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Square-Wave Response of P.I. Microscopes

The optical performance of three stereomicroscopes commonly used for photointerpretation were tested in terms of magnification, field of view and square-wave response.

Abstract: *The optical performance of three stereomicroscopes commonly used for photointerpretation is described in terms of magnification, field of view, and square-wave response* (SqWR). *For a given field size, the* SqWR *can be used to compare the amount of information in the image of each microscope. The measured* SqWR *was used to evaluate the relative ability of each microscope to perform two typical photointerpretation tasks: (1) detailed viewing of a target, and (2) scanning or searching for a target.*

Introduction

Many types of microscopes are used by photointerpreters as an aid in viewing aerial photography. Often it is necessary to compare these microscopes and evaluate their usefulness in a particular photointerpretation situation. A comparison of their optical performance is usually done in terms of their magnification, field of view, and resolution. Each of these is measurable and influences the photointerpreter's impression of image quality and information transfer. The resolution gives an idea of the finest detail (or maximum information density) that can be imaged through the microscope. If the field of view is also stated, we have an indication of the maximum amount of information that may be contained in the microscope image. The magnification of the microscope determines how well the eye can receive the image. That is, the finest detail resolved by the microscope must be magnified sufficiently to be resolved by the eye.

Unfortunately, this description of the optical system of a microscope is unnecessarily restrictive because it refers only to the ability of the microscope to resolve very fine detail. It does not directly indicate how well the microscope can image a general object distribution. The description takes on substantially more meaning if the microscope is characterized by the modulation transfer function (MTF) or sine-wave response (SWR), rather than resolving power.

In this paper the optical properties of three microscopes commonly used in photointerpretation are compared. The comparison is based on magnification, field of view, and the square-wave response (SqWR), a relative of the sine-wave response. In the next section the meaning of and relationship between SWR and SqWR are discussed, and the technique used to measure SqWR is described. A description of the microscopes is given in the third section. The fourth section is concerned with the equipment and techniques used to measure the SqWR. In the fifth section the curves are interpreted, and the microscopes are compared for two photointerpretation tasks.

The Microscopes

Three microscopes are being widely used for photointerpretation: the Bausch and Lomb 240, the Olympus SZ III, and the

Wild M-5. They are characterized by relatively low magnifications (less than 100×) and low numerical apertures (less than 0.18), and all have two optical channels whose optical axes intersect at the object plane. All three microscopes can be converted to stereoscopes by attaching rhomboid arms to the bottom of the microscope body or pod. This paper is concerned only with the microscopic, not the stereoscopic, mode of operation.

Each microscope consists of eyepieces, auxiliary objectives, and a pod containing the primary objectives. In this study 10× eyepieces were used exclusively. The Bausch and Lomb 240 and Olympus SZ III microscopes both have zoom optics in their pods to provide continuously variable magnification. The Bausch and Lomb 240 has a 4:1 zoom range from 7 to 30×, while the Olympus SZ III has a 5.6:1 zoom from 7 to 40×. The Wild M-5 pod has fixed magnifications of 6×, 12×, 25× and 50×. The auxiliary objectives screw into the bottom of the microscope pod and are used to halve (0.5×) or double (2×) the magnification provided by the pod and eyepieces.

For identification in this paper, a microscope at a particular magnification will be assigned a designation of the form *B/12/2*. The *B* indicates the Bausch and Lomb microscope (*O* for Olympus, *W* for Wild), the *12* indicates the magnification of the pod/eyepiece combination, and the *2* indicates the magnification of the auxiliary objective. If no auxiliary objective is used, the last designation is *1* as this is equivalent to using a zero power (1×) auxiliary objective. The total magnification of the microscope is the product of the pod/eyepiece magnification and the auxiliary objective magnification (24× in this example).

The exit pupil sizes of the microscopes were measured and found to be less than 2 mm in diameter. As the pupil of the eye is always greater than 2 mm, and nearer 4 or 5 mm for microscopic viewing, the exit pupil of the microscope is the limiting aperture in the microscope/photointerpreter combination. Hence the microscope, not the eye, is the significant limiter of image quality because the images have been sufficiently magnified. Therefore, magnification is not a distinguishing characteristic of the information transfer, and only SqWR and field of view need to be used for comparison.

