Enlargement the Sighting Distance of Sokkia Digital Level SDL30

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Key words: Digital Level; sighting distance; trigonometric leveling; bar code; enlargement.

SUMMARY

The digital leveling technique which is a combination of automatic levels and automatic reading and booking is commonly applied in precise leveling nowadays. The sighting distance used in line leveling is usually 50 m, and maximum 90 m. The longer sightings are needed in some applications such as crossing valleys and water areas and some times in road and rail surveying.

In this paper SOKKIA Digital Level SDL30 was used to investigate the possibility of enlargement of the sighting distance up to 600 m. The key factor in this investigation is magnification the bar code scale of the rod. The bar code was magnified 2, 4 and 6 times the original design. The leveling performed by using the new enlarged bar codes is compared to that performed using the bar code of normal size. Trigonometric leveling using the total station is also performed and the results were compared.

The results show that the Sokkia digital level SDL30 can process the bar code readings at a maximum sighting distance of 400 m with bar code magnified by four times the original size (4x). It doesn't work properly with the 6x magnified bar code. The accuracy of the first order leveling can be achieved by using the magnified bar code when the sighting distance was within 200 m.

ملخص:

رغم تأخر ظهور الميزان الرقمي في مجال القياسات المساحية مقارنة بأجهزة قياس المسافات والزوايا الرقمية إلا انه أصبح أداة مهمة لانجاز أعمال الميزانية بما فيها الدقيقة منها نظرا لدقة وسـهولة اخـذ القراءات وتخزينها. وتعتبر مسافة الرؤية (القياس) المحدودة للميزان الرقمي والتـي لا تتجـاوز 100 متر عائقا في سبيل استخدامه في الأعمال التي تتطلب مسافة رؤية طويلة كحالة الميزانية عبر الوديان أو المجارى والمسطحات المائية.

وهذا البحث يعرض طريقة لتكبير مسافة الرؤية للميزان الرقمي من نـوع Sokkia SDL30 وذلـك بتكبير الكود المستخدم مع القامة. وقد تم تكبير الكود مرتين وأربع وست مرات الكود الأصلي واختبار اكبر مسافة رؤية في كل حالة وكذلك عمل ميزانية باستخدام الكود المستحدث ومقارنة النتائج بالميزانية في حالة استخدام الكود الأصلي. كما تم عمل ميزانية مثلثية Trigonometric leveling باسـتخدام المحطة المتكاملة ومقارنة النتائج بالنتائج السابقة.

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1. INTRODUCTION

During the last decades the surveying instruments including levels have become more automatic, which reflected positively on the accuracy of the measurements and on productivity of the surveying crews. The appearance of the digital level in the beginning of the 90's really conduced the leveling into the new era (Takalo and Rouhiainen, 2004a).
The digital leveling technique which is a combination of automatic levels and automatic reading and booking is commonly applied in precise leveling nowadays. It becomes as popular as total stations (Pepling, 1996).
Two elements distinguish the digital level: the bar code rod instead of the metric one and the Charge-Coupled Device (CCD) to estimate the reading. The rod reading is calculated by evaluating the image of the coded rod, which was projected onto the CCD. Different measurement techniques have been developed with related codes. Algorithms used for the calculation of the rod reading are correlation, geometric averaging and Fourier analysis (Woschitz et al 2002).
The maximum sighting distance is recommended to be 50 m for the first order leveling and 90 m for the third order leveling as stated in (Standards and Requirements for Leveling [4]). The longer sightings are needed in some applications such as water and valley crossing (Takalo and Rouhiainen, 2004b) and may be needed in roadway and railway surveying.
To perform a long sighting leveling by using digital levels which are designed for a maximum sighting distance of 100 m as mentioned in its specifications [2], one of the following possibilities should be carry out as stated by (Takalo and Rouhiainen, 2004b): using magnifying optics, use of digital zoom or enlarging the bar code scale. In conventional leveling by using numerical rod, it is possible to place a target on the rod, and once it has been moved into alignment with the horizontal cross hair, is read by the rod person.
The objectives of this research are to investigate the possibility to enlarge the sighting distance of Sokkia Digital Level SDL30 up to 600 m and to check the accuracy of the long sighting leveling compared to the conventional leveling and trigonometric leveling using the total station.

