# Some Calibration Results of Digital Levelling Systems

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**Key words**: system calibration, scale correction, thermal expansion, digital level, precise levelling


## SUMMARY

We expect that digital level will produce height reading quickly and reliably. But is the reading correct? That we must find out by calibrating rod scale or even better the rod and the level together. In this paper we have done both. For some years we have been comparing modern levelling systems ie. digital levels and bar code invar rods using the vertical comparator of the Finnish Geodetic Institute. Our customers come from Baltic and Nordic countries where the precise levelling work is still going on busily. In our laboratory it is possible to vary both sight length and temperature for simulating outdoor circumstances. In this study we included six digital levels and nine invar rods, which were calibrated in 2006-2008. Digital levels were made by Leica and Trimble. We used three meters long invar rods with aluminium frame. The aim of our research was to compare the results of system and rod calibrations to find out their characteristics. Our results showed that scale corrections of levelling systems are compatible with those of rods. We estimate that the accuracy of system calibration can be of order ±3 μm/m with short sighting distance. According to our tests there is no clear dependence of sight length. But the thermal expansion factor of the whole levelling system can exceed remarkably the value attained purely from rod scale. For this ground we think that full calibration of digital levelling system is very important.

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## 1. INTRODUCTION

Calibration of levelling equipment has changed a lot when moving from traditional levels to digital systems. In case of conventional levelling rod scale was a direct source of metric height while in digital levelling system we have two affecting components: level and bar code rod (Rüeger, 2000). In Finnish Geodetic Institute (FGI) we started calibrations with bar code rods in our vertical comparator eleven years ago (Takalo 1997). When the digital levelling became more common there rose a question if we could calibrate whole equipment i.e. rod and level together. In FGI we have been able to do that kind of system calibrations since 2002 when we constructed two observation pillars at distances 3.0 and 7.6 meters (Takalo 2004). In our laboratory we also have a possibility to control temperature in range of 5°-35° C to determine thermal expansion of levelling system and rod. In this paper we deal with Leica NA3000/3003 and Trimble DiNi12 levelling systems (Ingensand 1999).

## 2. SYSTEM CALIBRATIONS

In this study we took one Leica NA3003, two Leica NA3000 and three Trimble DiNi12 instruments under research. We had nine bar code invar rods, which were three meters long. Both system and rod calibrations were made following the same routine during 2006-2008. In final counting we handled only readings between 0.2 – 2.8 meters because the bottom and top readings may be lacking or they are faulty (Woschitz 2003). Typically we have used three different temperatures to attain at least 12 data points for every level and rod system.

We use linear approximation to correct rod readings:

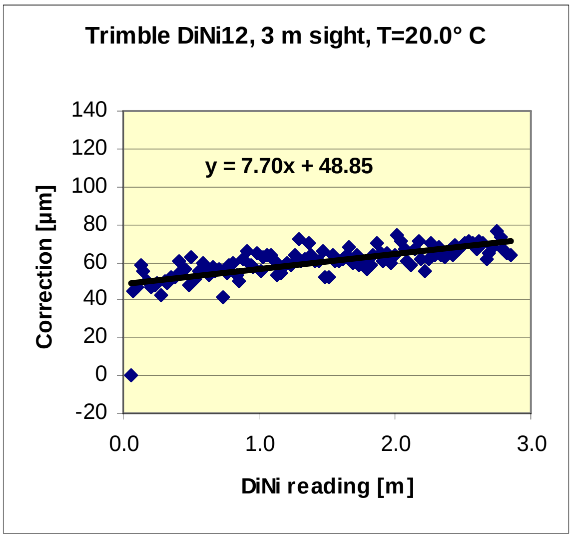
$$L = L_O * [A + B\,(T-20)]\ ,$$

where L is corrected reading, $L_O$ observed reading, A correction factor of scale, it is 1 + scale correction in temperature of 20° C, B thermal expansion coefficient, ~ $10^{-6}$ [1/°C] and T ambient temperature [° C].

## 3. RESULTS

In figure 1 there is a typical system calibration measurement, where the slope of the source data is +7.7 µm/m. Observation interval is 25 mm. Note: There is a deviating reading in the beginning. When we repeat measurements in different temperatures we get more data points and the linear regression like in figure 2. From that regression line of system No. 7 we can figure out the scale correction (+5.6±2.3) µm/m in temperature of 20° C and the slope (0.84±0.08) µm/(m°C) with standard error. These are the two parameters we need for correcting rod readings. Respectively the scale correction from rod calibration gives

(+1.4±1.2) µm/m and thermal expansion (0.74±0.07) µm/(m°C). This comparison is also shown in figures 5a-6b.



