steepness of the terrain. The U. S. "Joint Specifications for Map and Chart Compilation" state that the contour interval of the 1:250,000-scale map can range from 50 to 500 feet. A commonly used interval is 100 feet. At map scale this is 120 microns.

Extensive AMS testing shows two important results: (1) that the AMS Bausch and Lomb Multiplex equipment, as used in stereocompilation of 6-inch focal length, vertical photography, is capable of satisfying *all* normal 1:250,000-scale mapping requirements; and (2) Multiplex, with a *C*-factor of 750, will theoretically satisfy the 100-foot contour requirement with photography flown all the way up to an altitude of 75,000 feet.

In other words, the present aircraft ceiling of about 30,000 feet does not come anywhere near exhausting the 1:250,000-scale mapping potential of the Multiplex. Flying, therefore, at the limits of instrument capability, 75,000 feet, would increase the present aircraft ceiling by a factor of 2.5. The ground coverage, then, would be increased by a factor of 2.5^2, or, 6.25. A corresponding reduction of photographic processing, aerial triangulation, and compilation orientation time would be appreciated.

Since the much-heralded USQ-28 Survey and Mapping System will have an operational flight ceiling of 60,000 feet, we expect Multiplex, or its equivalent, to be capable of satisfying our normal 1:250,000-scale vertical stereocompilation needs until the next generation of aerial systems arrives. No problem, of course, will be encountered in meeting those 500 microns of horizontal tolerance.

Extraterrestrial Mapping

Turning from the mapping needs of the underdeveloped areas of the earth to those of the planets, insofar as we know we are dealing not with underdeveloped, but *never*developed, areas. In fact, unless Dick Tracy is right, a more desolate area than the moon could scarcely be imagined. It will be some time before cadastral surveys are needed there to settle property lines.

The Army Map Service started a new chapter in the history of Cartography by stereocompiling the first map of the moon with all detail referred to a common datum. This map, at a scale of 1:5,000,000, was published in 1960.

Why are we mapping the moon? Because man is going there, and wherever man will go, he will need a map to guide him. In fact, he would like to have this map before he goes there so that he can plan his arrival, especially where no established points of entrance exist, as is the case with the moon.

Two new types of lunar photography from space will soon enable us to make a map better than that which could be made from earth-based photography. These are: Ranger (probe-type), and Orbiter, photography. In

[5] *Modern Cartography—Base Maps for World Needs*, Chapter II, "Status of World Mapping" 1949.

the first case (Ranger), photography is transmitted to earth until impact, and in the second case (Orbiter), the product will be satellite photography, except that, initially the original exposures will not be recoverable. The present general characteristics of this extraterrestrial mapping material are that: (1) the physical ranges of much of our mapping equipment are exceeded; and (2) the image is degraded during acquisition, transmission and reassembly.

Again, we should differentiate between the control solution (spatial triangulation) and the stereocompilation of the map manuscript. As in terrestrial mapping, we must freeze what microns exist in our material and not let them run rampant in the favorable environment of spatial triangulation. It seems that numerical (micron) photogrammetry would offer the best solution here for the following reasons: (1) it has no physical limitations so long as the diapositive plate is not too large for the comparator; and (2) it would hold the micron population explosion to a minimum.

The stereocompilation phase, on the other hand, is quite a different matter. The accuracy of the single model can be no greater than the error propagated in the strip will allow. Because of the successive degradation of the photography, the material handed the stereocompiler is not expected to warrant compilation by instruments of better than a 1,000 *C*-factor.

Although little more than Multiplex accuracy appears to be warranted in the stereocompilation equipment, we cannot use any of our anaglyphic equipment because of base-height limitations. During the course of some recent lunar mapping experimentation, it became quite apparent why the Autograph A-7, and Stereoplanigraph C-8, are called "Universal" instruments. Among other things, they can be set to simulate the hypothetical "zero base" situation.

The base-height ratio needed for one experiment was less than 0.10. The minimum base-height settings on the AMS anaglyphic equipment are 0.39 and 0.47, for Multiplex and M-2, respectively, as calculated at optimum projection distances. At these minimum base settings, the projectors bump each other.

Consequently, extraterrestrial mapping needs have forced us to take a new look at our stereocompilation equipment requirements. Our tentative conclusions are that we need a stereoplotter of moderate accuracy, but the accommodation range of the universal plotter is somewhat less than a practical minimum. In other words, we are not interested in the last few microns; we just need the physical space to work in.

Conclusion

As we press ever forward on our hunt for what Dr. Loewen[6] called "The Elusive Micron," let those of us who make maps carefully analyze the requirements of the various types of mapping to be done. At the same time, let us take into account the presently unavoidable limitations of the materials and methods we will have to use.

Let us not be obsessed with a general mania for micron elimination, claiming that the only good micron is a dead micron. Let us, instead, distinguish between good and bad microns and the circumstances where it makes little sense to wage all-out war against any of them.

[6] Loewen, Erwin G., "Coordinate Measurement—The Elusive Micron," PHOTOGRAMMETRIC ENGINEERING, Vol. XXX, No. 6, November 1964.