2. DIGITAL LEVEL

The digital level virtually eliminates reading errors and automates the collection of data. With the speed, accuracy, and the automation capabilities of digital levels, it is expected to replace manual leveling procedures (Radcliffe, 1999).
Digital levels consist of two new elements added to the technology used in the automatic level: a bar-coded rod which has pattern with an absolute scale (do not repeated along the rod face) instead of the metric rod read by humans, and a CCD at the image plane in the telescope

which acts as the camera to accurately estimate the part of the rod being observed (Cheves, 2002).

The eyepiece is used by the observer to sight through the telescope and place the image field on the rod. The focus knob is then rotated to bring the image of the rod sharply into focus. The measure button is then pressed and the CCD captures an image of the rod and processes it, resulting in a rod reading and a distance to the rod. Details on how digital levels read the bar code are illustrated by (Khalil R. 1999) and (Radcliffe, 1999).

Because the CCD must be set at a distance that allows it to read individual bars on the rod, the digital level has a practical limitation on how far the rod can be from it. The maximum distance of Sokkia digital level SDL30 is 100 m [2]. (Woschitz and Brunner 2002) and (Gassner et al 2004) summarized the systematic effects of the digital leveling as scale value of the rod, reading at the ends of the rod, damaged bar code lines, illumination of the rod and the improper focusing.

3. BAR CODE

The rod has a scale which is represented as a series of bars of different widths along the rod height. The scale does not repeat along the face of the rod. Thus, the pattern and the relationship of the pattern to the adjoining patterns are unique for every group of bars on the rod. Bars may be constantly spaced or variably spaced depending on the manufacturer. The spacing and width of the bars denote the code (Cheves, 2002). The distance between the centerline of every bar for the bar code used with SDL30 is fixed at 16 mm. Bars of 3, 4, 7, 8, 11 and 12 mm width are separated along the height of the bar

4. METHODOLOGY

To enlarge the sighting distance of Sokkia digital level SDL30 the bar code size was magnified. The instrument counts the number of bits between the centers of the black bars visible to the CCD. Because it knows that the distance between the centers of each black bar is 16mm, and knows how many bits on the CCD equal 16mm on the rod, it can measure the distance to the rod. The instrument will see the enlarged bar code rod closer according to the enlargement scale ratio. Theoretically, the sighting distance could be enlarged (n) times 100m if the bar code was enlarged (n) times the original size.

To enlarge the bar code, the width of each element of the original bar code was measured then drawn through AutoCAD and resized to 2, 4, and 6 times the original. Three new bar codes were prepared as strip of 5 cm width and 3 m length. They were plotted on high quality glossy white paper then laminated to protect the paper. Each strip was stuck on one piece metal bar of 4 x 8 cm cross section and 3 m length.

A leveling line with 25 points that are 50 m spaced, was established throughout east-west direction in King Abdulaziz University Campus area to investigate the accuracies which could be obtained by differential leveling using the new bar codes and comparing them to the accuracies obtained by differential leveling using the original bar code and to those obtained by trigonometric leveling. The east-west direction was chosen to investigate the effect of

shadow on the new bar codes.
The points of even numbers (i.e. 2, 4, 6, ….) were used for instrument setup, while the points of odd numbers (i.e. 1, 3, 5, ….) were used for height difference computations and accuracies comparison.
Sokkia Digital level SDL30M (No. 005142/D11804) was used in this research. Its measuring range according to its specifications is 1.6 m to 100 m [2]. Sokkia Total Station SET 600 (No.18520/D21828) was used for the trigonometric leveling. The specifications of the used Total Station stated its accuracy as ± (3 + 2 ppm x D) for fine measurement with prism, the accuracy of measuring vertical and horizontal angle is 6″ seconds. A weather station DAVIS (No. 7440) was used to measure the temperature, atmospheric pressure and humidity during the experimental work.