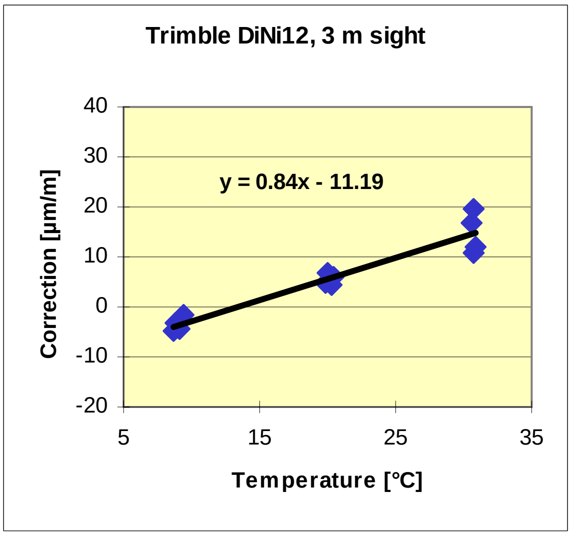




**Fig. 1**. One measurement of system No. 7 in 2008. **Fig. 2**. Set of measurements, system No. 7 in 2008.

Table 1. Levels and rods.

| System No. | Level | Type | No. | Rod | No. | Year |
|---|---|---|---|---|---|---|
| 1 | Trimble | DiNi12 | 701742 | LD13 | 10803 | 2006, 2007 |
| 2 | Trimble | DiNi12 | 701743 | LD13 | 10803 | 2006, 2007 |
| 3 | Trimble | DiNi12 | 701742 | LD13 | 14605 | 2006, 2007 |
| 4 | Trimble | DiNi12 | 701743 | LD13 | 14605 | 2006, 2007 |
| 5 | Trimble | DiNi12 | 701742 | LD13 | 14620 | 2006, 2007 |
| 6 | Trimble | DiNi12 | 701743 | LD13 | 14620 | 2006, 2007 |
| 7 | Trimble | DiNi12 | 320204 | LD13 | 13815 | 2007, 2008 |
| 8 | Trimble | DiNi12 | 320204 | LD13 | 13830 | 2007, 2008 |
| 9 | Leica | NA3000 | 89687 | GPCL3 | 27961 | 2007, 2008 |
| 10 | Leica | NA3000 | 89687 | GPCL3 | 9543 | 2007, 2008 |
| 11 | Leica | NA3000 | 90848 | GPCL3 | 26484 | 2007 |
| 12 | Leica | NA3000 | 90848 | GPCL3 | 28870 | 2007 |
| 13 | Leica | NA3003 | 93475 | GPCL3 | 26484 | 2008 |
| 14 | Leica | NA3003 | 93475 | GPCL3 | 28870 | 2008 |

In figure 3a we have six DiNi12 levelling systems, which are combinations of two levels and three rods. System 1, 3 and 5 have the same level but different rod. In systems 2, 4 and 6 we have another level, see Table 1. As we can notice the correction seems to depend more on rod than level. Results with sight lengths of 3 and 8 meters are shown separately. One year later the measurements were repeated and the corrections are in figure 4a. Thermal expansion

of systems 1-6 is shown in figures 3b and 4b. In Figures 5a and 5b there is another six systems set up. Systems 7 and 8 have the same DiNi12 level but different rod. Systems 9 and 10 consist of NA3000 level with two rods as well as systems 11 and 12. In 2008 we have same rods as in the year 2007 but the level with systems 11 and 12 has changed so there are two new systems 13 and 14.

