Design and Performance of the Varatioscope

John W.M. Peterson

School of Information Systems, University of East Anglia

Norwich NR4 7TJ, United Kingdom

e-mail: jwmp@sys.uea.ac.uk

Abstract

Some Roman land surveys (centuriations) appear to have been used to plan features of the same period which are oblique to the survey grid. This method of oblique construction, documented by the Roman land surveyors and known in Latin as uaratio, *restricts the orientations of the features, relative to the grid, to a small set of "significant" angles with rational tangents. Useful information may therefore be gained by studying a set of linear features, such as segments of Roman roads or boundary lines, from various angles to see how well they conform to this model.*

The varatioscope is designed to give a score for each angle of observation, high scores corresponding to an angle to which the features, as a whole, have a large number of "significant" relationships. It can be used in two ways, either to test a hypothesis of centuriation or to suggest such a hypothesis, corresponding to a peak in the varatiogram. The paper describes the construction of the varatioscope as an Excel spreadsheet, results obtained, and the sensitivity of the tool to the choice of "significant" angles.

Key words: Roman, cadastre, centuriation, oblique planning, varatio

1. Varatio

In the writings of the Roman Land Surveyors the term *uaratio* refers to a process of oblique surveying. Anne Roth-Congès (1996) has shown, by careful study of the texts, that at least two approaches were employed. In *uaratio fluminis* the distance of an inaccessible point could be calculated by the construction of right angled triangles. By *uaratio in agris diuisis* the surveyors could construct, or reconstruct, lines along the hypotenuse of right angled triangles defined in a rectangular coordinate system; this sort of *uaratio* interests us here.

Even before we had this improved understanding of the texts it had become apparent to several independent workers in the last quarter of the twentieth century that linear features frequently coincide with centuriation grid intersections (Chouquer et al. 1983, Clavel-Lévêque 1991, Morra and Nelva 1977, Romano and Tolba 1996). The authors all ascribe this to design, rather than accident. If so, it a result of the use of *uaratio*.

It is even possible that one effect of *uaratio* was seen and understood much earlier. Since the variety of observed oblique relationships (1:1, 1:2, 2:3, 3:4 ...) is limited, there is a good chance that some linear features defined by a particular coordinate system, for example road segments, will be parallel. Parallel road segments have been observed in British contexts. In one case Margary (1973:60) thought it "likely" that it was the result of sighting by stars - an approach which does not seem very feasible, since it would have obliged surveyors to work at night. In another case Haverfield (1921) seems to have favoured a quite different mechanism, which may have been *uaratio*. In a study on two parallel road segments whose spacing would not allow them both to be the axes of a centuriation, he hinted at a connection between British centuriation and observable coincidences in orientation of Roman road segments. Unfortunately he did not live to enlarge on this.

2. The varatioscope

If *uaratio* was used in this way we may gain useful information by studying a set of Roman linear features - such as segments of roads or boundaries - from various angles to see how well they conform to this model.

The varatioscope is designed to give a score for each angle of observation, high scores corresponding to an angle to which the features, as a whole, have a large number of "significant" relationships.

Given an angle for the varatioscope reading, the orientation of any given feature defines a relative angle. We can put the tangent of this angle in the range 0 to 1 by taking reciprocals and changing the sign, if necessary. This defines the smallest angle between the feature and a centuriation with the current angle of the varatioscope. A score for this tangent value can then be derived from a scoring function such as that shown in figure 1. This has a value of one for "significant" tangent values and descends linearly to zero midway between them. In this particular case the "significant" values are those which, according to the author's knowledge, have been observed most often in reality.

In order to obtain a varatioscope reading for a given angle of observation, the procedure is as follows. For a segment of length l_i the tangent of its orientation is calculated from the coordinates of its endpoints and the corresponding score, s_i is derived from the scoring function. The score, S, for the population of n segments is then the normalised weighted sum of scores

$$S = \frac{\sum_{i=1}^{n} s_i l_i}{\sum_{i=1}^{n} l_i}$$

The current version of the varatioscope is implemented with an Excel spreadsheet, using a macro command to generate values of S for angles of observation between - 45° and 45° at intervals of

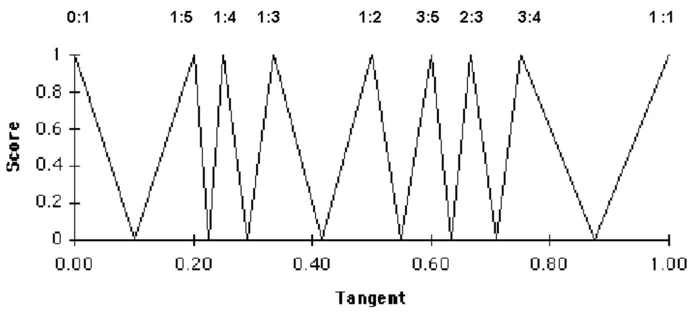

Figure 1: A scoring function for tangents of angles.

