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Prism Monitoring: Obstructions Delay-Time Effect on Measurement Accuracy

DAGUWOR K. DENNIS[1], THOMAS. B. AFENI[2], AFOLABI F. ISIAKA[3]
[1, 2, 3] Department of Mining Engineering, Federal University of Technology, Akure, Nigeria

Abstract- Total stations being a lightweight and handy integrated equipment, is being worshipped as a solution for acquiring correct data for timely project completion in surveying. Though there are emerging technologies like the Global Positioning System (GPS), Unman Aero Vehicle, and scanners, the total station remains the preferred, and dominant instrument currently in surveying because of its high accuracy, durability, and incorporates many functionalities than others. However, this high accuracy is dependent on a clear line-of-sight. In this research, selected temporary obstructions of opaque nature were used to obstruct the line-of-sight between the instrument and reflector at regular time interval. This was intended to examine the effect on the accuracy of distance measurement. It was observed that, significantly the obstructions resulted in readings that fall within the accuracy of ±2mm. In practice, all the readings are not likely to be obstructed and that would therefore further improve the accuracy.

Indexed Terms- Accuracy, error, line-of-sight effect, prism monitoring, temporary obstruction, total station

I. INTRODUCTION

A total station is an angular measuring instrument, incorporated with Electronic Distance Measurement elements; this thus benefits the surveyor in terms of handiness, convenience and speed [1]. The instrument is used today for numerous applications due to their accurate, fast and automated measuring processes [2]. However, there are several sources of errors which have an effect on the accuracy of its reading during distance measurement such as line-of-sight obstruction [3]. When prism is used as the target for measurement which is otherwise known as prism measurement or prism monitoring [4], the laser beam must first hit such prism and bounce back for accurate reading. Regardless of the magnitude, the integrity of surveying data becomes affected when the line-of-sight between the measuring instrument and the target is obstructed [5]. Nonetheless, in spite of the clear and fixed characteristics of every surveying error, it is generally not easy to illustrate on a board their effects in practice. Reason being that several errors occur concurrently and interactively [6]. In most instances, the temporary and invisible attributes of some obstructions warrant them being considered ignorantly as negligible [7]. However, when the demand for accuracy becomes a must, especially in an effort to meet regulatory requirement, safety standards, and rescue planning, the need to investigate every potential source of error becomes necessary [8]. Total station uses in mining for slope monitoring, volumetric data collection, leveling, correlation and distance measurement, exposes it to potential line-of-sight obstructions arising from dust, vibration, human, moving objects among others [9].

II. PRISM MONITORING AND LINE-OF-SIGHT OBSTRUCTIONS

During total station distance measurement with a reflector type, the surveyor focuses on a mounted prism. The equipment then aims at the targeted prism with a beam of infrared light. When the light hits the prism, it bounces back. The time taken for the beam to reach the reflector and back to the total station is recorded electronically in its memory. In the event where there is an obstruction in the line-of-sight when the beam has been released by the operator, the cycle time of the beam is affected since it must first hit the reflector before bouncing back. Basically, this is due to the operating principle as indicated in equation 1.

$$d = v(\Delta t) \quad (1)$$

where d is the distance of interest, v is the speed of light in vacuum and Δt is the change in the time of flight. Obstructions in the line-of-sight are generally of two nature: transparent (partial) and opaque (Full) obstruction [10]. Partial obstruction include glass [11], [7], dust [9], mesh [12], and reflecting tape lights [13]. These obstructions only delay the speed of the laser ray. This delay generally increases the measured distance. On the other hand, opaque obstructions like vehicles, human, wood, or leaves, totally block the ray from traveling to the prism [14]. For example as speeding vehicle may pass through the line-of-sight when survey is ongoing. Or prisms installed in a working phase of a mine for slope monitoring purposes may encounter obstruction due to haul trucks [15]. Unlike transparent obstructions whose impacts have been lengthily investigated, little is known about what impact is resulted from a delay beam which stills read to the prism after few second of delay.