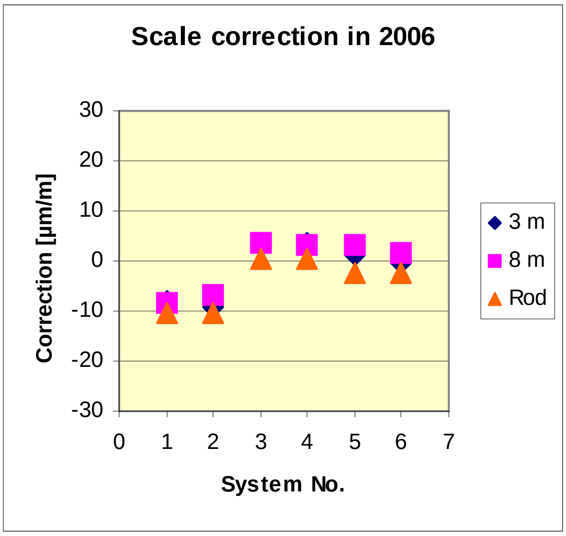



**Fig. 3a**. Scale correction of systems 1-6 in 2006.

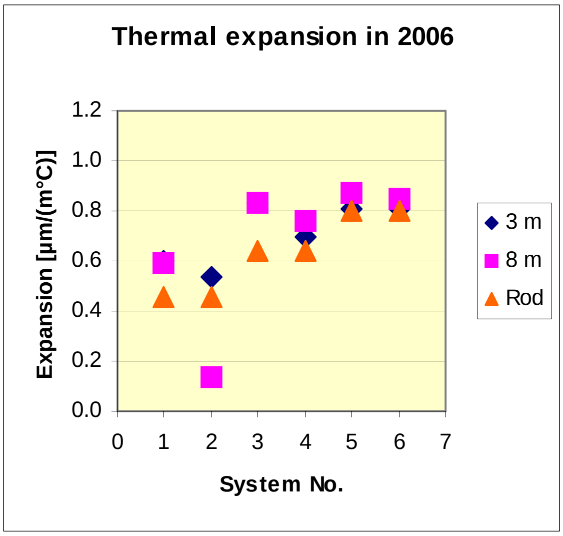



**Fig. 3b**. Expansion of systems 1-6 in 2006.

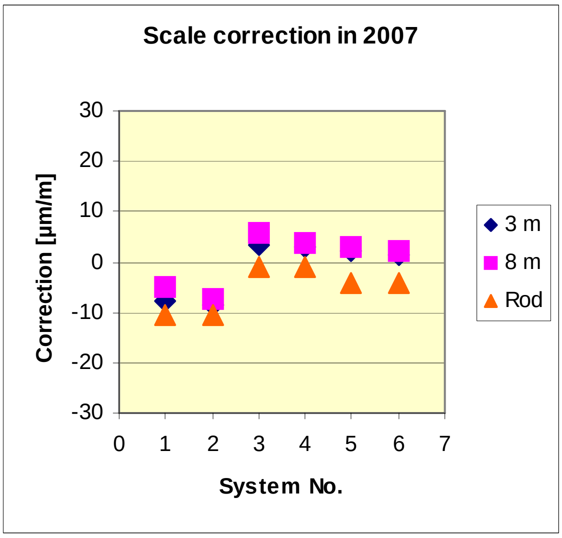



**Fig. 4a**. Scale correction of systems 1-6 in 2007.

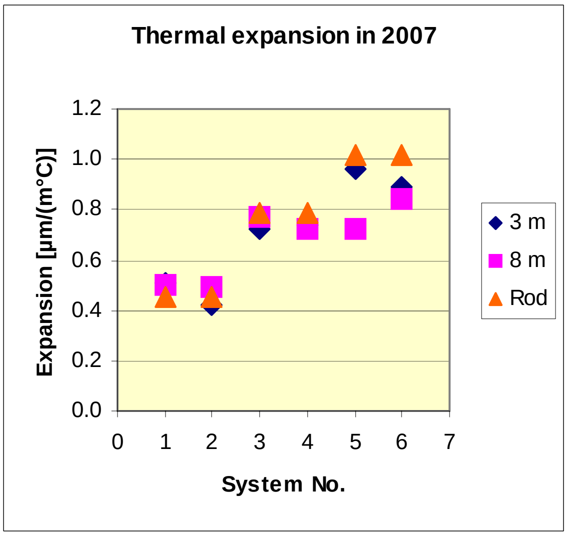



**Fig. 4b**. Expansion of systems 1-6 in 2007.

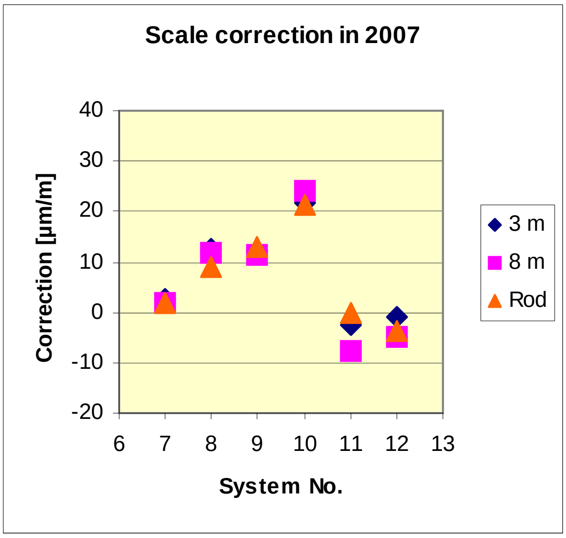



Fig. 5a. Scale correction of systems 7-12 in 2007.