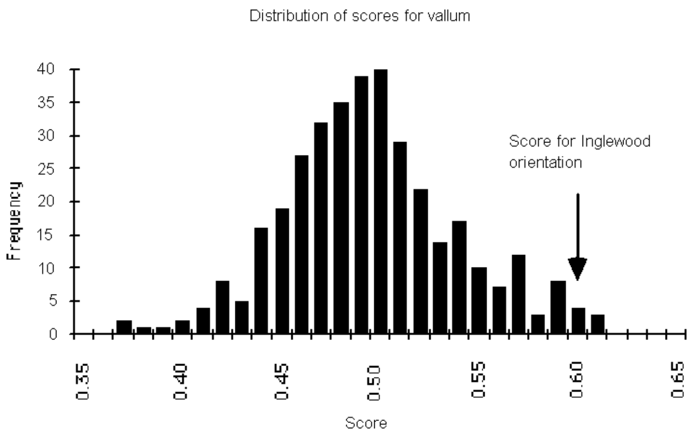

Figure 2: Score for orientation of Inglewood centuriation compared to all scores for the vallum of Hadrian's Wall.

quarter of a degree. This covers the whole range of possible centuriation angles. Because of the linearity of the scoring function between 0 and 1 the distribution of these scores has a mean of 0.5. Results suggest that it is normal, as you would expect from the central limit theorem and the arbitrary definition of observation angles.

3. Use of the results

3.1. Hypothesis testing

We may already have a hypothetical centuriation, proposed perhaps from the layout of existing surface features. The score for its orientation, with respect to a well defined set of Roman linear features in an area, can be compared with the general distribution of scores.

An example is the Inglewood centuriation in Cumbria, Britain and the vallum of Hadrian's wall. The orientation of the hypothetical centuriation, as defined by Alan Richardson (1999) , is N 30.96° W (-0.5404 radians). The vallum was defined by a set of coordinates for the endpoints of 104 segment taken from the OS map of the Wall (Ordnance Survey 1964). These segments have a total length of 98.3 km. Their score relative to the angle of the proposed Inglewood centuriation is 0.600.

The general distribution of scores (figure 2) has the following parameters:

mean	0.500
standard deviation	0.044

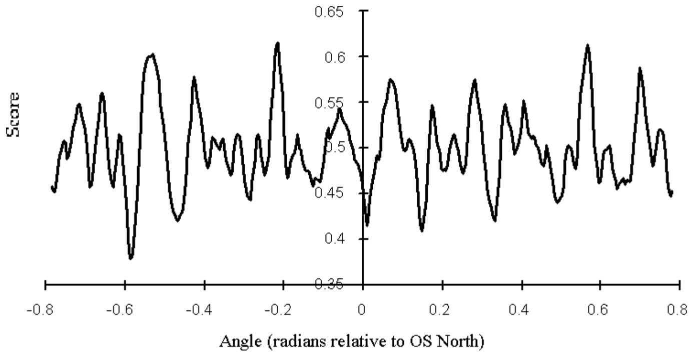

Figure 3: Varatiogram for the vallum of Hadrian's Wall.