III. TOTAL STATION APPLICATION IN MINING

Probably, the most widely and indispensable use of total stations in the mine is for monitoring purposes. The Excavation of rocks during mining processes continuously initiate a response of rock mass movement [16]. This movement, which is an originator of mine slope failure is accurately monitored using total station [7] [17], [18]. According to [19], observation is carried out from a stationed monitoring house as prisms are inserted on different slope faces as seen in Figure 1.

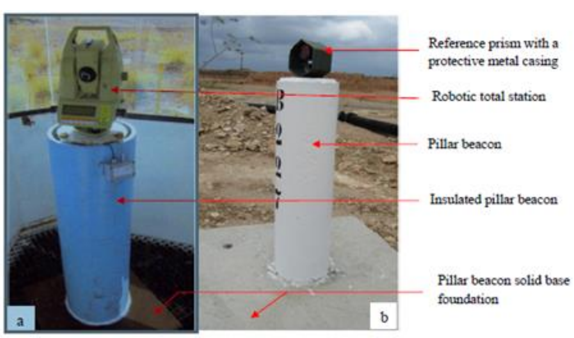

Figure 1: (a) total station in a shelter (b) Installed prism (source: [4])

The position of the prism is predetermined by geotechnical engineers [15]. Other applications include establishing reduced levels [20] correlating surface to underground working and height measurement [21], and volume calculation [22] among others. However, the later applications can conveniently if not preferably be substituted by aero-photogrammetry, GPS, laser scanner, or surveying radar, that have ability of larger coverage area continuously [16].

IV. MATERIALS AND METHOD

The research materials consisted of simulation of common obstructions associated with mining environment. For this research, *leaf, wood, cotton, rubber, plastic and metal* sheet were used as obstructions simulation for trees, branches, human/reflector jackets and vehicles. NTS 370R Total

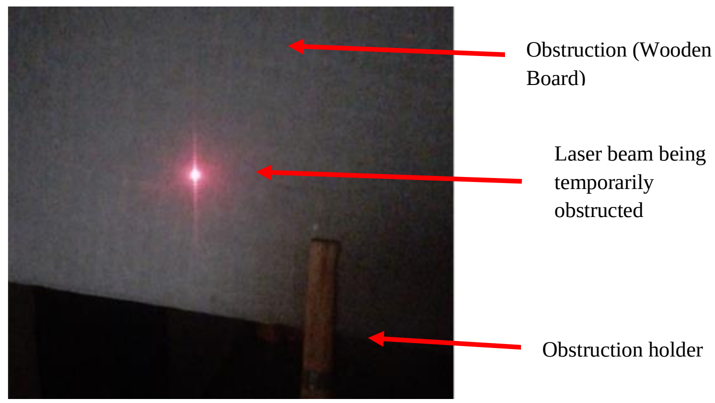

Figure 2: Illustration of obstructions of the laser beam

Station and its accessories were used for the data collection. Each obstruction was increasingly delayed in the line-of-sight as illustrated in Figure 2 until the instrument could no longer locate the prism after the sight was cleared.

A. *Standards*

In order to achieve the objectives, the methodology was in accordance with [23], [24], and [14].

B. *Reconnaissance and Site Preparation*

One of the fundamental principles of surveying is reconnaissance. At this stage, preliminary assessment for all project activities were carried out. This included assessment for:

1. A suitably control environment adequate for the project need of at least 30 meters in length
2. Set-up data collection center:

a) Pre-marked three metres interval leading to ten chainages away from the total station setup point
b) Mounted prism holder to ensure the true value is constant
c) Established reference points of the instrument using the plummet to confirm the setup was always at the same orientation
d) Established the height of instrument correspondent to the prism height.
e) Vertical and horizontal angles were recorded to further guarantee that the initial setup was maintained throughout the data collection period.

