

**INVAR ROD CALIBRATION ON VERTICAL COMPARATOR
EXECUTED IN THE GEODESY METROLOGY LABORATORY
OF THE AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY
IN KRAKOW – POLAND
WITH USE OF COMPUTER-AIDED IMAGE ANALYSIS**

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1. INTRODUCTION

Examinations of leveling rods in the Geodesy Metrology Laboratory (GLM AGH) of the AGH University of Science and Technology are conducted with use of vertical comparator. The first concept of the comparator in question was designed in the Department of Geodesy and Cartography of the Faculty Mining Surveying and Environmental Engineering in the years 1998 – 1999 by research team represented by: Józef Mróz, Andrzej Pokrzywa and Tadeusz Szczutko. The comparator consists of three systems: carrying system, measuring system and environmental conditions monitoring system (Frukacz 2010). General view of the vertical comparator is shown in Fig. 1.



Fig. 1. General view of the vertical comparator – GLM AGH.

The carrying system allows vertical leveling rod positioning and free movement of the carriages along measurement column of the observation plane. The Hewlett Packard interferometer is a basal element of the measurement system. The interferometer, together with transmitting-receiving system composing of helium-neon based head and retro-reflectors, is a length master in the calibration process. The monitoring system comprises three material sensors allowing temperature measurement of the leveling bar invar band, which is needed for thermal correction, as well as temperature, pressure and vapor pressure measurement unit allowing calculation of atmosphere correction.

Original measurement concept assumed precise aim at the edge or middle of the observed line using Abbe's optical retro-reflector of the interferometer. Assigned with use of interferometer successive positions of the carriage allowed differential measurement of the distance, as well as defining real locations of individual elements of the leveling rod scale. Scheme of the system is shown in Fig. 2.

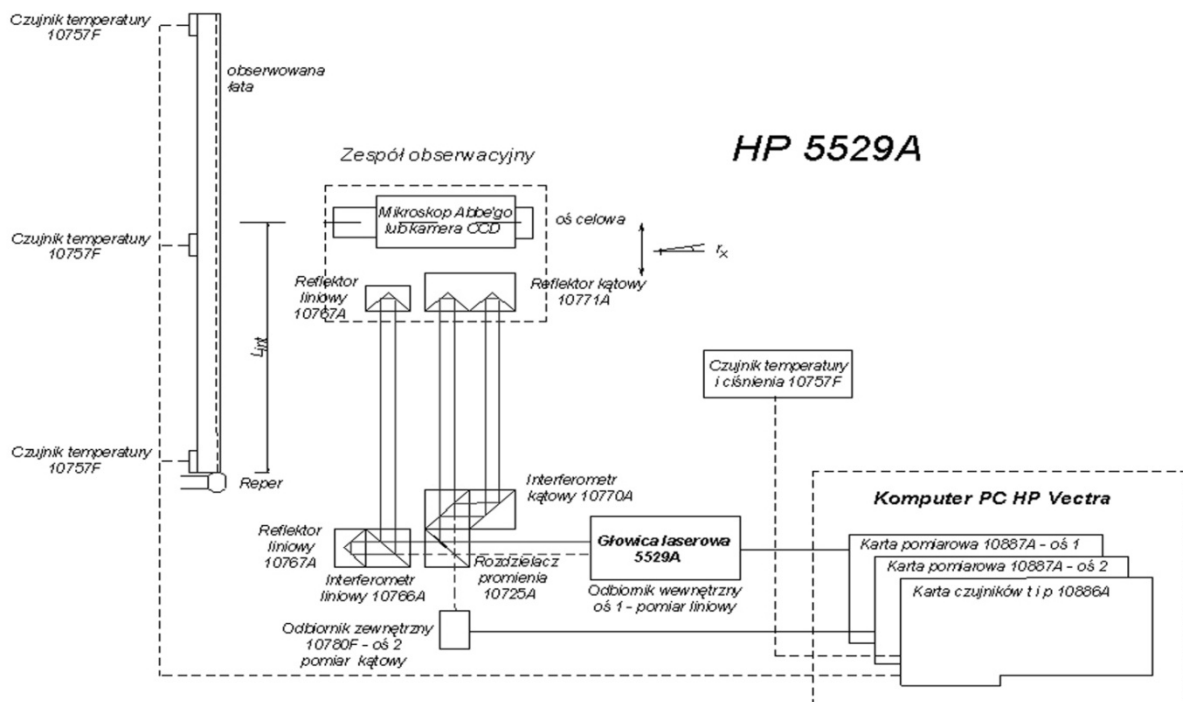


Fig. 2. Scheme of vertical comparator (Beluch et al. 2008).