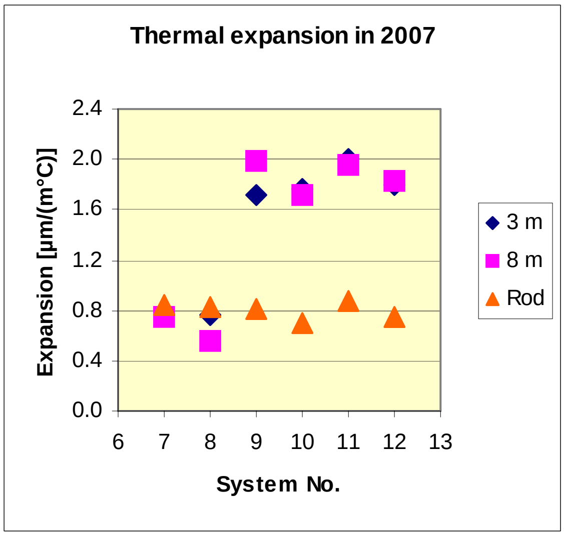



**Fig. 5b**. Expansion of systems 7-12 in 2007.

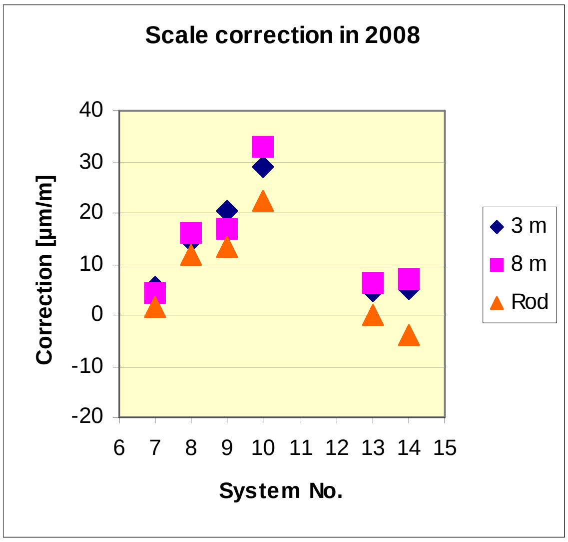



**Fig. 6a**. Scale corrections of syst. 7-10, 13-14 in 2008.

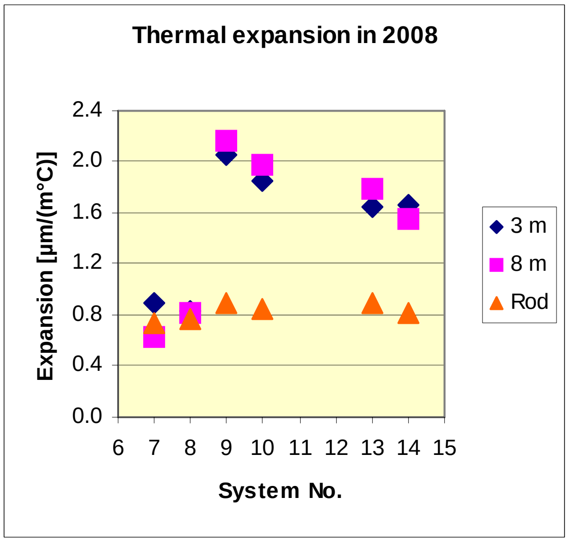



**Fig. 6b**. Expansion of systems 7-10 and 13-14 in 2008.

## 4. CONCLUSIONS

We may have a reason to assume that rod and system calibration should give approximately the same correction for height reading. Occasionally it seems that there will come an extra part from the digital level too. It is because the level may have its own scale and way to react on ambient temperature. Our results tell that the expansion coefficient of the whole system can be even two times what is coming from rod scale. In this kind of case the rod calibration alone is not enough to correct height readings exactly. Neglecting system calibration may cause an error of 1 µm/(m °C) which depends on height difference and average temperature. That is why we need system calibration. On the other hand rod calibration is very precise tool to investigate rod scale and its thermal dependence. It can be used as a reference for system calibration. The complete way to control levelling system is to perform both system and rod calibration. We call it ”total calibration”.

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