5. MEASURING PROCEDURE

The prepared bar code rods were calibrated by performing a leveling over a stair of ten steps each of 15 cm height. The height of the digital level was adjusted so that the 10 rod readings on the stair fall on the first half of the rod. The leveling was repeated by readjusting the height of the digital level so that all the 10 rod readings on the stair fall on the second half of the rod.
The elevation of leveling line's points were reduced by performing a double-run leveling using the original bar code. Equal backward and foreward observation range and the technique of BFFB (Backward Forward Forward Backward) were used during the work. The reduced levels were corrected from the misclosure error and considerd as references. The difference in elevation between each two points was computed.
The new bar codes were used to perform the leveling once in unidirection to the maximum distance the instrument can operate for each code and once again using BFFB technique with distances between the level and the bar code rod equal to 100 and 200 m. The slope of the surface in the test location prevented using sighting distances longer than 200 m when using BFFB technique. The difference in elevation between each two observed points in each case was computed.
The total station was used to perform trigonometric leveling using also two techniques: unidirectional trigonometric leveling along the whole length of the leveling line (i.e. 1200 m) and leap-frog trigonometric leveling with distances 100, 200, 400 and 600 m between the total station and the reflector. The vertical angle and slope distance were measured for each observed point. The difference in elevation between each two observed points in each case was computed.

6. COMPUTATIONAL MODEL

The observations of the unidirectional trigonometric leveling have been made by using total station that is set up in a station point and measuring the slope distance S_{ij} and zenith angle Z_{ij}

to vertically established target as shown Figure (1). It is assumed that level surfaces are same centered sphere surfaces in the survey model as that sugested by (Ceylan et al 2005).

In figure 1,
Z_{ij} : zenith angle that is observed
dZ_r : model error that is caused by refraction
dZ_c : model error that is caused by curvature
S_{ij} : slope distance
R_m : radius of the Earth spheroid
HI : height of the instrument
Hr : height of reflector

After transforming the equation for curvature and refraction that presented by (GIA, 2006) and (Jackson and Leong, 2003) to the metric units and take into account the height of the instrument (HI) and the height of the reflector (Hr), the height difference between points P_i and P_j (Δh_{ij}) can be writen as follows:

$$\Delta h_{ij} = \left(S_{ij}\,.\cos Z_{ij}\right) + 0.86\left(\frac{S_{ij}^2}{2R_m}.\sin^2 Z_{ij}\right) + HI - Hr \qquad (1)$$

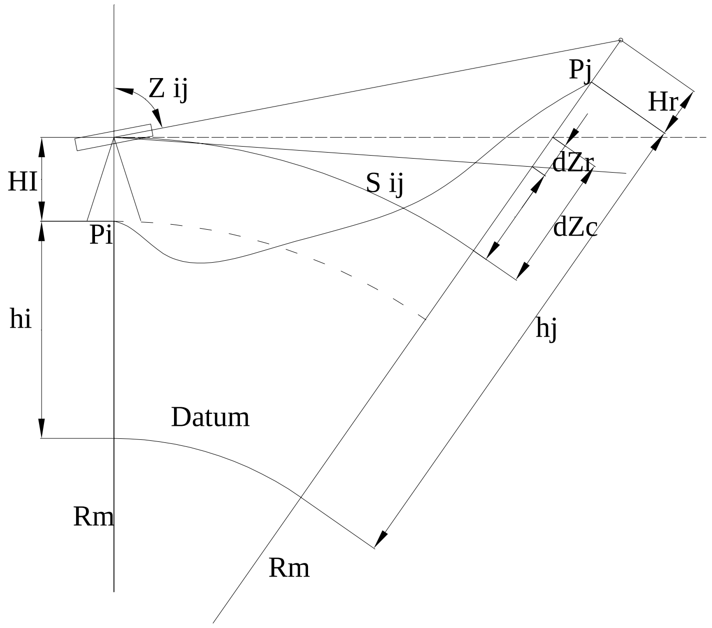

Figure (1): Survey model for the unidirectional trigonometric leveling.

In equation (1), the first term is nominal height difference, the second term is the effect of refraction and earth curvature on height difference, the third term is the instrument height and the fourth term is the reflector height.