2. APPLICATION OF CCD CAMERA

The solution presented above, (for wider description see Beluch et al. 2008), satisfied taken research assumption and allowed obtaining results satisfying standard criterions and technical requirements, as well. However, optical observations comprising precise aiming with use of Abbe's telescope at measured scale element were hard and time-consuming. For this reason, modification, comprising replacing the microscope with digital measurement camera was implemented (Fig. 3).

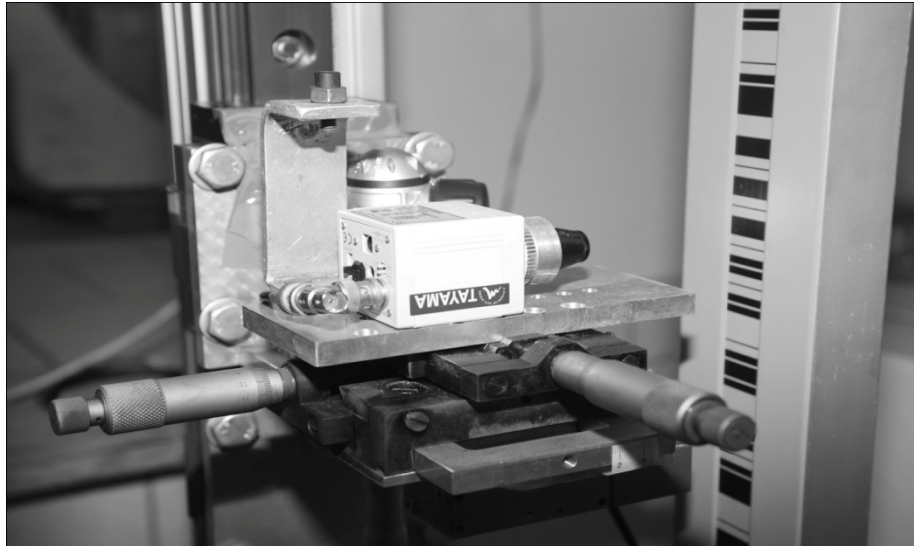


Fig. 3. Measuring system with CCD camera.

Thanks to application of the camera and image processing program aiming at the searched point takes place in approximate manner on the screen of additional LCD monitor, which is installed just near the camera. Depending on the observed scale type, middle of scale mark or measurement code is measured (in reality – whole narrow band) or its edge/margin. Measurement points for individual scale types are marked with dots in Fig. 4.

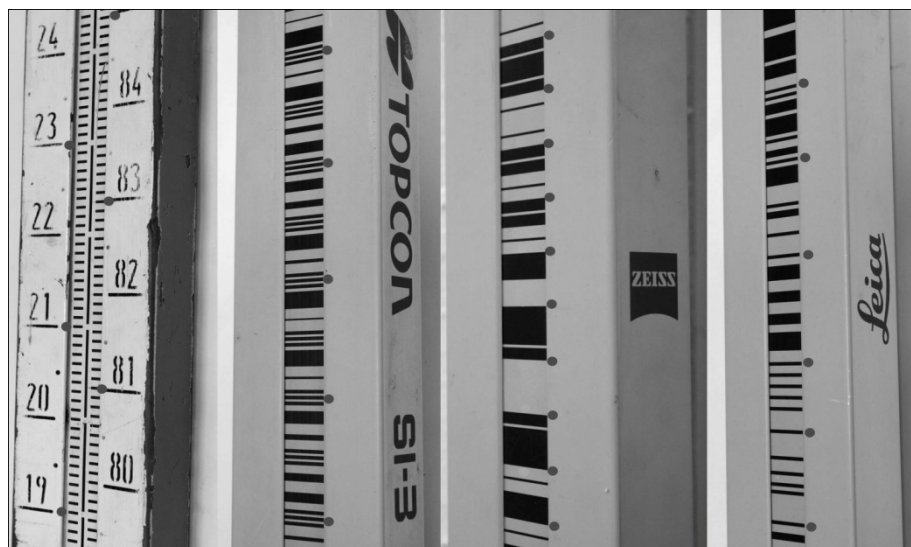


Fig. 4. Measurement points for individual scale types.

