On System Calibration of Digital Level

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Abstract: The high precision digital levelling systems use invar bar code rods and CCD technique. The scale of code is a function of temperature and a constant, which both are determined by the rod calibration. When carrying out the digital levelling, the scale of the whole system, in fact the scale given by the instrument is expected to be equal with the scale of the rod.

However, with time, the scale of an instrument and a rod can change. To check the behavior of the whole system we have to use the "system calibration" procedure, where the rod readings are taken from different sectors on the bar code rod and compared with their true values obtained by a laser interferometer.

In the Finnish Geodetic Institute (FGI) automated rod calibrations have been carried out since 1996 using the FGI vertical laser rod comparator and system calibrations since 2002. The FGI system calibration comparator applies elements of the existing FGI rod comparator. Thus, it is now possible to determine the scale of a rod and the system. Preliminary measurements to calibrate the Zeiss DiNi12 system have been carried out.

Importance of system calibration

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 conduced the levelling into the new era.

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 leveling instruments and in most cases, we were able to quickly locate the functional faults and to correct small imperfections.

Today, it seems that manufacturers have diluted the precision mechanics in production, mostly, due to high costs. The instruments and systems are examined and calibrated by the manufacturer when finding some imperfections, corrections are added into the measuring program and all that is kept secret by appealing into commercial reasons (Woschitz et al. 2002a). The user in the field pushes an operation button and gets nice readings without any possibilities to control them and in the worst case does not even care the correctness of readings. This is one reason, why we need the system calibration of digital leveling systems.

Digital levelling system

The first almost totally automated levelling system in the world Wild NA2000 (Fig. 2) was launched in the beginning of the 90's (Ingensand 1990). Currently, the following four manufacturers of the digital levels are on the market: Leica, Trimble (Zeiss), Sokkia and Topcon. The measuring system of the digital levelling consists of a level comprising optics and compensator, a bar code scale mostly on an invar band fixed into a rod frame, a CCD linear array and a software controlling all operations, procedures and process of the digital level (Ingensand 1999).

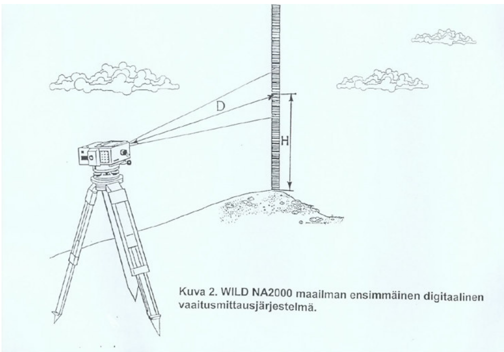


Fig. 1. *The principle of a digital levelling system.*

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 as illustrated in Fig. 1. 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 (Ingensand 1999).

We can recognize following differences between the digital levelling system and the conventional leveling:

1. 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.

2. A CCD camera replaces the human eye.
3. In processing a rod reading the digital levelling employs more than just one code line. For instance, in Zeiss DiNi12 system (Fig. 2), a 30 cm sector of bar code scale is used whereas in conventional levelling the rod reading is based on observation of one graduation line (Feist et al. 1995).
4. 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. (Woschitz et al. 2002b).