In the leap-frog trigonometric leveling the total station was set up in a point among the station points as shown in figure (2). Zenith angles Z_{ki} and Z_{kj}, slope distances S_{ki} and S_{kj} were measured to the reflector which was mounted vertically on station points.
When applying equation (1) on observations in backsight and foresight and considering the reflector height is the same on both station points, equation (2) was obtained.

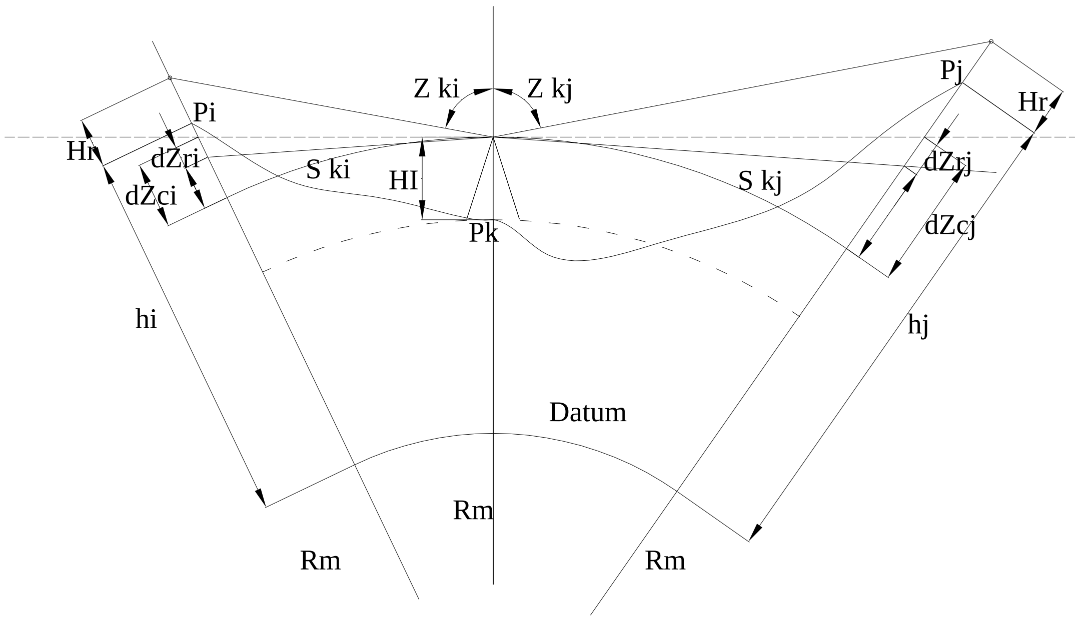

Figure (2): Survey model for the Leap-frog trigonometric leveling.

$$\Delta h_{ij} = \left(S_{kj}.\cos Z_{kj} - S_{ki}.\cos Z_{ki}\right) + \frac{0.86}{2R_m}\left(S_{kj}^2.\sin^2 Z_{kj} - S_{ki}^2.\sin^2 Z_{ki}\right) \qquad (2)$$

In equation (2), the first term is nominal height difference, the second term is the effect of refraction and earth curvature on height difference.

7. RESULTS

7-1 Results of calibration of barcodes

The results of calibration the magnified bar codes are shown in figure (3) which represent the error in hieght differences and the position of the reading on the bar code. The figure shows that the error in the hieght difference is within ± 0.5 mm for the bar code magnified by 2x and within ± 1.0 mm for the bar code magnified by 6x. There is a gab between the two set ups because the height difference starts at the second reading . Figure (4) shows the error in the measuring distance and the position of the reading. The mean errors in measuring the distance were 0.05 m and 0.35 m when using 2x and 6x bar code respectivily.

The figures show that the digital level can not operate at the first 35 cm of the 6x bar code.

