Abstract. Digital levels are a precise instruments used for precise leveling. Operation of digital levels is based on the digital processing of video indications of a coded staff. Changes in leveling methodology and sources of specific errors occur using digital levels for precise levelling. The marks on the leveling meters also are modified and consist from the coded strokes put on the meter’s surface in specific order. The accuracy of performance of all the measuring equipment mostly depends on accuracy of position of those strokes. This paper deals with an analysis of an accuracy calibration of leveling meters.

Keywords: coded staff, digital level, leveling error, accuracy, calibration.

1. Introduction

Changes in leveling methodology and sources of specific errors occurs using digital levels for precise levelling. Precision investigations of a particular model of levels and coded staffs and digital levelling are necessary. Operation of levelling instruments is based on the digital processing of image of the coded meter. Every company producing the leveling instruments has developed its own codes and methods of their processing: correlation (LeicaWild NA2000/2002/3000/3003 systems), geometric method (Zeiss DiNi 10/20 systems), phase method (Topcon DL – 101/102 systems) [1-6].

At the beginning of measurement a visual pointing of the instrument into the surface of leveling meter is performed. After that the instrument automatically points the focus of its optical system on the surface of the meter and then a rough correlation calculation is performed followed by the precise correlation. According to data received in the processor of the instrument an exact distance from the axes of the instrument to the surface of the level meter is calculated. According to the information received by decoding it from the photodiode matrix the height of the level placing is calculated in the processor. During this operation the coded view of the meter is compared with that saved in the memory of the instrument. A true meter’s height position is determined according to the shift of the image in the photodiode matrix.

Processing of information is quite complicated in various leveling systems. For example, in Leica systems the code bars (strokes) are put on the all length – 4050 mm of the meter. The bar code has 2000 elements, each of them having 2,025 mm in width. It is evident, that the production of such meter is quite complicate; its accuracy mostly depends on the errors of placement of the coded bars. The matrix of the photodiodes (pixels) has 256 elements placed with the pitch of 25 \( \mu \)m from each other. Accuracy of placement of these cells also has an influence on the overall accuracy of the instrument’s performance.

An accuracy of the calibration of placement of the coded bars on the surface of the meters is analyzed in this paper.

2. Calibration of the coded staffs

The system calibration can be used to determine the correction values of rod readings and hence the scale of the digital leveling system, secondly to examine its behavior and thirdly, to estimate the accuracy.

During the last decades the geodetic instruments have become more automatic and electronic, fine constructed and externally well operating systems. The software has replaced more and more observer’s task. Also the levelling experienced the similar development: The discovery of the digital levelling in the beginning of the 90’s really conducd the levelling into the new era. [12, 13]
In old times the levelling instruments were simply constructed, but they were also manufactured in great care applying precision mechanics. So, we users knew more and understand better the function of the levelling instruments and in most cases, we were able to quickly locate the functional faults and to correct small imperfections. When we operate with a digital levelling system, a CCD camera takes picture from the rod, which covers a certain sector of the bar code scale above and below the horizontal level. The picture is then compared to the picture of the whole scale stored in the memory of the instrument. Each manufacturer has its own method to process the rod reading [1, 2]. In a digital level the rod readings are automatically processed applying electro-optical technique, while in conventional levelling the observer manually gets a rod reading using the optical tools of the instrument, e.g., line of sight, hair cross, ocular, micrometer, line of level etc. A CCD camera replaces the human eye. In processing a rod reading the digital levelling employs more than just one code line.

In conventional levelling the scale is based on the scale of a rod, while in digital levelling we can speak about two scales: Scale of an instrument and scale of a rod. The digital level gives the former, but in fact the scale of level is expected to be equal with the scale of rod. However, with time, the scale of level can be changed e.g. by aging of the CCD sensor. Also the scale of level is sensitive for scratches of code elements or shadows on invar band etc.

All coded meters can be calibrated by use of the interferometric comparators. Usually it is enough to measure every stroke (or bar) of 2.025 mm width at the pitch determined. The gaps between the bars are at the distances in times of 2.025 mm. Vertical comparators are mostly used for this purpose. By horizontal comparators the thermal expansion coefficients and thermal resistance of the meter are investigated. The meters are calibrated at 0, 10, 20, 30 and 40 °C of temperature.

The comparators partly repeat the operations of leveling. (Fig.1)

3. Photogrametric calibration

Principles of photogrammetry can be used for the comparing the views of the etalon and meter to be calibrated. The correlation factor determination can be used successfully as well as in the case of Digital leveling operation. The etalon view is save din the PC memory, and the view of tested meter must be extracted from the CCD camera. All the measurements are performed in the PC screen using analyzing gap covering the both images (Fig. 3 and 4).

At first, adjustments of the meters views in the direction of x and y axes must be taken. As it is seen in Fig. 1, bad image projection causes the faults in the images, not horizontal alignment result in the cosine error to be present at the misalignment angle $\vartheta$. It is evident that the true length $h$ of the image will differ from the misaligned length $l$ as $\Delta l = l(1-l\cos \vartheta)$.

The meters have an opportunity to be shifted along each other on the computer screen. CCD camera is supplied by the analyzing window for the selection the part of the meters that are selected for the comparison between themselves [7-11]. The analyzing window is shifted along the length of the meters or replaced by steps at least three times – at the beginning, in the middle and at the end of the meters. In this case it is easier to apply zooming process for the part taken in step measurement.