The SqWR measurements of the microscopes were made with the microscopes adjusted to the same field size. This permitted the SqWR curves to be compared as indicators of the information content of the image. The field sizes were adjusted by varying the magnifications of the microscopes. Because the Wild M-5 has discrete magnifications whereas the Bausch and Lomb and Olympus microscopes have continuously variable magnifications, all the microscopes had to be tested at the Wild's field sizes. The field sizes at which the SqWR was measured are 4.0, 8.1, 16.8 and 34.5 mm. These correspond to magnifications of approximately 50, 25, 12 and 6×, respectively. In addition, the microscopes were tested at their minimum field size (corresponding to their maximum magnification).

The Measurements

The square-wave response of the microscopes was determined by scanning a square-wave test target in the object plane of a microscope and measuring the irradiance variations at a particular point in the image plane.[1] The test target contained 30 high-contrast, 15-cycle square-wave patterns which ranged in spatial frequency from 1 cycle/mm to 501 cycles/mm.

The test target was illuminated by a diffuse light source which simulated the light tables on which the microscopes are normally used.

The microscope being tested was focused with its virtual image of the test target located at infinity (the focal position for most comfortable viewing). Light emerging from one of the eyepieces was collected by a high-quality telescope objective and the microscope image was focused into a plane containing a pinhole. The intensity distribution of the image was measured with a pinhole and photomultiplier tube. The measured modulation of the image was compared with the known modulation of the test target to obtain the square-wave response of the microscope. The pinhole was sufficiently small and the relay lens was of sufficient quality that they did not significantly influence the measurements.

The SqWR of the microscopes were measured at one focal position—that which gives the maximum on-axis resolution. The microscopes were not refocused for the off-axis measurements.

For each field size mentioned in the previous section, seven SqWR curves were made. The curves included one on-axis position and three off-axis positions for both radial and tangential orientations of the test target. The field positions for which SqWR

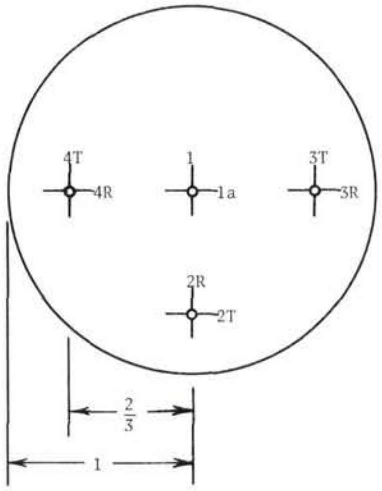

FIG. 1. Microscope field positions at which the SqWR was measured.

curves were made are shown in Figure 1. This figure shows the field as viewed through the left eyepiece with the microscope in its normal operating position.

INTERPRETATIONS

Many ways are available to interpret and use SWR and SqWR information. For this paper, the measurements are applied directly to two *typical* tasks encountered in photointerpretation.* The two tasks considered are (1) examining a target in detail and (2) scanning imagery as if searching for a target. Of course, these are not the only tasks for which the microscopes can be evaluated; other tasks, with different requirements, can be treated in a similar manner. However, the tasks considered are fundamental to photointerpretation and are representative of how microscopes are used by photointerpreters.

TASK 1, DETAILED VIEWING

If a target is examined in detail, usually it is positioned in the center of the microscope field because on-axis performance is assumed to be better than off-axis performance and because the photointerpreter can better relate the target to its surroundings in this position. For this task only the on-axis SqWR is of importance; the off-axis SqWR is of little or no concern.

The on-axis SqWR curves are shown in Figures 2 through 6 for the 34-mm, 17-mm, 8-mm, 4-mm, and minimum field sizes, respectively.

In Table 1 the SqWR curves are ranked,

* All of the SqWR curves made during this study are not included in this article because of their great number. Those interested in receiving copies of them should contact the author.