In case of leveling rods with classic scale, scale marks within the interval 0,10m on both scales are observed, what gives 60 measured points in total. Scale of basal module of Leica leveling rod amounts for 2,025mm, thus scale marks with width equal to one module separated with about 0,05m (60 on whole leveling rod) are used as observed measuring points. Measurement points for Topcon scales are distanced with 0,06m and are defined by middle bands of the reference module R, what gives 50 observed points for whole leveling rod. In case of all mentioned scale types, scale marks or code elements are observed symmetrically (whole scale mark is within the camera field of view) and center of the element is determined. In case of leveling rods with Zeiss/Trimble scale,

theoretical position of barcode is known instead of its center. That is why in case of these leveling rods the measurement points are spaced every 0,04m, what gives 75 measurements for whole leveling rod. Better-equipped option was also used, in which code edges/margins were observed every 0,02 m, but essential increase of measurement accuracy was not proved.

Monochromatic image obtained from camera with resolution of 640x480 pixel is handled by camera servicing program named „Kamera” designed by T. Szczutko, and then the frame is described. In the experimentally determined window (comprising whole width of band of edge/margin) image decimal-to-binary conversion is made (change from width scale into black and white image), the edges of scale marks are smoothed, and position of camera center with respect to center (or edge for Zeiss/Trimble leveling rods) of the scale center, using previously determined image scale factor. The resulting position of the leveling rod code band is a sum of the interferometer readout and calculated camera readout, which is registered in text file or exported into Excel. Because of high program calculation requirements, independent industrial computer is used for servicing „Kamera” program. On the basis of calculated real position of individual code elements and their theoretical value, corrections of the leveling rod and its scale are calculated (equivalent with scale average meter). The „Kamera” program visualization is shown in Fig. 5, where monochromatic image from camera – window (1), which is in limited area transferred into black and white image allowing the analysis is visible in window (2), calculated shift of the barcode strip with respect to camera axis (3) and monitoring of the file with registered results for previous scale marks (4), are shown.

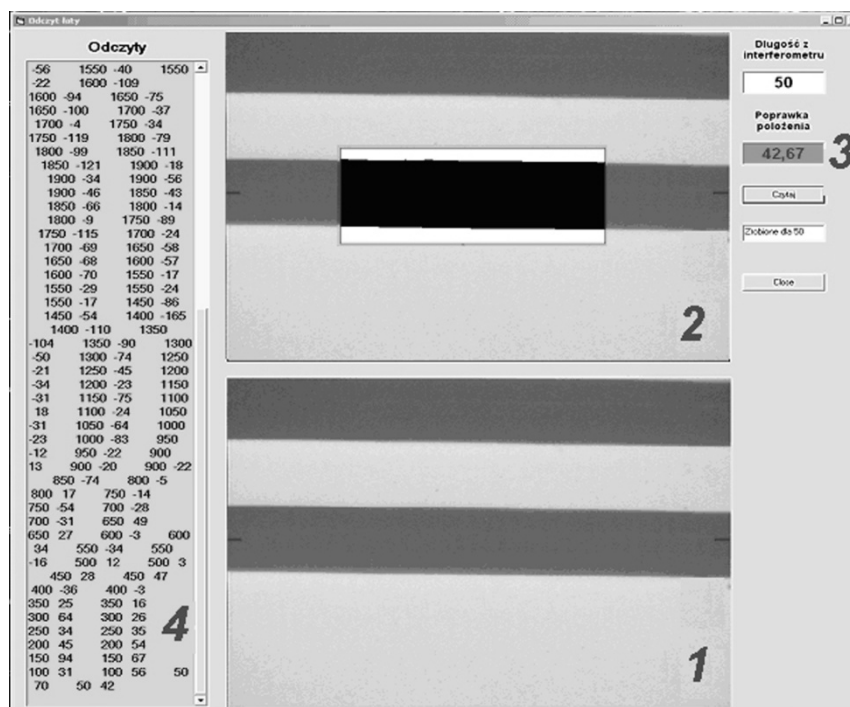


Fig. 5. „Kamera” program window.