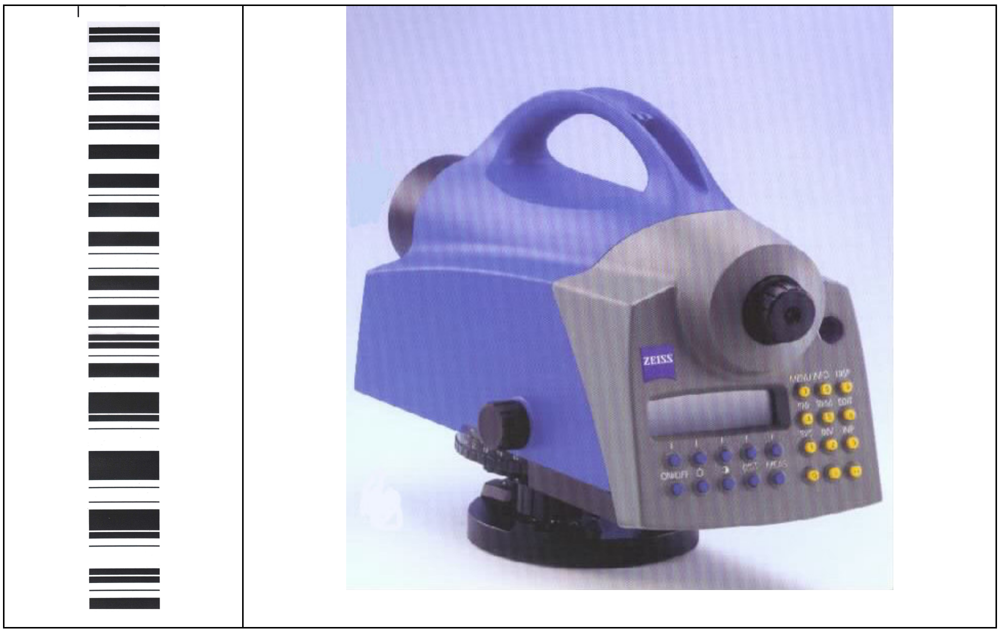
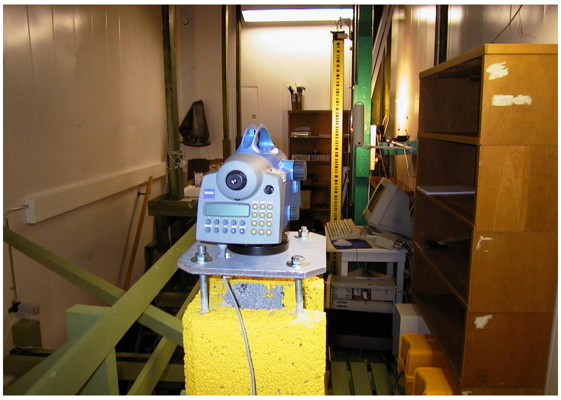


Fig. 2. *Zeiss DiNi12 digital levelling system. Bar code and digital level. System was adopted by the Finnish Geodetic Institute at the end of year 2000 (Photos: Zeiss DiNi12 Manual).*

System Calibration

In the system calibration the rod is set on the vertical conveyor controlled by laser interferometer and the digital level at a certain distance from the rod as illustrated in Fig. 3. The rod is moved step by step in vertical direction and the rod readings are observed with the instrument during the stop between the steps. The readings are taken from different sectors of the bar code rod and then compared with true values obtained by the laser interferometer (Rüeger et al. 2000).



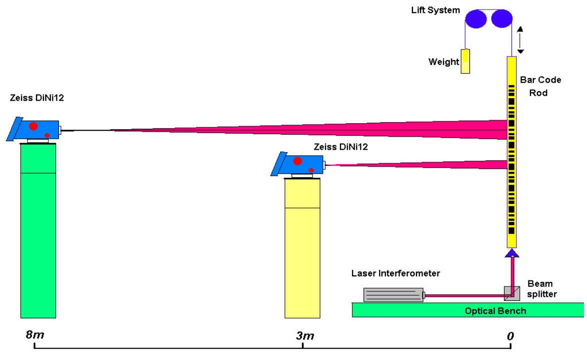


Fig. 3. *The FGI system calibration in the FGI laboratory (left). Especially designed for the Zeiss DiNi12 digital levelling system with two observation pillars.*

The FGI system calibration comparator is particularly designed for calibration of Zeiss DiNi digital levelling system (Fig. 3, right), but we are also able to calibrate all types of digital levelling systems on market (Takalo et al. 2001a; Takalo et al. 2001b).

Our system calibration comparator consists of two 4 m high concrete pillars for instruments and the vertical comparator to move a rod. Two pillars at the distance of 3 m and 7.5 m are used, because the Zeiss DiNi digital level changes its calculation mode at the distance of 6 m. The comparator employs some components of the existing FGI vertical laser rod comparator (Takalo 1997), e.g., lift system with stepping motor, automatic weather station, laser interferometer, the data computer etc. The first stage of software development was completed in spring 2002.