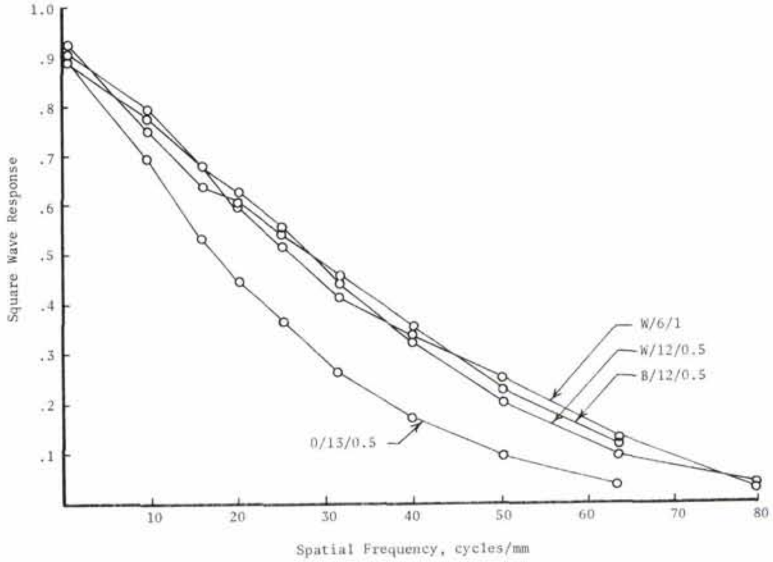

FIG. 2. On-axis SqWR for a 34-mm field.

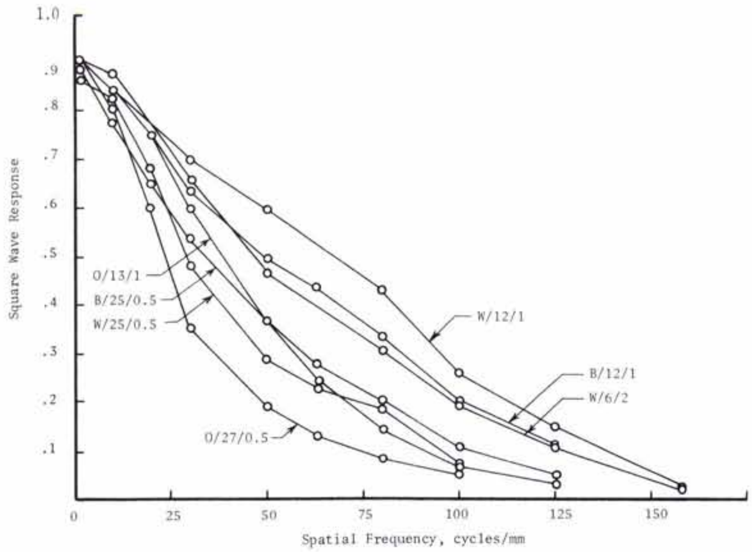

FIG. 3. On-axis SqWR for a 17-mm field.

each against the others. One SqWR was judged to be better than a second if the value of the SqWR of the first was greater than that of the second over nearly the entire frequency range. If one SqWR was not obviously better than another, then both were judged to be equal and were given the same ranking.

Two generalizations can be made from the information in Figures 2-6 and Table I. First, the Bausch and Lomb and the Wild microscopes are superior to the Olympus for on-axis viewing. The Bausch and Lomb and Wild each ranked first for three out of the four field sizes (not including the minimum field size), whereas the Olympus never ranked first. Second, for a given field size a microscope has a better SqWR if a high-power, rather than a low-power, auxiliary objective is used. The two exceptions to this rule are that *W/12/1* is better than *W/6/2* and approximately equals *W/12/0.5*.

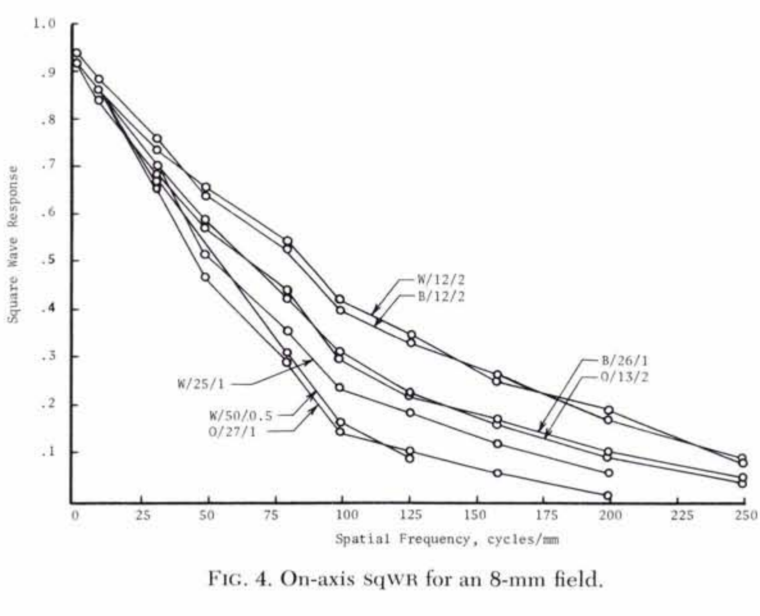

FIG. 4. On-axis SqWR for an 8-mm field.

