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Comparison of indoor and outdoor Accuracy Performance of Optical Automatic, Digital and Laser Levels

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***Abstract*:- One of the most important survey data is the levels of points on ground surface which leads to topographic mapping, Digital Elevation Models (DEM), earthwork calculations and other surveying and civil engineering applications where three- dimensional coordinates are needed. This is also important for indoor applications such as leveling floors, installing drop ceilings and checking door or window heights**

The accuracy performance of level surveying instruments is generally affected by atmospheric conditions such as temperature, atmospheric pressure and humidity.

In this study, three levelling instruments of different designs: Ordinary Automatic Optical, Digital and Laser Levels were tested for accuracy performance inside laboratory and outside in the field.

A precise optical level was used to provide control data for indoor and outdoor tests.

Results showed that ordinary optical level is the mostly affected by atmospheric conditions when working in the outdoor environment. Results also showed that all three tested levels were significantly affected when used outdoor. In all cases, however, the digital level gave the best accuracy performance.

INTRODUCTION

One of the most and widely used approach for obtaining elevations is the Levelling of ground points relative to a reference datum. Levelling is usually carried out as a separate procedure to those used in fixing planimetric positions. The basic concept of leveling involves the measurement of vertical distance relative to a horizontal line of sight. Hence it requires a graduated staff for the vertical measurements & an instrument that provides a horizontal line of sight.

Construction, control and monitoring of large size civil projects is an important and well-known application area for topographical and geodetic methods. On the other hand, projects that involve applying precision geodetic methods in monitoring in a smaller scale (structural elements: beams, columns, slabs, etc.) also require levelling data (Francoso, et al, 2019).

Most of the surveying instruments have changed with the rapid change of technology. One of these instruments is the level. Some leveling works require to be executed in a short time with a high level of accuracy. Also, costs are required to be as cheap as possible. Example of these works is the establishment of bench marks (Zaky, et al, 2002).
Although applications of levelling in the outdoor is wide and well known; such as establishing geodetic height networks, earthwork calculations for establishing grades, data for contours and topographic mapping to mention a few, indoor applications of Levels include levelling floors, installing drop ceilings, installing chair rails, align and plumb walls, checking door or window heights.

The objective of this article is to evaluate accuracy performance of levels of different designs in and out door to check the effect of atmospheric conditions on the different levels' performance.

In the following section types of different levels will be introduced before considering those used in the test.

TYPES AND ACCURACY OF LEVELS

Levels are of different versions and designs. The following are few basics of the different available levels:

a. Ordinary Levels: These are levels used with staffs graduated with 1cm as the smallest graduation and where millimeters are to be estimated which lead to an accuracy in the range of 2cm to 3cm. These include Dumpy, Tilting and Automatic levels.

Optical automatic ordinary level (Figure 1) is now, the mostly used for site engineering operations.

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Figure 1. Optical Ordinary Automatic Level in the Field (https://en.wikipedia.org/wiki/Level_(instrument)#/media/File:Us_land_survey_officer.jpg)

b. Digital Levels: This type of levels uses a special bar-coded staff. The image of the staff passes through the objective lens and then via a beam splitter to a photo detector array, where it is digitized (Figure 2). The microprocessor compares this image to a copy of the bar code and calculates the staff reading, which is displayed and/or stored. The sensitivity of the device is such that single reading accuracy of 0.2mm to 0.3mm can be achieved, and sight lengths can be extended up to 100m.