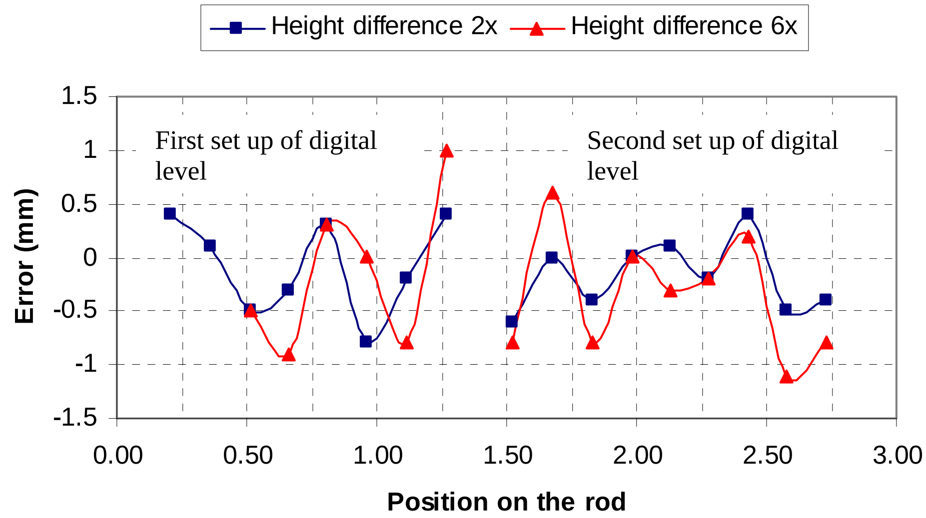

Figure (3): Error in the height difference and the position of the reading on the rod.

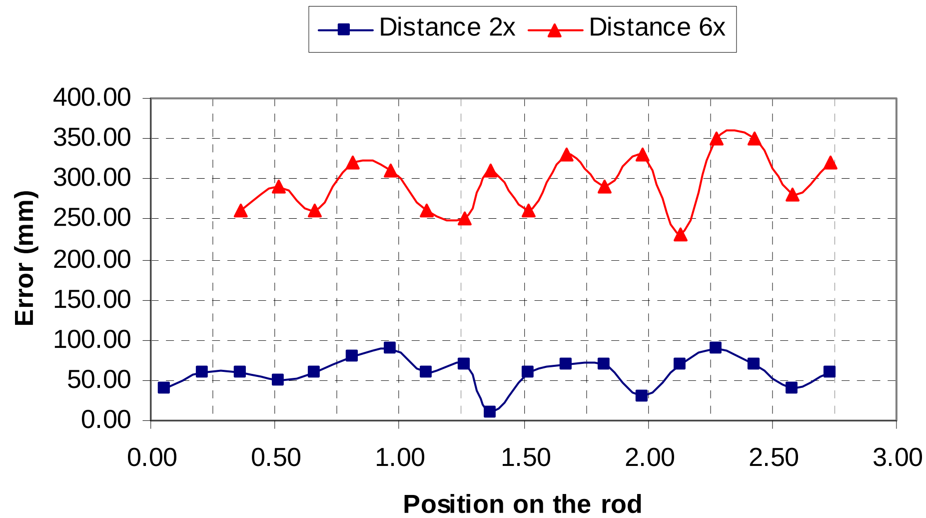

Figure (4): Error in the measured distance and the position of the reading on the rod.

7-2 Results of leveling loops

The height difference between each two observed points was computed. The height differences obtained by using the original bar code (1x) and 50 m measuring distance were assumed corrected and were used as reference values for computation of the accuracies. The error in the height differences (ε) resulting from different bar code scales and different measuring techniques were computed. The Standard diviations (σ) of the error in the height differences were then computed using the following equation:

$$\sigma = \pm \sqrt{\frac{(\varepsilon - \mu)^2}{n-1}} \qquad (3)$$

Where μ is the mean error and *n* is the number of height differences.

The height differences and standard diviation of the errors are summarized in the following tables.

Table (1): The height differences of differential leveling (Leap-frog).