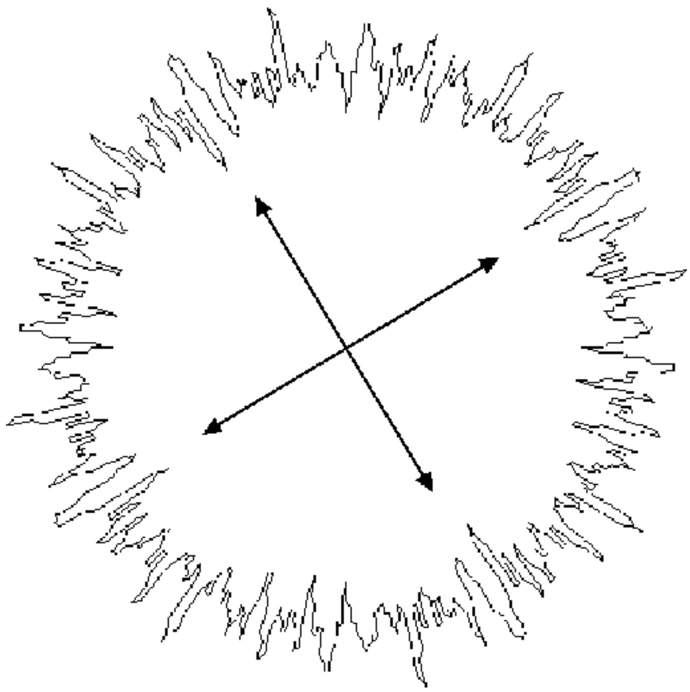

Figure 4: Varatiogram for the vallum of Hadrian's Wall in circular form. The arrows indicate the orientation of the axes of the Inglewood centuriation.

Only a small part of a normal distribution with this standard deviation exceeds the observed score of 0.600. The chance of seeing such a high value is 1.2%. The idea that we would have seen such a high score if we had been interested in some orientation other than that proposed by Richardson can be rejected at the 2% level.

3.2. Generation of hypothesis

The varatioscope output can be displayed as a varatiogram, a graph of scores for the complete range of possible centuriation angles. In the case of that for the vallum (figure 3) there are three high peaks, and four lesser ones. If the presence of a centuriation were suspected in the area, for example because landscape features had consistent orientation or Roman road segments were parallel, each peak could be the basis of an individual hypothesis to be tested against these other indicators.

So that the results of this approach might be seen more clearly, the varatiogram can also be displayed in circular form (figure 4).

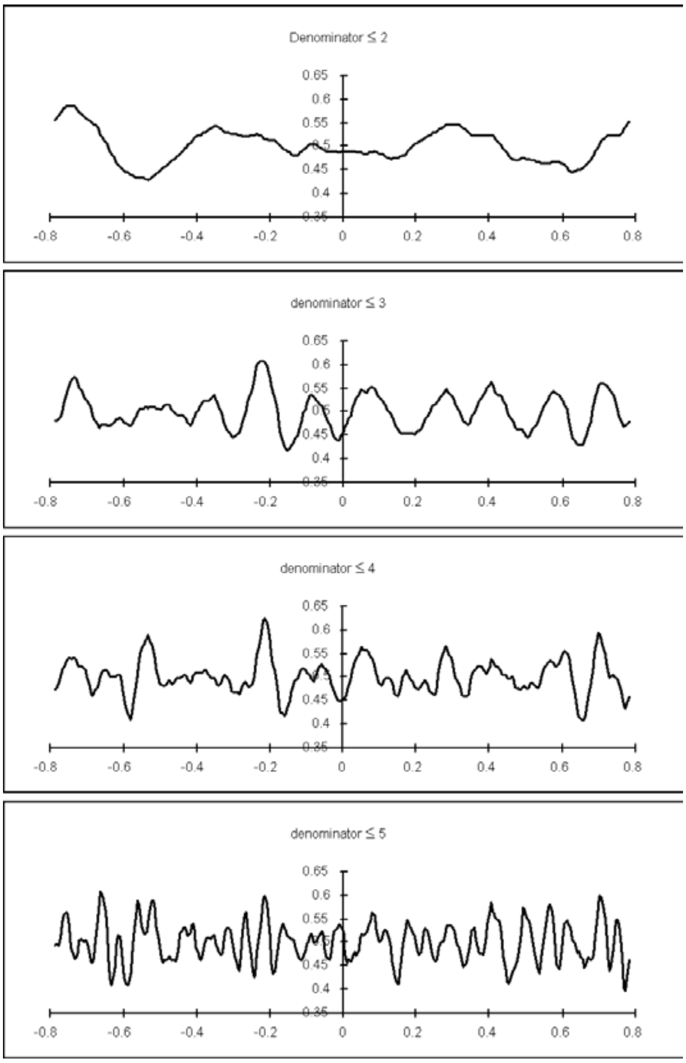

Figure 5: Varatiograms for the vallum of Hadrian's Wall, using scoring different scoring functions.