3. REMARKS RESULTING FROM EXPERIMENTAL MEASUREMENTS

Application of large image magnification (Carl Zeiss Jena objective) and small depth of focus results in the fact that some of exploitation damages of leveling rods make the

observation difficult. That refers in particular to the leveling rod flexion toward observed object caused by deformation of the leveling rod resulting from improper application of supports, which in turn influences the camera image sharpness. Liquidation of the damages and impurities is possible thanks to proper selection of image parameters and filtration manner (Fig. 6).

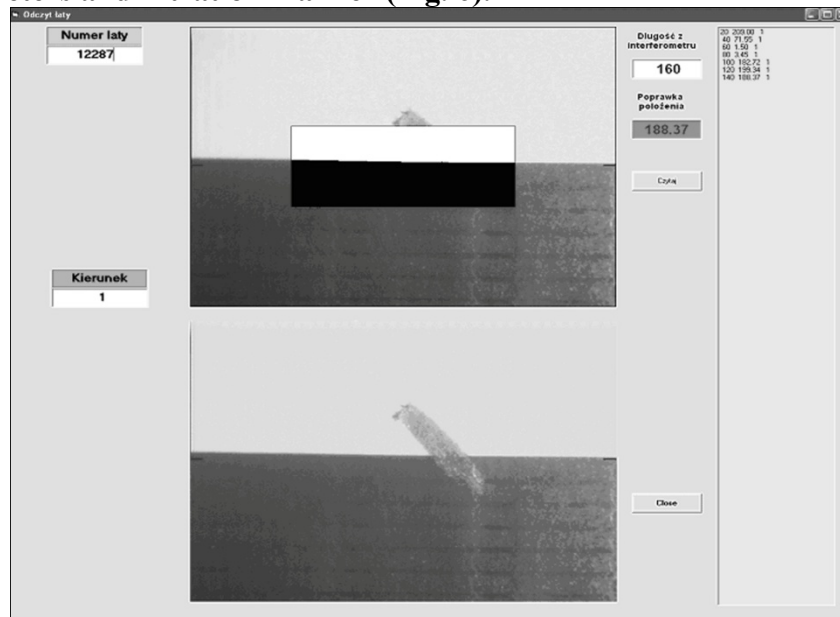


Fig. 6. Example of the scale damages filtration.

Experience related with elimination of system errors observed in former optical measurements (Beluch i in. 2005) were taken into consideration in the present study. In case of camera-aided measurement the errors are connected with Zeiss/Trimble code scale, where the scale edges are observed, and camera axis is set in central position with respect to them. This phenomenon is presented in Fig. 7. In the production process of all types of leveling rods manufactured by NEDO (Fischer and Fischer 1999), black varnish layer (2) is covered onto invar rod (1), and then yellow varnish layer (3) is put, in which scale elements are burned with use of pulsed laser. Half-shadows, which can generate edge identification errors during image processing are formed around 50 μ m thick yellow edges.

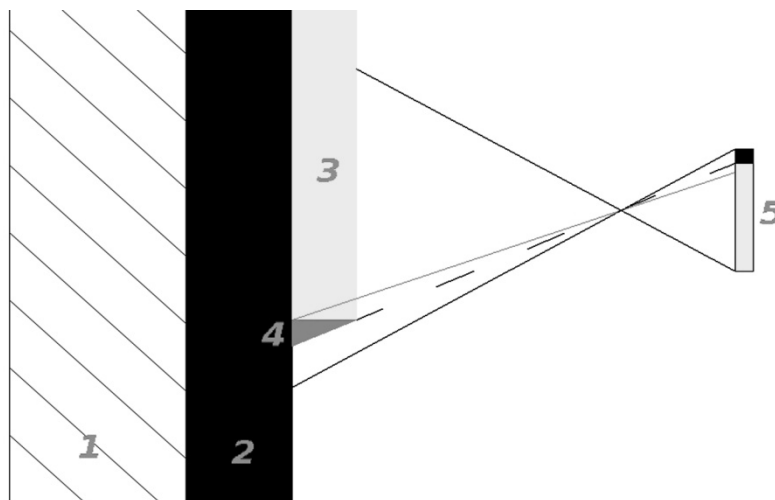


Fig. 7. Errors of the code edge identification – camera axis over the edge.