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Fig. 1. The FGI system calibration in the FGI laboratory

Fig. 2. Especially designed for the Zeiss DiNi12 digital levelling system with two observation pillars.

Fig. 3

Fig. 4
It would be impossible in such view as it is shown in Fig. 1.

The readings are taken by using the standard software AutoCad. The readings are shown only as an example without any statistical processing. According to the example it can be stated that the accuracy of measurement by this method can reach tens of microns in average.

Fig. 3. General view of photogrametric calibration of leveling meters: 1 etalon meter, 2 meter to be calibrated, 3 linear and vernier scale for readings, 4 moving reticle

An accurate comparing of the meters can be accomplished by the correlation method. A better case to apply this is comparison of the same type of the meters, for example, both coded meters by the same producer. The signals from the photoelectric sensors (pixels) is output to the PC making an array of numerical values from the both meters at the same position. It coincides with the known area-based method described in [11]. The difference is only in the aim of its applying. In our case it is the comparison of the position of edges of the bars on the tested meter. The processing of the images goes in the same way as according to the method above. Smaller subarrays from the both arrays are taken and the correlation factor is calculated using the formula [11]:

\[
\rho = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} (A_{ij} - \bar{A})(B_{ij} - \bar{B})}{\left( \sum_{i=1}^{m} \sum_{j=1}^{n} (A_{ij} - \bar{A})^2 \right)^{1/2} \left( \sum_{i=1}^{m} \sum_{j=1}^{n} (B_{ij} - \bar{B})^2 \right)^{1/2}}
\]

\( \rho \) – correlation coefficient; \( m \) and \( n \) – numbers of rows and columns; \( A_{ij} \) – digital number from subarray \( A \) in the row \( i \) and in the column \( j \); \( \bar{A} \) - average of all digital numbers in subarray \( A \), and \( \bar{B} \) - average of all digital numbers in subarray \( B \). \( i = 0, 1, 2, 3, ..., m; j = 0, 1, 2, 3, ..., n. \)

It is evident that a total array of numbers representing position of the bars on the surface of the levels will be received from the array of sensors of the CCD camera converting voltage output into the digital form. General diagram of photosensors (pixels) with the view of the coded bar of shown in

![Diagram of photosensors and bars](image)

Fig. 4. Array of photosensors and the bars of the meter on it: 1 – coded bars of the meter, 2 array of CCD sensors, 3 analyzing window

![Digital output from the photosensors](image)

Fig. 5. Digital output from the search array of photosensors and the analyzing window for subarrays selection

A digital output from the photosensors presented in the form of matrixes \( A \) and \( B \), from the view of etalon meter and calibrated meter respectively, are shown in Fig. 3.

The correlation coefficient is calculated from the subarrays selected by analyzing window. The error of the displacement (difference between the position of bars on the meters) is determined by the local correlation coefficient. Such operations are performed for this process:

- preliminary correlation coefficient calculation at the beginning, middle and the end part of the meters using the formula (1);
- shift of the subarray \( B \) at the predetermined pitch \( \Delta_t \) and repeating an operation as described above;
- repeating the first two operations in the investigation region \( \pm k\Delta_t \), where \( k = 1, 2, 3, ... \)
covering the zone of expected error of the meter’s bars placement;
• statistical processing of the results of correlation coefficient calculations determining the position in the discrete numbers of pitches \( \Delta_t \) in the length \( x \) of the meter.

More exact evaluation of edges of the bars can be performed by using the feature-based digital image assessment technique. In case of a blur image of the meters additional statistical means must be taken for determination the position of bars. The values of the photogrammetric points of the image are assessed by evaluates of standard deviations \( S_x \), \( S_y \) and

\[
S_{xy} = \sum (x, y) - \left( \frac{\sum x_i}{n} \right) \left( \frac{\sum y_i}{n} \right).
\]

(2)

Both coordinates \( x \) and \( y \) are needed for better determination of position of the bar’s points as it can be seen in Fig. 3. Linear regression equation \( y = \alpha + \beta x \) can be used for this as well, where \( \beta = \frac{dx}{dy} \) is the slope of the line, parameter \( \alpha \) is a constant at value \( x = 0 \). The same can be determined as \( \beta = \frac{S_{xy}}{S_x^2} \); \( \alpha = \frac{\sum y_i}{n} - \beta \frac{\sum x_i}{n} \).

Accordingly the sample correlation coefficient can be calculated as

\[
r = \frac{S_{xy}}{\sqrt{S_x^2 S_y^2}}.
\]

(3)

Such calculations as it is presented in [11] would be easier for the determination of the points on the meter’s bar edges, and their systematic error will be determined by changing the pitch \( \Delta_t \) of subarray sample selection.

Using the analyzing window on the search array of digital numbers, its position must be changed by steps at the chosen pitch \( \Delta_t \). So a maximal value of correlation coefficients will be determined at some values \( \Delta_t \) of the meter’s length, different from those on the etalon meter. This difference will be equal to the systematic error of the bars position at all its length.

3. Conclusions

Preliminary experiments show a possibility to perform the calibration of leveling meters using the photogrammetric methods of its comparison. Digital output array processing using an analyzing window is to be used. Area based comparison method used in general purpose photogrammetry can be applied for this purpose calculating the correlation coefficients at the shift of the images to each other by the discrete pitch that show the difference between the position of meter’s bar edges where maximal values of the correlation coefficient exist.

The systematic error of the meter under the calibration is determined by the values of position where these maximal values are found along the total length of the meter.

References