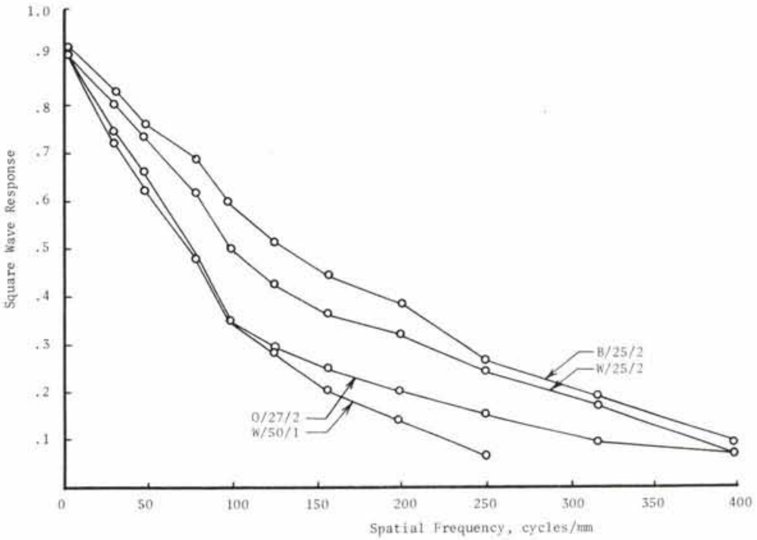

FIG. 5. On-axis SqWR for a 4-mm field.

TASK 2, SCANNING

The microscope performance required for the second photointerpretation task is distinctly different from that required for the first task. If the photointerpreter is scanning or searching imagery with the microscope, he needs good performance across the entire field, not just on axis. It is not expected that the best off-axis performance will be obtained with the microscope configuration giving the best on-axis performance.

With the on-axis SqWR, the curves were directly compared and the best SqWR was easily found. However, seven SqWR curves describe the off-axis viewing for each microscope, and these are too many to be compared directly. An alternative to the direct comparison method is to characterize each curve by a meaningful number (or numbers) and then average these numbers in some way. Such a procedure is fraught with danger[2] and can produce erroneous conclusions because an SqWR curve cannot be en-

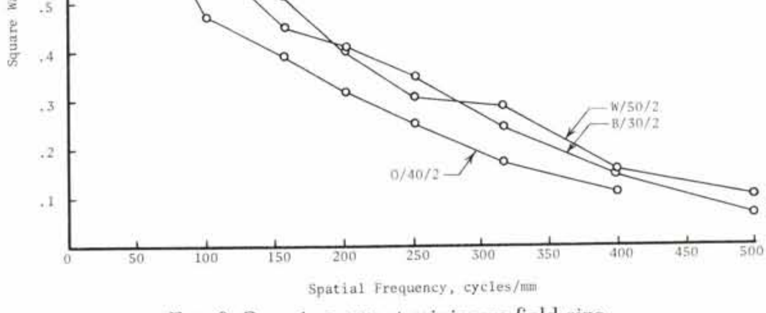

FIG. 6. On-axis SqWR at minimum field size.

TABLE 1. RANKING OF THE MICROSCOPES FOR TASK 1

(Detailed Viewing)

Field size (mm)	*Microscope*	*Rank*
34	B/12/0.5 W/6/1 W/12/0.5	1
	O/13/0.5	2
17	W/12/1	1
	B/12/1 W/6/2	2
	B/25/0.5 O/13/1 W/25/0.5	3
	O/27/0.5	4
8	W/12/2 B/12/2	1
	B/26/1 O/13/2	2
	W/25/1	3
	O/27/1	4
	W/50/0.5	5
4	B/25/2	1
	W/25/2	2
	O/27/2	3
	W/50/1	4
minimum	W/50/2 B/30/2	1
	O/40/2	2

tirely described by a single number. However, the reduction of SqWR information in this way permits convenient comparison of numerous SqWR curves.