	Bar code used and distance between instrument and rod							
Line	1x 50 m	1x 100 m	2x 100 m	4x 100 m	6x 100 m	2x 200 m	4x 200 m	6x 200 m
1 - 5	**-1.1347**	-1.1335	-1.1358	-1.1356	-1.1352			
1 - 9	**-2.3716**	-2.3713	-2.3744	-2.3752	-2.3766	-2.3756	-2.3736	-2.3754
1 - 13	**-3.6845**	-3.6833	-3.6890	-3.6900	-3.6918			
1 - 17	**-4.8705**	-4.8691	-4.8760	-4.8768	-4.8798	-4.8784	-4.8704	-4.8798
1 - 21	**-5.8787**	-5.8762	-5.8844	-5.8844	-5.8896			
1 - 25	**-6.9297**	-6.9294	-6.9360	-6.9380	-6.9438	-6.9378	-6.9316	-6.9426
5 - 9	**-1.2369**	-1.2378	-1.2386	-1.2396	-1.2414			
5 - 13	**-2.5498**	-2.5498	-2.5532	-2.5544	-2.5566			
5 - 17	**-3.7358**	-3.7356	-3.7402	-3.7412	-3.7446			
5 - 21	**-4.7440**	-4.7427	-4.7486	-4.7488	-4.7544			
5 - 25	**-5.7950**	-5.7959	-5.8002	-5.8024	-5.8086			
9 - 13	**-1.3129**	-1.3120	-1.3146	-1.3148	-1.3152			
9 - 17	**-2.4989**	-2.4978	-2.5016	-2.5016	-2.5032	-2.5028	-2.4968	-2.5044
9 - 21	**-3.5071**	-3.5049	-3.5100	-3.5092	-3.5130			
9 - 25	**-4.5581**	-4.5581	-4.5616	-4.5628	-4.5672	-4.5622	-4.5580	-4.5672
13 - 17	**-1.1860**	-1.1858	-1.1870	-1.1868	-1.1880			
13 - 21	**-2.1942**	-2.1929	-2.1954	-2.1944	-2.1978			
13 - 25	**-3.2452**	-3.2461	-3.2470	-3.2480	-3.2520			
17 - 21	**-1.0082**	-1.0071	-1.0084	-1.0076	-1.0098			
17 - 25	**-2.0592**	-2.0603	-2.0600	-2.0612	-2.0640	-2.0594	-2.0612	-2.0628
21 - 25	**-1.0510**	-1.0532	-1.0516	-1.0536	-1.0542			

Table (2) Standard diviations (σ) computed for the differential leveling (Leap-frog).

Bar code	100 m sighting distance		200 m sighting distance	
	σ mm	σ mm/√km	σ mm	σ mm/√km
1x	1.2	1.1	-	-
2x	1.9	1.7	2.9	2.7
4x	2.4	2.2	1.7	1.5
6x	3.8	3.5	3.7	3.3

Table (3): The height differences of trigonometric leveling (Unidirectional).

Line	Measuring range		
	Up to 600 m	Up to 400 m	Up to 200 m
1 - 3	-0.5897	-0.5897	-0.5897
1 - 5	-1.1480	-1.1480	-1.1480
1 - 7	-1.7998	-1.7998	
1 - 9	-2.4140	-2.4140	
1 - 11	-3.0764		
1 - 13	-3.7103		
3 - 5	-0.5583	-0.5583	-0.5583
3 - 7	-1.2101	-1.2101	
3 - 9	-1.8242	-1.8242	
3 - 11	-2.4867		
3 - 13	-3.1206		
5 - 7	-0.6518	-0.6518	
5 - 9	-1.2660	-1.2660	
5 - 11	-1.9284		
5 - 13	-2.5624		
7 - 9	-0.6142	-0.6142	
7 - 11	-1.2766		
7 - 13	-1.9106		
9 - 13	-1.2964		
11 - 13	-0.6339		

Table (4) Standard diviations (σ) computed for the trigonometric leveling (Unidirectional).

Maximum Distance	σ mm	σ mm/√km
200	3.9	8.7
400	13.3	21.0
600	17.7	22.9

Table (5): The height differences of trigonometric leveling (Leap-frog).

	Distance to the instrument			
Line	100 m	200 m	400 m	600 m
1 - 5	-1.1315			
1 - 9	-2.3709	-2.3978		
1 - 13	-3.6944			
1 - 17	-4.8717	-4.8906	-4.8408	
1 - 21	-5.8662			
1 - 25	-6.9371	-6.9439		-6.9418
5 - 9	-1.2395			
5 - 13	-2.5629			
5 - 17	-3.7402			
5 - 21	-4.7347			
5 - 25	-5.8056			
9 - 13	-1.3235			
9 - 17	-2.5007	-2.4928		
9 - 21	-3.4953			
9 - 25	-4.5661	-4.5461		
13 - 17	-1.1773			
13 - 21	-2.1718			
13 - 25	-3.2426			
17 - 21	-0.9945			
17 - 25	-2.0654	-2.0533		
21 - 25	-1.0709			

Table (6) Standard diviations (σ)computed for the trigonometric leveling (Leap-frog).