One of our objectives is to calibrate simultaneously two instruments using the both pillars and also simultaneously calibrate a rod. To realize the latter task some constructional changes of the comparator are still required.

Standard Uncertainty of system calibration

In order to estimate the uncertainty of the system calibration measurement, we model the measuring process using the FGI system calibration comparator. As illustrated in Fig. 3 there are digital level set on the top of observation pillar and the bar code rod in the conveyor of the comparator. Rod readings are taken three times at each position of rod and the whole rod scale is measured three times down to up and back, thus including 6 independent measurements. The correction of rod reading for each position of rod is

(1) $\delta H = \Delta H - \Delta L = (H_i - H_0) - (L_i - L_0)$,

where

H_i = Height reading from the rod in position i
H_0 = Height reading from the rod in initial position
L_i = Laser reading from the rod in position
L_0 = Laser reading from the rod in initial position.

According to the law of error propagation of uncertainty applied to the equation (1) we get

(2) $$u(\delta H)^2 = 2xu(\Delta H)^2 + 2xu(\Delta L)^2 = 2\{u(H_R)^2 + u(H_C)^2 + u(L_L)^2 + u(L_C)^2\},$$

where

$u(\delta H)^2$ = Variance of correction for rod reading
$u(H)^2$ = Variance of rod reading
$u(L)^2$ = Variance of length measurement
$u(H_R)^2$ = Variance of rod reading resolution
$u(H_C)^2$ = Variance of compensator
$u(L_L)^2$ = Variance of laser interferometer
$u(L_C)^2$ = Variance of conveyor.

The reading resolution of the Zeiss DiNi12 digital level is

$$H_R = 10\ \mu m.$$

Hence we get the standard uncertainty due to the reading resolution

$$u(H_R) = 10 / (2\sqrt{3}) = \pm 2.89\ \mu m$$

The horizontal vibration of pillar causes a movement of the compensator of the digital level and this in turn, uncertainty of rod reading as follows:

The random tilt of compensator is estimated to be 1/3 of setting accuracy 0.2" and this causes an error of 2.67 µm when sight distance is 8 m and hence we can estimate the standard uncertainty due to the compensator of level

$$u(H_C) = 2.67 / (2\sqrt{3}) = \pm 0.77\ \mu m.$$

The combined standard uncertainty of the rod reading (n=3) is

$$\mathbf{u(H)} = \sqrt{(2.89^2 + 0.77^2)/3} = \mathbf{\pm 1.73\ \mu m}.$$

The length measurements (3 m) with laser interferometer involve following sources of errors (Takalo 1999):

Dead path	2×10^{-9}
Edlen equation	25x
Frequence of laser	3x
Pressure of air sensor	28x
Humidity sensor	19x
Temperature sensor	48x
Abbe error	70x
Alignment of laser	54x
Installation of rod	2x
Thermal expansion: Rod	74x
Thermal expansion: Humicap	35x

Hence we get the standard uncertainty of laser interferometer measurement

$$u(L_L) = \pm 0.14\ \mu m.$$

During the observation time with Zeiss DiNi12, 4-6 seconds, the rod can slide in vertical comparator even 2 µm due to the imbalance of the lift system (See Fig. 3). Hence we can estimate the standard uncertainty due to sliding of rod to be

$$u(L_C) = 2/(2\sqrt{3}) = \pm 0.58\ \mu m.$$

Thus, the combined uncertainty of the length measurement is

$$\mathbf{u(L)} = \sqrt{(0.14^2 + 0.58^2)} = \mathbf{\pm 0.60\ \mu m}.$$

Applying the equation (2) we get the standard uncertainty of the system calibration measurement

$$\mathbf{u(\delta H)} = \sqrt{2}\ \{u(\Delta H)^2 + u(\Delta L)^2\} = \sqrt{2}\ (1.73^2 + 0.60^2) = \mathbf{\pm 2.59\ \mu m}$$

and hence we get the expanded standard uncertainty by using the coverage factor of k = 2, i.e., with the 95% level of confidence

U(δH) = ±5.18 µm.