Figure 2. Digital Level in the field
(http://www.merlinlazer.com/Sprinter-250M-Digital-Level---Plus-FREE-Barcode-Staff)

c. Precise Levels: These appeared as a modification of the ordinary levels where a parallel plate micrometer is placed in front of the objective lens. This allows the image of the staff graduation to be moved up or down by very small measurable amounts. For sight lengths of under 50m, single reading accuracies of 0.02mm to 0.03mm can be achieved. Hence this type of levels is mainly used for establishing bench marks with high precision at widely distant points and monitoring engineering structures that need high accuracy.

d. Laser Levels: These consist of a rotating laser beam projector that can be affixed to a tripod. The tool is leveled according to the accuracy of the device and projects a fixed red or green beam in a plane about the horizontal and/or vertical axis. In simplest terms, laser level is an electronic device that projects a red or green beam along the horizontal and vertical axis (Figure 3). This description is, of course, very brief and requires some elaboration, starting with the fact that the height at which the beams are projected is adjustable within a range specified by the manufacturer - generally one that allows all interior work from floor level to the ceiling. these devices are small - weighing and fragile, so they need to be treated with great care and not allowed to fall or tilt suddenly. The budget rotary lasers on the market offer: ±3mm at 30m. Most of the lasers with this level of accuracy are affordable - and are used in internal applications - rather than external worksites and surveying, and shouldn't be used at long range if precision is critical.

Figure 3. Laser level installed in the Field (Topcon, 2020) https://www.topconlaser.com.au/accuracy_laser_levels

Some researches that carried out accuracy test for some of the discussed levels in or outdoor are summarized below.

LITERATURE REVIEW

A Sokkia LP,3A automatic laser level was tested by Ali and Al garni, 1996 using reference data established with a precise level. The results showed that the instrument was able to give misclosure values better than ±7 mm for level circuits up to 340 m in length and better than ±2 mm for distances of 150m. This is commensurate with the requirements for third order optical levelling. It has been concluded that the laser level could be effectively used in place of conventional optical levels in localized surveys concerned with preparation of construction sites, drainage works, inner-city road surveys etc. where only lower order accuracy is required.

A Leica NA3000 electronic digital level, one of the newly-introduced levelling equipment, was evaluated for vertical and horizontal distance measurement. A well protected 170 m long 17-section test line was first established. Two tests were followed. In the first, closed loops were run from one end of the line to each of the pegs on the line and back to the starting point in an out-and-back manner. In the second approach, heights of some pegs on the line were re-established several times with the instrument erected on the one end of the line. Standard deviations better than ± 0.06 mm could easily be obtained (Algarni and Ali, 1998).

A part from a road of 2 km length in El Abour City was selected and leveled using an ordinary level, a precise level and a digital level for accuracy, cost and time comparison by (Zaky, et al, 2002). The results of this test showed that the precise and digital levels gave more accurate levels than the ordinary one. The actual closing error of the precise and digital leveling were ±4.01mm and ±3.3mm respectively, while their corresponding one of the ordinary leveling was ±13mm. we can notice that, the last one is three times the actual closing error of the precise leveling and four times that of the digital leveling.

The effect of atmospheric conditions on the accuracy of staff readings measured by ordinary optical level, digital level, precise level and laser level was investigated practically by comparing the performances of these levels inside and outside the lab (Beshr and Elnaga, 2011). The test was carried out outdoors using digital level Trimble DiNi and its bar-code staff. Measurements were made from different level positions at different distances to staff; ranging from 5m to 30m. The readings were taken in the direction of the sun and in the direction opposite to sun 25 times at each level position. The test was carried out at a temperature of 34 °C. The results of staff readings and horizontal distances in the directions of sun and opposite to sun indicate that the accuracy of digital level observations and compare its value with the accuracy of precise optical level, the first experimental test is done in laboratory. Measurements were made at six stations of level, each of which was carried out 25 times on the staff at distances from 4m to 28m. The test was carried out during the daytime under natural light and temperature of 27 °C. For the analysis of the results, the mean square error of staff readings measurements was calculated for all positions and the difference between measurement errors resulting from used digital levels and optical levels was found to be on average by 10–15%.