In case when the camera axis is set over the scale edge, instead of proper edge position (grey line), the edge of yellow band (dotted line) will be registered on matrix CCD (5). Shade (4) resulting from eventual scale lighting directivity is less important. If the camera is set below the code edge, the shade from surface varnish layer can also result in incorrect identification of the code edge position (Fig. 8).

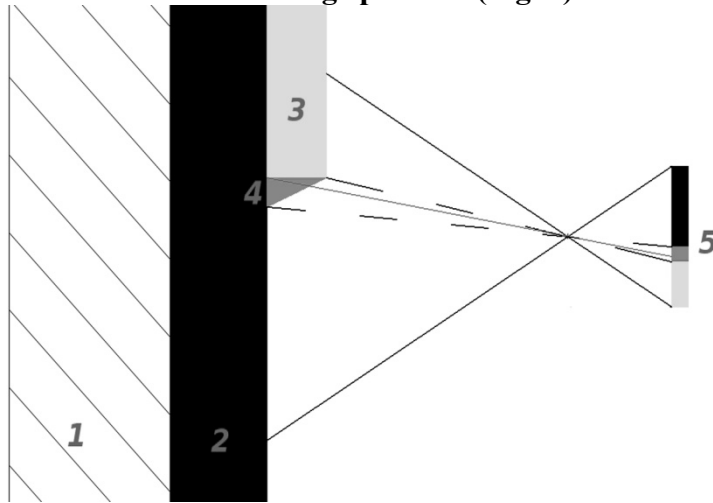


Fig. 8. Errors of code edge identification – camera axis set below the edge.

The executed analysis proved that absolute value of the error is constant irrespectively of the camera axis position, whereas its sign depends on the scale: for transition „yellow-black” value z amounts for „-1”, whereas for transition „black-yellow” value z amounts for „+1”. That is why, in case calibration of leveling rods with Zeiss/Trimble, program „Kamera” registers also type of transition in case of given edge, what is illustrated in Fig. 9. Influence of this systematic factor is eliminated during scale calculation process.

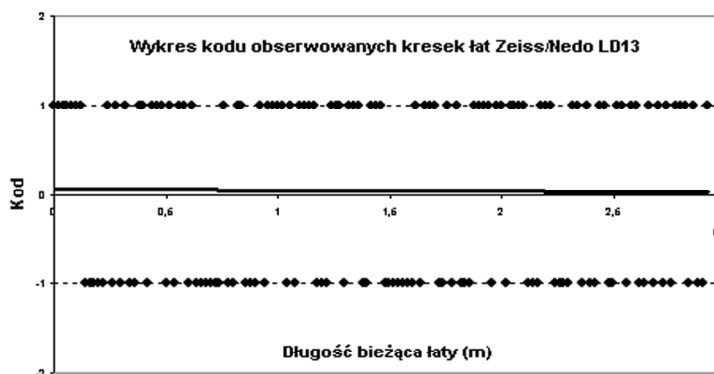


Fig. 9. Values of transitions z of the scale edge.

„Calibration Certificate” is a formal document containing information obtained during calibration comprising: value of scale factor (averaged leveling rod meter), scale mark errors, deviation of zero point and equation of corrected leveling rod readout (Fig. 10). It is a formal document issued to Orderers.



AKADEMIA GÓRNICZO-HUTNICZA
IM. STANISŁAWA STASZICA W KRAKOWIE

Wydział Geodezji Górniczej i Inżynierii Środowiska

KATEDRA GEOMATYKI

WGGiŚ: 27Ł/04/10

Kraków dn. 13.04.2010

ŚWIADECTWO KOMPARACJI

Rodzaj łąty : Precyzyjna łąta inwarowa kodowa GPCL3
firmy Leica/Nedo

Numer łąty : 50839

Zakres pomiarowy : 0.000 m - 2.95 m .

Zlecniodawca Geodezja Tadeusz Nadowski
43-100 Tychy, ul. Rybna 34

Wyniki komparacji.