The system calibration with the FGI comparator consists usually of six independent measurements. Thus, we can achieve the uncertainty better than ±2.11 µm.

Results

The tests have been carried out since spring 2002 just after the completion of the software. The system calibration procedure consists of forward (A) measurements from the lower to the upper end of the rod and the backward (B) measurements from the upper to the lower end of the rod. When moving the rod, the length of step, 25 mm and the sighting distance 7.5 m was selected.

Figure 4 illustrates an example of the system calibration. In this case the corrections of rod readings are less than ±50 µm. According to residuals we can estimate the accuracy of the system calibration to be 5-7 µm, which indicates that the computing resolution of Zeiss DiNi12 may be higher than the output resolution 10 µm for one rod reading.

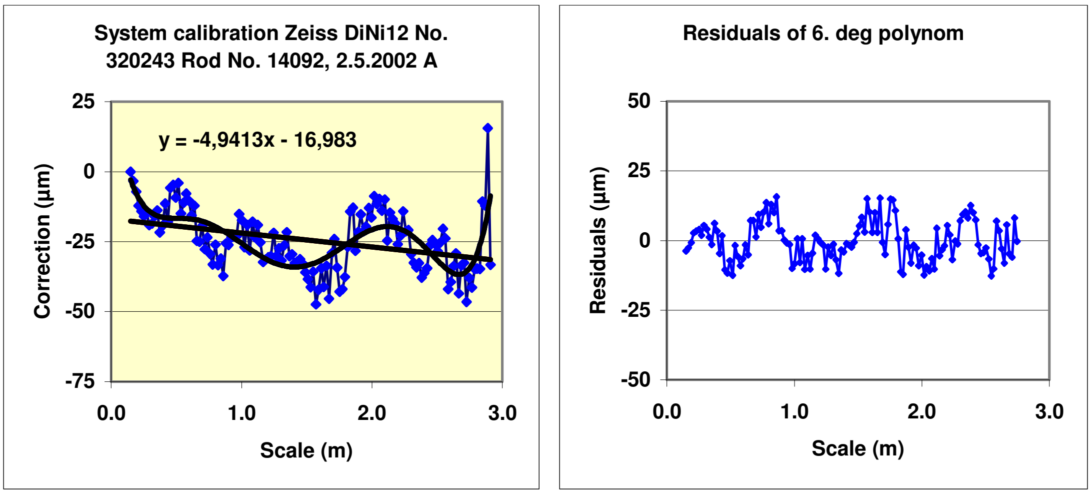


Fig. 4. *A system calibration with the FGI comparator for the Zeiss DiNi12 digital level No. 320243 and the 3m long bar code invar rod No. 14092. Measurements have been done in spring 2002.*

According to a separate calibration of the Nedo LD13 rod No. 15814 with the FGI vertical laser rod comparator (Takalo 1999) the obtained scale –6.8±1.7µm is near to that –5.8±1.3µm obtained from system calibration using the same rod and the digital level No. 700960 (Fig 5, lower and middle picture).

The system calibration is an excellent tool to detect possible errors in digital levels as we can see in Fig. 5 (upper picture). In this case the readings taken from the upper and lower end of the bar code rod deviate from the main trend because only apart of barcode scale is visible and imaged by CCD. Hence we can concluded that the readings between 0.25 m and 2.8 m are correct and can be used to determine the scale (Fig. 5, middle picture).