To increase the possibility of a meaningful comparison, we describe each SqWR curve by two numbers, each describing a different characteristic of the SqWR curve. We then compare and correlate these numbers, and thereby more validly compare the curves. The first number is the value of the SqWR at a particular spatial frequency, which may be the cutoff frequency of the reconnaissance system that produced the imagery being viewed. One microscope is *better* than another if it has a higher response at this frequency. The frequencies used are 100 cycles/mm for the 4-mm and minimum-size fields, 80 cycles/mm for the 8-mm field, 50 cycles/mm for the 17-mm field, and 25 cycles/mm for the 24-mm field. For each microscope configuration were seven of these SqWR values, which were then arithmetically averaged to form a general descriptor. The descriptor characterizes the average SqWR across the field of a particular microscope configuration but has no real physical significance itself; it is only a figure of merit. This descriptor is called the *modulation descriptor*.

The second characteristic number of an SqWR curve is the spatial frequency that corresponds to an SqWR value of 0.2. Physically, this is approximately the cutoff frequency that is observed visually if a low-contrast test target (density difference of 0.20) is viewed through the microscope. Again, the seven numbers were simply averaged to form the *frequency descriptor*, a figure of merit with no real physical significance except as a tool for comparisons.

In Table 2 the microscopes are ranked for each field size according to the values of their modulation and frequency descriptors. Two conclusions can be made: first, the Wild microscope is ranked first for all field sizes and, therefore, is the best for Task 2 type photointerpretation; second, for a particular field size, the best performance across the field is obtained by using the lowest-power auxiliary objective with the Olympus and Wild microscopes (except at the 34-mm field). However, with the Bausch and Lomb microscope the best performance is achieved with the highest-power auxiliary objective.

COMBINATION OF TASKS

Many photointerpreters will have a single microscope with which to perform both the detailed viewing (Task 1) and scanning (Task 2) functions. In such an instance we would want to know which microscope best performs both functions. By comparing Tables I and II we find that the Wild is by far the best (the Bausch and Lomb being second, and the Olympus third). With the Wild, scanning is performed using the lowest-power auxiliary objective (except at the 34-mm field), and detailed viewing is performed using the highest-power auxiliary objective.

If the photointerpreter does not want to or is not able to change between various auxiliary objectives, then we may ask what microscope/lens combination best performs both tasks. Using Table 2 and Figures 2 through 6 we find that for the 34-mm field, W/6/1 is best but B/12/0.5 is nearly as good; for the 17-mm field, B/12/1 is best; for the 8-mm field, B/12/2 is best; and for the 4-mm field, B/25/2 and O/27/2 are about equal. There-

TABLE 2. RANKING OF THE MICROSCOPES FOR TASK 2

(Scanning)

Field size (mm)	*Microscope*	*Rank*	*Modulation descriptor*	*Frequency descriptor*
34	W/6/1	1	.16	21
	O/13/0.5		.15	21
	B/12/0.5	2	.12	18
	W/12/0.5	3	.05	12
17	W/25/0.5	1	.20	50
	B/12/1	2	.17	40
	O/27/0.5		.10	35
	O/13/1	3	.12	36
	B/25/0.5		.14	32
	W/6/2	4	.04	24
	W/12/1	5	.03	19
8	W/50/0.5	1	.27	87
	W/25/1	2	.21	80
	B/12/2	3	.16	77
	O/27/1	4	.15	64
	O/13/2	5	.13	58
	B/26/1	6	.10	45
	W/12/2	7	.03	23
4	W/50/1	1	.37	187
	O/27/2	2	.22	118
	B/25/2	3	.18	90
	W/25/2	4	.13	88
minimum	W/50/2	1	.40	165
	O/40/2		.36	171
	B/30/2	2	.20	108

fore, in this instance the Bausch and Lomb is best.

VALIDITY OF THE CONCLUSIONS

The measurements and comparisons that have been made indicate the relative performance of the particular microscopes that were tested. The results are not necessarily representative of the performance to be obtained from other microscopes with the same model designations. The variance in performance of other microscopes from the ones tested will depend heavily on the quality control of the manufacturer. In addition, the measurements were not exhaustive—the SQWR was measured at only four field positions and one focal position. It is conceivable, although unlikely, that these do not accurately represent the overall performance of the microscope.

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