C. Ensured Standard Atmospheric Temperature and Pressure

According to NTS-360R operation manual, Atmospheric parameters affect the reading of electronic distance measurement instruments like the total station. For this reason. There are established correction factors, but observing under conditions with a preset parameters that don't significantly vary, the instrument automatically compensate based on the setting. In this instance, the impact is minimized to a greater extend and subsequently neglecting the need for any correction. Normal temperature and pressure (NTP) according to the National Institute of Standards and Technology (NIST) was used. At this standard, temperature is of 20 °C (293.15 K, 68 °F) and an absolute pressure of 1 atm (14.696 psi, 101.325 kPa). Therefore, Atmospheric readings were monitored from the online acuteweateher station hourly. In the even to deviation, the appropriate setting with adjust in the instrument and therefore compensated for. The experiments were done during morning and evening hours indoor to ensure the desire atmospheric conditions were met.

D. Capturing of Reading for Unobstructed Line-Of-Sight

Based on the aim of comparative yardstick, reading from an unobstructed line-of-site to the mounted prism were recorded ten times and considered as the true value. Tapping technique for distance was also done to validate the accuracy of the electronic reading from the total station. Internal data storage was employed to minimize recording and human errors.

E. Capturing of reading for obstructed line-of-sight at varying time delay and intervals

A clear line of sight is highly necessary in prism surveying. Since nature and working environment are unavoidable in instances like a mining surroundings where huge equipment noise could confuse the operator's attention to duty, obstructions were simulated to examine their delay-time effect on the accuracy of distance measurement.

Stop watch (XL5853 Model) was used as timing instrument. As the distance key was trigged, the obstruction was held by a field assistant in the line-of-sight to obstruct or stop the laser beam from reaching the prism. Once the stop watch alarmed, the obstruction was removed. In that case, and the laser then assessed the prism and the reading was recorded for that that delayed time.

F. Data Analysis

The average of ten readings for each obstruction time was computed as an instrument of analysis following equation:

$$Ave = \sum \frac{x_i}{n} \qquad (2)$$

where Ave is the arithmetic mean (Average), x_i is the i^{th} variable and n is the number of captures.

Standard deviation of the mean which tells the variability of data on the average, that is how far away the individual measures are from the arithmetic mean was calculated from Equation 2. Sets of reading from different obstruction type may have equivalent mean but the standard deviation gives a true picture of accuracy and precision. It's calculated from the following formula:

$$SD_{(Ave)} = \sqrt{\sum_{i=1}^{n} \frac{(\hat{i} - l_i)^2}{n}}, \hat{i} = \sum_{i=1}^{n} \frac{l_i}{n} \qquad (3)$$

Where $\hat{i}$ is the true value, l_i is the individual measurement and $\hat{i}$ is the average of the captured measurement, and n is the number of reading.

To ensure the need for correction, the upper limit and lower limit of the true data set were computed using the Equation 3 and 4 respectivley.

$$UpperLimit = (3xSD) + Ave \quad (4)$$

$$UpperLimit = Ave - (3xSD) \quad (5)$$

where SD is the standard deviation and Ave is the average

V. RESULTS AND DISCUSSIONS

Table I: HORIZONTAL DISTANCE (HD) READING FOR METAL SHEET AS OBSTRUCTION

No	HD Reading without obstruction	HD Reading for 3 seconds of obstruction	HD Reading for 6 seconds of obstruction	HD Reading for 9 seconds of obstruction	HD Reading for 12 seconds of obstruction	HD Reading for 15 seconds of obstruction	HD Reading for 18 seconds of obstruction
1	31.238	31.236	31.237	31.235	31.234	31.236	NO READING
2	31.238	31.236	31.235	31.235	31.237	31.236	
3	31.238	31.236	31.236	31.236	31.236	31.236	
4	31.238	31.236	31.236	31.236	31.233	31.236	
5	31.238	31.235	31.229	31.236	31.237	31.234	
6	31.238	31.236	31.237	31.235	31.236	31.234	
7	31.237	31.236	31.236	31.236	31.236	31.236	
8	31.238	31.236	31.237	31.235	31.236	31.236	
9	31.238	31.237	31.237	31.237	31.236	31.236	
10	31.238	31.236	31.237	31.236	31.234	31.235	
Average	31.238	31.236	31.236	31.236	31.236	31.236	
SD	0.00032	0.00047	0.002452	0.00067	0.00135	0.00085	
Error	0.0001	0.0020	0.0023	0.0023	0.0025	0.0025	