Pırtı, et al, 2019 analyzed height differences obtained from three techniques: geometric, trigonometric, barometric and Global Positioning System (GPS) levelling using precise digital level, digital level, total station (trigonometric levelling) and GPS which collects phase and code observations (GPS levelling). The results obtained show that the precise digital levelling is more stable and reliable than the other two methods. The results of the three levelling methods agree with each other within a few millimeters. The different levelling methods are compared. Geometric levelling is usually accepted as being more accurate than the other methods. The discrepancy between geometric levelling and short-range trigonometric levelling is at the level of 8 mm. The accuracy of the short-range trigonometric levelling is due the reciprocal and simultaneous observations of the zenith angles and slope distances over relative short distances of 250 m. The difference between the ellipsoidal height differences obtained from the GPS levelling used without geoid and the orthometric height differences obtained from precise geometric levelling is 4 mm. The geoid model which is obtained from a fifth order polynomial fit of the project area is found to be good enough in this study. The discrepancy between the precise geometric and GPS levelling (with geoid corrections) is 4 millimeters over 5 km.

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METHODOLOGY

INSTRUMENTS USED

The precise optical tilting level Wild/Leica N3 was used to give control height data for both indoor and outdoor tests for the three: Optical precise level, digital level and digital laser level.
The Wild/Leica N3 level unit was in an excellent condition. It has been checked and calibrated by Leica Authorized Agent. It is an ideal level for the precise measurement. Graduation is in metric, reliable and simple estimation to 0.01mm. Wild/Leica N3 Precision Tilt Level has a built-in micrometer (Figure 4).

Figure 4. Wild/Leica N3 Precise Tilting Optical Level (https://agfsurvey.com/Leica_Wild_Heerbrugg_N3_Level)

1- Preci*se Level*

The classic Leica NA2 Levels from Leica were designed by professional surveyors and engineers with experience in the field. This automatic level is precise, reliable and convenient and suitable for all types of surveying projects, including engineering jobs, accurate geodetic control and routine levelling.
Its all-inclusive application makes it ideal for the construction of roads, pipelines, railways and tunnels and more. Monitoring of bridges and deformation measuring is possible alongside precise levelling and setting out work on the construction sites (Figure 5).

Figure 5. Leica NA2 Automatic Level (https://www.tequipment.net/Leica/NA2/Automatic-(Optical)-Levels/)

The compensator is protected against shocks and makes use of a very effective vibration damping system. For accuracy an attachable parallel-plate is available for fine, precise levelling. Other accessories such as the optional laser eye piece can enhance these levels with extra possibilities. The manufacturer claims the following accuracy: Standard deviation for 1km levelling – double-run up to ±0.7mm; when including parallel plate micrometer accuracy reaches ±0.3 mm. Shortest possible distance is 1.6m. Increasing the distance between the digital levels and bar-code staff will increase the errors of staff readings and horizontal distances.

2- Digital Level

The instrument is claimed to achieve height accuracy of 1.0mm using fiberglass RAB Code staves. With the top-of-the-line invar RAB-Code staves, 0.6mm accuracy is a reality (Standard deviation for 1km double-run leveling).
The SDL30 Sokkia Digital Level (Figure 6) employs a market proven pendulum compensator with magnetic damping system. Its working range is ±15'.

The SDL30 calculates height difference, elevation, setting-out and more. When measuring height of the ceilings, bridges and other objects, there is no need to change the measuring mode when the staff is held upside-down.
The internal memory holds 2,000 points of data in a maximum of 20 job files.
Measured data can be exported in CSV format using the software "SDL TOOL"

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Staff BIS30 invar of length 3.0m, cross-section 85mm x 40mm. The invar material has coefficient of linear expansion of $1x10^{-6}$/ºC. The instrument is claimed to have standard deviation accuracy of 0.6mm for electronic measurement and 1.0mm for visual measurement. This invar staff was used in the test.

Figure 6. SDL30 Sokkia Digital Level (https://eu.sokkia.com/products/levels-accessories/automatic-levels/sdl30-digital-level)

3- Automatic Laser Level

A Sokkia LP30AC automatic laser level equipped with a laser detector has been used in this test (Figure 7).