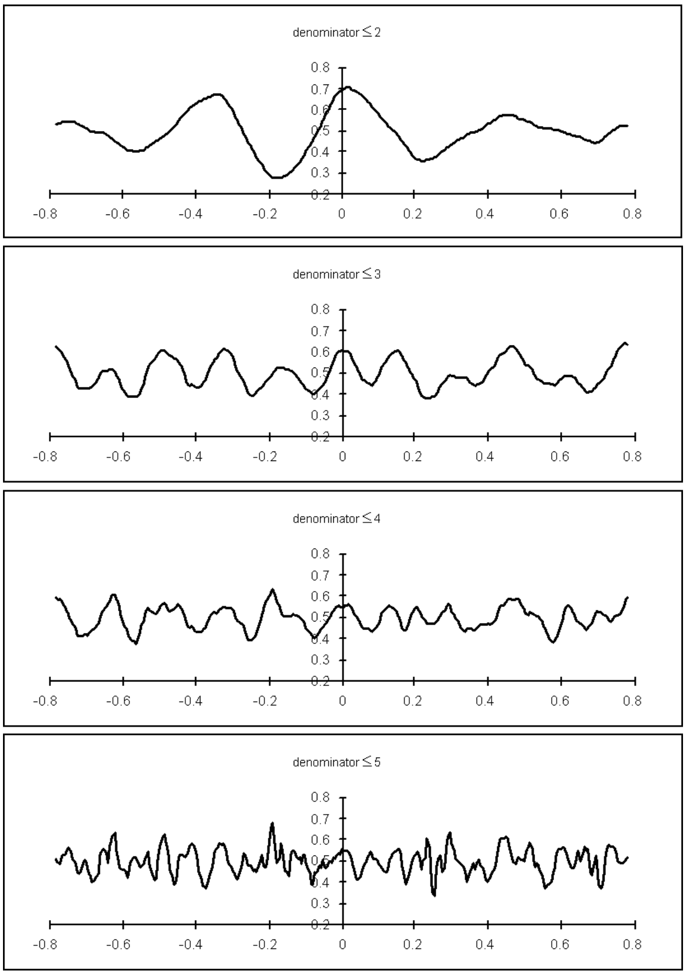

Figure 6: Varatiograms for the Wetterau limes, using different scoring functions.

4. Sensitivity

An important question about the usefulness of this approach is to how the choice of "significant" angles in the scoring function affects the varatiogram. The angles chosen as "significant" need to be matched to some well defined reality. Those chosen in the scoring function shown in figure 1 attempted to meet this criterion, but it is one of many choices which could have been made. How can we distinguish between these choices?

One approach is to use sets of angles of different sizes, each defined to include angles with tangents which are: rational, less than one and with a denominator less than a given value. The first set (denominator ≤ 2) includes 0:1, 1:1 and 1:2. The next set includes these three plus 1:3 and 2:3, and so on.

4.1. Tests of sensitivity using the vallum data

For the vallum data the results are shown in figure 5.

4.2. Trials using Wetterau limes data

The Wetterau *limes*, on the German frontier, provides another set of data. The maps in the *limes* guide (Klee 1989) show that a part of it takes advantage of the terrain, changing orientation frequently, whereas another part ignores the smaller natural features and includes several relatively long straight sections. In its relationship to the ground, it appears very similar to the vallum of Hadrian's Wall. For the purposes of this investigation this part is used, starting at Kleinkastell 21 of Strecke 4, at Langenhain, and ending at the end of Strecke 5, at Groß-Krotzenburg.

The results for different scoring functions are shown in figure 6.

5. Discussion and conclusions

From these graphs (figures 5 and 6) we can see a clear result of increasing the number of "significant" angles from 3 (denominator ≤ 2) to 11 (denominator ≤ 5). The number of peaks in the varatiograms increase in both cases. There is a greater range of options for the construction of centuriation hypotheses.

It is also clear that the position of peaks, and their height, is sensitive to this choice. This is most true for the change from denominator ≤ 2 to denominator ≤ 3, but it is also true for other sets. In the case of the Vallum, neither of the two largest sets defined in this way produces as significant a score for an input angle of -0.5404 as that produced by the set used in figure 1. This set was a particularly fortunate choice, from the point of view of supporting the Inglewood centuriation hypothesis.

The results therefore need to be handled with care, using information principally from the denominator ≤ 4 and ≤ 5 varatiograms in order to allow for the detection of the largest possible number of oblique relationships, if they exist.

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