Table II: HORIZONTAL DISTANCE (HD) READING FOR WOODEN SHEET AS OBSTRUCTION

No	HD Reading without obstruction	HD Reading for 3 seconds of obstruction	HD Reading for 6 seconds of obstruction	HD Reading for 9 seconds of obstruction	HD Reading for 12 seconds of obstruction	HD Reading for 15 seconds of obstruction	HD Reading for 18 seconds of obstruction
1	31.237	31.237	31.237	31.237	31.237	31.237	NO READING
2	31.238	31.237	31.236	31.237	31.237	31.237	
3	31.238	31.237	31.237	31.236	31.238	31.236	
4	31.238	31.236	31.237	31.237	31.236	31.236	
5	31.238	31.237	31.237	31.237	31.237	31.238	
6	31.238	31.236	31.237	31.237	31.236	31.238	
7	31.238	31.237	31.236	31.236	31.236	31.236	
8	31.238	31.237	31.236	31.237	31.236	31.230	
9	31.238	31.238	31.237	31.237	31.236	31.236	
10	31.238	31.237	31.237	31.239	31.237	31.237	
Average	31.238	31.237	31.237	31.237	31.237	31.236	
SD	0.00032	0.00057	0.00048	0.00082	0.00070	0.00228	
Error	0.0000	0.0011	0.0013	0.0010	0.0014	0.0019	

Table III: HORIZONTAL DISTANCE (HD) READING FOR COTTON CLOTH AS OBSTRUCTION							
No	HD Reading without obstruction	HD Reading for 3 seconds of obstruction	HD Reading for 6 seconds of obstruction	HD Reading for 9 seconds of obstruction	HD Reading for 12 seconds of obstruction	HD Reading for 15 seconds of obstruction	HD Reading for 18 seconds of obstruction
1	31.238	31.238	31.237	31.238	31.238	31.238	NO READING
2	31.238	31.236	31.235	31.237	31.237	31.236	
3	31.238	31.236	31.237	31.237	31.236	31.236	
4	31.238	31.237	31.237	31.236	31.237	31.237	
5	31.238	31.238	31.239	31.237	31.237	31.240	
6	31.238	31.239	31.240	31.238	31.238	31.239	
7	31.238	31.240	31.240	31.239	31.237	31.229	
8	31.238	31.239	31.239	31.240	31.240	31.237	
9	31.238	31.238	31.238	31.237	31.237	31.238	
10	31.238	31.239	31.237	31.239	31.239	31.239	
Average	31.238	31.238	31.238	31.238	31.238	31.237	
SD	0.00000	0.00133	0.00160	0.00123	0.00117	0.00307	
Error	0.000	0.000	0.000	0.000	0.000	0.001	

Table IV: HORIZONTAL DISTANCE (HD) READING FOR COTTON CLOTH AS OBSTRUCTION							
No	HD Reading without obstruction	HD Reading for 3 seconds of obstruction	HD Reading for 6 seconds of obstruction	HD Reading for 9 seconds of obstruction	HD Reading for 12 seconds of obstruction	HD Reading for 15 seconds of obstruction	HD Reading for 18 seconds of obstruction
1	31.238	31.236	31.236	31.237	31.238	31.236	NO READING
2	31.238	31.237	31.236	31.237	31.237	31.239	
3	31.238	31.234	31.236	31.237	31.236	31.237	
4	31.238	31.229	31.236	31.236	31.236	31.238	
5	31.238	31.239	31.234	31.237	31.235	31.236	
6	31.238	31.236	31.237	31.236	31.236	31.236	
7	31.238	31.236	31.236	31.236	31.239	31.237	
8	31.238	31.238	31.237	31.236	31.236	31.236	
9	31.238	31.236	31.236	31.237	31.238	31.237	
10	31.238	31.237	31.236	31.236	31.236	31.236	
Average	31.238	31.236	31.236	31.237	31.237	31.237	
SD	0.00000	0.00274	0.00082	0.00053	0.00125	0.00103	
Error	0.000	0.002	0.002	0.002	0.001	0.001	