Figure 7. Sokkia LP30AC Automatic Laser Level (https://www.sokkia.com.sg/products/laser/uploads/LP30A_31A.pdf)

The instrument has two sensitivity settings. Setting 1, for short range precision measurement of sensitivity ±0.8mm was selected for the test. The instrument is claimed to score 1mm for 30m accuracy. LP30A Leveling Laser System Specification Leveling Lasers LP30A LP31A PSA1 Aluminum telescopic tripod (domed head) PFA1 Aluminum telescopic tripod (flat head) LPT2 Aluminum elevating tripod (unit height: 1~2m).

TEST SITE and PROCEDURE

The first part of this test was carried out within surveying engineering laboratory in the Civil Engineering Department at King Saud University for the inside test. Two staffs were held up at two points on the lab floor. Each sight was observed 15 times and the observation values were used to compute the difference in level between the two end points of the test line. The observations were repeated for the same two points taking readings in the back-fore set readings and results were recorded. Observations were recorded using all tested levels including the precise level which would provide the reference data.

The other site was selected outside the college building on a road falling between the Engineering College and the Agriculture and Food Sciences College for the outside test. Again, two points 100m apart were selected for the staff positioning. The levels were set up in turn on a station equidistant from the two staff stations. Readings were also observed 15 times for each sight to determine the average value of the difference in height between the two test points. Test levels in addition to the precise level which provides the reference values were used.

TEST RESULTS and NALYSIS

The standard deviations of the precision of observations for the tested levels for indoor test were as follows: ±0.20mm for Precise level; ±0.040m for Digital level; ±0.052m for Ordinary optical level and ±0.062m for Laser level.

The standard deviations of precision of observations for the tested levels indoor and outdoor tests are given in Table1 and Table 2, respectively. Summary of the results and effects on observations are given in Table 3.

Table 1. Indoor Height Readings Results

Level Type	Mean Height Difference between two points (A-B) (mm) Indoor	Mean Height Difference between two points (B-A) (mm) indoor	Mean Height Differences between the two end points (mm) indoor	Displacements of height differences from reference data (mm) indoor
Precise Level N3	5.10	4.90	5.00	-
Digital Level	05.90	05.70	05.80	00.80
Laser Level	06.00	06.50	06.30	01.30
Ordinary Automatic Level	07.20	07.40	07.30	02.30

Table 2. Outdoor Height Readings Results

Level Type	Mean Height Difference between two points (A-B) (mm) outdoor Lab	Mean Height Difference between two points (B-A) (mm) outdoor Lab	Mean Height Differences between the two end points (mm) outdoor Lab	Displacements of height differences from reference data (mm) outdoor
Precise Level N3	10.16	10.20	10.18	-
Digital Level	07.50	07.70	07.60	02.58
Laser Level	04.00	04.40	04.20	05.98
Ordinary Automatic Level	03.00	03.00	03.00	07.18

Table 3. Summary of Indoor and Outdoor Levelling Results

Level Type	error (mm) indoor observation	error (mm) outdoor observation	% difference
Digital Level	00.80	02.58	69.0%
Laser Level	01.30	05.98	78.3%
Ordinary Automatic Level	02.30	07.18	86.6%

It can be seen that in general the inside results of levelling is better in accuracy than the outside tests for all tested levels. This in fact, is expected due to the atmospheric effects on the light rays. The difference between inside and outside test results vary between 69% for the digital level to 78.3% for the laser level and 86.6% for the ordinary level.

For indoor tests the Digital level gave better accuracy than both the laser and ordinary levels: 0.8mm for digital level, 1.3mm for laser level and 2.3mm for ordinary automatic level.. This is also true for outside test where accuracy for digital level recorded 2.58mm, while for laser and ordinary automatic levels were 5.98mm and 7.18mm, respectively. All three levels gave accuracy within the accuracy claimed by the manufacturer.

CONCLUSIONS

Based on the analysis of the experimental results of this study, the following conclusions can be summarized:

(1) The Ordinary automatic optical level is the mostly affected level when used outdoor.
(2) The influence of the outdoor effect on all level instruments was effective ranging from 69% for digital level to 86.6% for ordinary automatic level.
(3) The accuracy performance of the digital level is superior both indoor and outdoor when compared to the ordinary automatic level and laser level.

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