Maximum Distance	σ mm	σ mm/√km
100	10.6	9.7
200	16.0	14.6
400	29.7	27.1
600	12.0	11.0

In table (6) the root mean square error for the measurements of 400 and 600m considered as (σ).

The digital level can operate and process the bar code reading until the sight distance reached 100 m when the magnification factor of the bar code is 1x. Theoretically, it can process readings on the magnified bar code up to distance equal to 100 m multiplied by the magnification factor (i.e. 200 m for 2x, 400 m for 4x …. etc.), but this depends on other parameters which were recognized during the experimental works. These parameters are the time of measurements, temperature, the read part of the bar code (the position where the central cross hair lay on the bar code), the background seen through the telescope, illumination and magnification factor. The digital level start to process the shadowed bar code one hour after the sun rise, before that time the bar code looks dark and can not be read. When the temperature exceeds 30 degrees and the image starts to shake, the digital level can not operate. To get a correct reading, the central cross hair should be at least 0.35 m away of the rod ends. During the experimental works, the background was a white building with black windows. This background caused confusion for the digital level and it couldn't process the reading, especially when the bar code rod was away from the instrument so that the focus knob couldn't change the scene.
Although the recommendations mentioned by (Ingensand, 2002) were followed during the experimental work, the digital level didn't operate in some cases described in the following sentences. For the 4x bar code the digital level processed the readings up to 400 m sight distance and in another working day the maximum distance it can process the reading at was 320 m. For the 6x bar code, the maximum distance was 200m and at another time it was only 150 m. The glossy of the white parts of the magnified bar code can cause a problem to the digital level.
As a conclusion of the above discussion, Sokkia Digital level SDL30M can operate with bar code magnified by 2x up to 200 m sighting distance and with 4x bar code up to 300 m. It is not recommended to magnify the bar code by more than 4x.

Looking at table (2), and according to the leveling order specifications (FGCSVERT, 2004), it is clear that the accuracies obtained with the magnified bar codes for measuring distance up to 200 m are within that of the first order leveling.
From the results shown in table (4) and table (6) and refering to the specifications, it can be concluded that trigonometric leveling with total station can be used for third order leveling with sighting distance equal to 100 m. The second order trigonometric leveling specifications (NOAA, 2002) recommended that the maximum sight distance never exceed 70 m.

From the shown results and as a comparison between using digital level with magnified bar code and total station for performing leveling, one can conclude that the digital level can be used with 4x magnified bar code and sight distance up to 200 m for first order leveling . Total station can be used for third order leveling up to 100 m sighting distance.

8. CONCLUSIONS

From the results getten from the exprimental work of this research, the followings could be concluded:

1. Enlargement of the sighting distance of Sokkia digital level SDL30 is possible by magnifying the bar code.
2. It is not recommended to magnify the bar code for Sokkia digital level SDL30 by more than 4x.
3. The magnified bar code can be used with sighting distance up to 200 m for first order leveling.
4. The maximum sighting distance should not exceed 300 m in good measuring conditions with bar code magnified by 4x.
5. The maximum sighting distance for Sokkia digital level SDL30 with 6x magnification bar code is 200 m.
6. To avoid taking readings in the half meter next to the rod ends, the height difference between back and foresight should not exceed 2.0 m when using a rod of 3.0 m height.
7. Trigonometric leveling can be used for thrid order leveling with maximum sighting distance of 100 m.
8. Using digital level with magnified bar code to enlarge the sighting distance is more accurate than using total station in performing leveling.

Recommendations

For longer sight distance, it is recommended that the digital level producers to:

1. Enhance the resolution of the CCD used in the digital level.
2. Enlarge the magnification power of the instrument lenses.
3. Produce calibrated magnified bar codes.

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BIOGRAPHICAL NOTES

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