1. Odchyłka punktu zerowego (stopka): $b = -0.018 \text{ mm} \pm 0.011 \text{ mm}$
2. Średnia wartość błędów kresek pomiarowych: $\pm 0.0042 \text{ mm}$
3. Metr średni łąty: $m_s = 1.000\,0056 \text{ m} \pm 1.3 \mu\text{m/m}$
4. Współczynnik rozszerzalności termicznej łąty – przyjęto średnią wartość dla inwaru produkcji Nedo: $\alpha = 0.8 \mu\text{m}/(\text{m}\cdot 1^\circ)$
5. Równanie poprawionego odczytu z łąty :

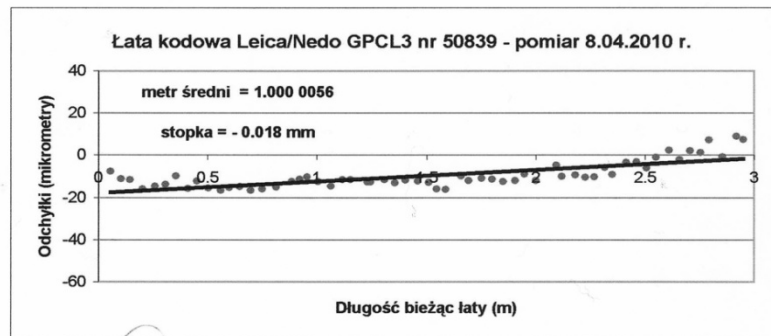
$$L = L_p [m_s + \alpha \cdot 10^{-6} (t - 20^\circ)] + b$$

gdzie:

L - poprawny odczyt z łąty w temperaturze 20°C w metrach

L_p - odczyt z łąty w temperaturze pomiaru $t^\circ\text{C}$ w metrach

Łata spełnia wymagania dokładnościowe dla niwelacji
sieci podstawowej I klasy.



Opracował:
dr inż. Tadeusz Szczutko

KIEROWNIK
KATEDRY GEOMATYKI
Prof. dr hab. inż. Józef Czaja

Fig. 10. Example of Calibration Certificate.

4. RESULTS OF IMPLEMENTED MODIFICATION

Numerous research studies conducted after implementation of the CCD camera-aided measurements proved that thanks to described modernization of the leveling rod, the calibration time is about 30-50% shorter as compared with microscope-aided calibration. The applied calculation algorithms, which eliminate systematic factors, suitable selection of uniform lighting of the leveling rod during measurements and the proper measurement procedure guarantee that the scale factor of leveling rod (average

meter) can be determined in Geodesy Metrology Laboratory of the AGH University of Science and Technology in Krakow-Poland with average error of ± 2 ppm (± 2 $\mu\text{m}/\text{m}$), what is comparable with accuracies obtained in the most renowned research laboratories at Technical Universities in Munich and Gratz.

REFERENCES

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- FISCHER T., FISCHER W. (1999) *Manufacturing of High Precision Leveling Rods*, [w:] Lilje M. [red.] *The Importance of Heights*, FIG, Gävle.

SUMMARY

Vertical comparator designed in Geodesy Metrology Laboratory of the AGH University of Science and Technology in Krakow-Poland is used for calculation of calibration corrections of precise invar and technical leveling rods. Observation of the rod code marks were at first made with use of Abbe's microscope mounted on movable carriage on measurement column. Position of the carriage was measured with use of laser interferometer HP5529A at the moment of precise aim at the leveling rod barcode strip edge.

Modification of this system has been presented in the present study. The modification comprises replacement of the microscope with measurement camera. Aiming at the center (or edge) of the leveling rod barcode strip or at the center of classic leveling rod center is observed on the monitor screen, the camera image is recorded, and then the shift of the leveling rod barcode strip center/edge with respect to the image center is calculated. The resulting position of leveling rod barcode strip is a sum of the interferometer readout and calculated camera readout. The image processing requires application of high computation power computer in the measurement system.

The presented procedure allows more precise calculation of the leveling rod calibration corrections, as well as eliminates hard optical observations, including shorter measurement time. Experiences related with elimination of systematic errors observed in former optical measurements have been taken into consideration in the present study.