Table V: HORIZONTAL DISTANCE (HD) READING FOR LEAF AS OBSTRUCTION

No	HD Reading without obstruction	HD Reading for 3 seconds of obstruction	HD Reading for 6 seconds of obstruction	HD Reading for 9 seconds of obstruction	HD Reading for 12 seconds of obstruction	HD Reading for 15 seconds of obstruction	HD Reading for 18 seconds of obstruction
1	31.238	31.236	31.237	31.235	31.236	NO READING	NO READING
2	31.238	31.236	31.235	31.236	31.237		
3	31.238	31.236	31.237	31.236	31.234		
4	31.238	31.236	31.236	31.236	31.229		
5	31.237	31.234	31.229	31.236	31.239		
6	31.238	31.236	31.235	31.236	31.236		
7	31.238	31.235	31.239	31.236	31.236		
8	31.238	31.236	31.235	31.237	31.237		
9	31.238	31.237	31.237	31.236	31.236		
10	31.238	31.236	31.235	31.237	31.237		
Average	31.238	31.236	31.236	31.236	31.236		
SD	0.00032	0.00079	0.00264	0.00057	0.00267		
Error	0.000	0.002	0.002	0.002	0.002		

Table VI: HORIZONTAL DISTANCE (HD) READING FOR YELLOW RUBBER AS OBSTRUCTION

No	HD Reading without obstruction	HD Reading for 3 seconds of obstruction	HD Reading for 6 seconds of obstruction	HD Reading for 9 seconds of obstruction	HD Reading for 12 seconds of obstruction	HD Reading for 15 seconds of obstruction	HD Reading for 18 seconds of obstruction
1	31.238	3.015	The instrument read to the distance of obstruction though with some inaccuracy				
2	31.238	2.873					
3	31.238	2.907					
4	31.238	2.979					
5	31.238	2.995					
6	31.238	2.959					
7	31.238	2.959					
8	31.238	2.964					
9	31.238	2.889					
10	31.238	2.927					
Average	31.238	2.947					
SD	31.238	0.04639					
Error	0.000	0.053					

In other to understand the effect of the obstruction on the accuracy of distance measurement using prism, the mean, standard deviation, and absolute error, were computed for each obstruction time intervals of 3s, 6s, 9s, 12s, and 15s respectively as shown in Table I-VI. The tables further indicated that, the maximum obstruction time for all 15 seconds. Beyond this time of 15 seconds, it was impossible for the instrument to locate the prism after the obstruction is removed. The disparity of the standard deviation indicates that though the majority of the means are in the range of acceptable accuracy of ±2mm according to the manufacturer of the instrument, at least ten reading will be required to achieve this accuracy as further. Obstruction type didn't significantly matter except for yellow rubber which read the distance of the obstruction even though measurement was done in prism mode. The reflective nature of the rubber may have been a contributing factor. Leaf had the least obstruction time of 12 seconds.

CONCLUSION

This research work investigated effect of opaque obstructions completely blocking the laser ray for increasing time interval in prism mode. Though experiment was simulated indoor for complete normalized situations, it was intended to model a typical mining environment that has continuous movement of dumpers, and equipment noise that may distract the surveyor's attention to duty when the line-of-sight gets temporarily obstruction and reading being taken unnoticeably. Further research is underway to investigate the impact of the obstruction distance relative to time interval.

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