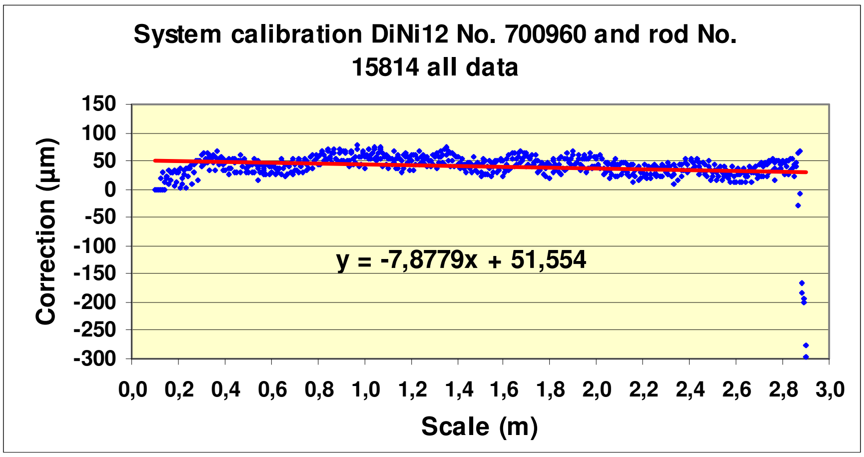
Summary and Future Works

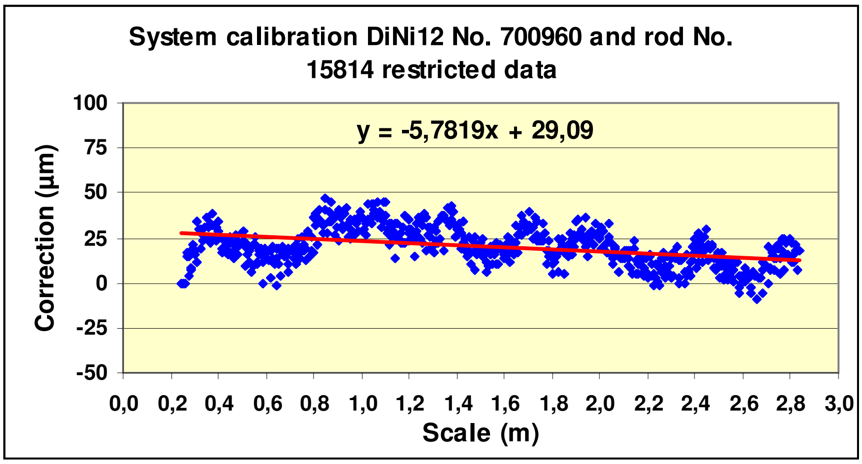
The FGI system calibration comparator is an efficient tool

- to determine the scale of digital leveling system, which is the final output to correct leveling data,
- to control variation of the scale, which can indicate changes in rod or in CCD sensor and
- to examine behavior of the digital leveling system, for example in different ambient temperatures.

As future works we need

- to develop the hardware and software to versatile activities of comparator for studying the digital leveling technique and
- inter-comparison with the corresponding comparator in Graz, Austria.





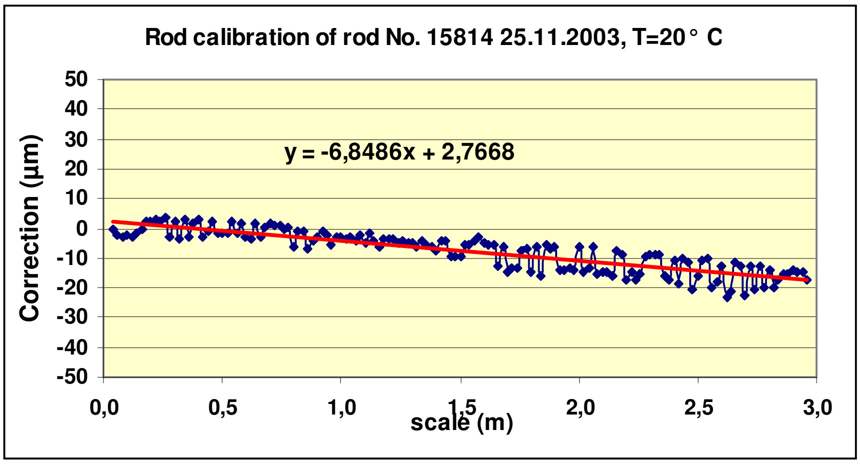


Fig. 5. *An example of comparison rod and system calibration and need to avoid the lower and upper end of bar code rod.*

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